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Carsten Schürmann,
Klaus Spiekermann, Michael Wegener

Accessibility Indicators

Deliverable D5 of Project

Socio-Economic and Spatial Impacts of Transport Infrastructure Investments and Transport System Improvements (SASI)

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Institut für Raumplanung
Fakultät Raumplanung, Universität Dortmund

D-44221 Dortmund
Tel. 0231-7552291, Fax 0231-7554788

IRPUD

Preface

This report originated in the project "Socio-Economic and Spatial Impacts of Transport Infrastructure Investments and Transport System Improvements" (SASI) commissioned by the General Directorate VII (Transport) of the European Commission as part of the 4th Framework Programme of Research and Technology Development.

The SASI project aims at the development of a comprehensive and transferable methodology for forecasting the socio-economic and spatial impacts of large transport investments in Europe, in particular of different scenarios of the development of the trans-European transport networks (TETN) planned by the European Commission. With respect to the cohesion objective of the European Union the model is to answer the question which regions of the European Union are likely to benefit from the TETN and which regions are likely to be disadvantaged.

To achieve this objective the project focuses on developing a comprehensive, consistent and transferable methodology for the prediction of the impacts of transport infrastructure investments and transport system improvements (road, rail and air) on socio-economic activities and development, including spatial and temporal distribution of impacts; designing an interactive, transparent modelling system for forecasting of socio-economic impacts of transport investment decisions and policies and demonstrating the usability of the modelling system by applying it to a number of relevant case studies in the framework of various scenarios of political, social and economic developments.

The SASI project is associated with the EUNET project co-ordinated by Marcial Echenique & Partners Ltd., Cambridge, UK. SASI is carried out with two partners, the Institute of Urban and Regional Research of the Technical University of Vienna (SRF) and the Department of Town and Regional Planning of the University of Sheffield (TRP), with SRF acting as the project co-ordinator

This report, which is the fifth deliverable D5 of the EUNET project and the second deliverable of SASI, defines, discusses and tests *accessibility* indicators. Accessibility is the main ‘product' of a transport system. It determines the locational advantage of a region relative to all other regions and so is a major factor of its social and economic development. At the same time accessibility has a value by itself as an element of quality of life. The report identifies basic types of accessibility, proposes new disaggregate measures of accessibility, demonstrates their application with pan-European data and examines their contribution to the explanation of regional socio-economic development.

The authors thank the following individuals for their co-operation: Meinhard Lemke who supervised the generation of the regional and network databases on which the calculation of accessibility indicators was based, and Brigitte Kiesslich and Annerose Rummel-Kajewski who were responsible for most of the initial digitisation. Special thanks go to Yoshitsugu Hayashi who during his stay as a visiting professor at IRPUD provided invaluable ideas and suggestions for the implementation and interpretation of accessibility indicators.

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1. Summary

The Trans-European Transportation Networks (TETN) programme is one of the most ambitious initiatives of the European Union since its foundation. However, the impacts of this programme on the social and economic development of the European regions are uncertain. In the face of conflicting policy goals of the European Union, the consistent prediction and transparent evaluation of likely socio-economic impacts of major infrastructure investments will therefore become of great political importance for European decision-makers.

The relationship between transport infrastructure and economic development has become more complex than ever. There are successful regions in the European core confirming the theoretical expectation that location matters. However, there are also centrally located regions suffering from industrial decline and high unemployment. On the other side of the spectrum the poorest regions, as theory would predict, are at the periphery, but there are also prosperous peripheral regions such as the Scandinavian countries. To make things even more difficult, some of the economically fastest growing regions are among the most peripheral ones.

The central task of the SASI project is therefore to identify the way transport infrastructure contributes to regional economic development in different regional contexts. The main goal of the project is to design an interactive and transparent modelling system for forecasting the impacts of transport infrastructure investments and transport system improvements, in particular of the TETN, on socio-economic activities and developments in Europe. For that purpose the impacts have to be measured by means of indicators that can be related to the policy goals of the European Union.

This report, which is the fifth deliverable of the EUNET project and the second of the SASI sub-project, defines, discusses and tests *accessibility* indicators to be generated in the model. Accessibility is the main 'product' of a transport system. It determines the locational advantage of a region relative to all other regions and so is a major factor for its social and economic development. At the same time accessibility has a value by itself as an element of quality of life. Accessibility indicators therefore are a central sub-group of the socio-economic indicators discussed in Deliverable D4 of SASI (Bökemann et al., 1997).

This report identifies basic types of accessibility reappearing in the literature. Based on their weaknesses, new disaggregate measures of accessibility are proposed and demonstrated with pan-European data. For these accessibility indicators also 'cohesion' indicators measuring the distribution of accessibility across regions are developed. However, accessibility indicators also represents transport investments and transport system improvements in the SASI model. The suitability of accessibility indicators for SASI therefore also depends on their contribution to the explanation of regional socio-economic development.

The preliminary empirical findings presented in the report indicate that the trans-European networks, in particular the European high-speed rail networks, are likely to stabililise if not increase the differences in accessibility between central and peripheral regions in Europe, however, also that accessibility is no longer the most important factor determining location choice of firms but rather one of many transport and non-transport location factors. It seems appropriate to see accessibility as an enabling condition necessary to facility economic development but which, if present, does not guarantee that development will occur.

2. Introduction

2.1. Problem Statement

Article 2 of the Maastricht Treaty states as the goals of the European Union the promotion of harmonious and balanced economic development, stable, non-inflationary and sustainable growth, convergence of economic performance, high levels of employment and social security, improvement of the quality of life and economic and social coherence and solidarity between the Member States. A prominent role for the achievement of these goals play the envisaged trans-European networks in the fields of transport, communications and energy (TEN). Article 129b of the Treaty links the trans-European networks to the objectives of Article 7a (free traffic of goods, persons, services and capital in the Single European Market) and Article 130a (promotion of economic and social cohesion). In particular, the trans-European transport networks (TETN) are to link landlocked and peripheral areas with the central areas of the Community.

More recently the Decision No. 1692/96/CE of the European Parliament and of the Council (European Parliament, 1996) states that "the establishment and development of TEN contribute to important objectives of the Community such as the good functioning of the internal market and the strengthening of the economic and social cohesion." and underlines that TETN have "to ensure a sustainable mobility for persons and goods, in the best social, environment and safety conditions, and to integrate all transport modes".

In physical and monetary terms the trans-European transport networks are one of the most ambitious initiatives of the European Community since its foundation. The masterplans for rail, road, waterways, ports and airports together require public and private investment of 220 billion ECU until the end of the century, of which the Union is prepared to finance about 20 billion ECU per year.

However, the programme is not undisputed. Critics argue that many of the new connections do not link peripheral countries to the core but two central countries and so reinforce their accessibility advantage. Only forty percent of the new motorways in the road masterplan are in peripheral countries, whereas sixty percent are in countries with an already highly developed road infrastructure. Some analysts argue that regional development policies based on the creation of infrastructure in lagging regions have not succeeded in reducing regional disparities in Europe, whereas others point out that it has yet to be ascertained that the reduction of barriers between regions has disadvantaged peripheral regions. From a theoretical point of view, both effects can occur. A new motorway or high-speed rail connection between a peripheral and a central region, for instance, makes it easier for producers in the peripheral region to market their products in the large cities, however, it may also expose the region to the competition of more advanced products from the centre and so endanger formerly secure regional monopolies.

In addition there are environmental concerns. High-speed rail corridors or multi-lane motorways consume environmentally valuable open space in high-density metropolitan areas and cut through ecologically sensitive habitats and natural regions outside of cities and in addition contribute to the general trend of inducing more and higher-speed travel and goods transport.

In the face of these conflicting goals the consistent prediction and the rational and transparent evaluation of likely socio-economic impacts of major transport infrastructure investments become of great political importance both for the European Union and for its Member States. This is also underlined by the most recent *Cohesion Report* (European Commission, 1997) which emphasises that "regions should ensure that policy success is measurable, that results are regularly monitored, and that the public and political authorities are regularly informed of progress."

2.2. Objectives of the SASI Project

The SASI project aims at the development of a comprehensive and transferable methodology for forecasting the socio-economic and spatial impacts of large transport investments in Europe, in particular of different scenarios of the development of the trans-European transport networks (TETN) planned by the European Commission. With respect to the cohesion objective of the European Union the model is to answer the question which regions of the European Union are likely to benefit from the TETN and which regions are likely to be disadvantaged.

To achieve this objective the project focuses on

- developing a comprehensive, consistent and transferable methodology for the prediction of the impacts of transport infrastructure investments and transport system improvements (road, rail and air) on socioeconomic activities and development, including spatial and temporal distribution of impacts;

- designing an interactive, transparent modelling system for forecasting of socio-economic impacts of transport investment decisions and policies;

- demonstrating the usability of the modelling system by applying it to a number of relevant case studies in the framework of various scenarios of political, social and economic developments.

The proposed methodology and modelling system is innovative in that it is based on measurable indicators derived from advanced location-theory approaches to explain and predict the locational behaviour of investment capital and manufacturing and service activities and population. It is pragmatic and feasible in that it does not require massive and repeated collection of data on socio-economic distributions or trade flows and travel patterns. It is designed to facilitate political discussion and negotiation by being transparent, understandable and open for new indicators and issues that may become relevant in the future.

At the end of the project a combined report will be produced from the output of SASI and the EUNET and ECOPAC consortia working for the Commission in the same area.

2.3. The Position of D5 within SASI

The previous Deliverable D4 of SASI (Bökemann et al.,1997) linked the policy objectives of the European Union, in particular of its Common Transport Policy, to the model to be developed in SASI. For this purpose first the main political goals of the European Union were systematically structured. Then a set of socio-economic indicators was derived taking account of (i) the state of the art in social indicator research, (ii) the indicators most frequently used in other studies and their strengths and weaknesses, (iii) their relevance for the policy goals of the European Union, (iv) their ability to express socio-economic impacts of transport policies and (v) their interpretability by decision makers, as well as technical constraints such as (vi) their computability by the model to be developed and (vii) the availability of data. Finally, empirical illustrations of selected indicators were presented. In the conclusions limitations of the proposed methodology were discussed.

This report, Deliverable D5 of the EUNET project and the second deliverable of the SASI sub-project, defines, discusses and tests accessibility indicators to be generated and used in the SASI model. Accessibility is the main 'product' of a transport system. It determines the locational advantage of a region relative to all other regions and so is a major factor for the social and economic development of a region. At the same time accessibility has a value by itself as an element of quality of life. Accessibility indicators therefore are a central sub-group of the socio-economic indicators discussed in D4.

There is a great variety of approaches to measuring accessibility. This report identifies basic types of accessibility indicator reappearing in the literature in various forms. Based on their weaknesses, a range of new disaggregate measures of accessibility is proposed and demonstrated with pan-European data. Just as for the other indicators discussed in D4, also for these accessibility indicators 'cohesion' indicators measuring the distribution of accessibility across regions can be developed.

However, unlike the other indicators of D4, accessibility is not only output of but also input to the model; in fact it is the only way transport investments and transport system improvements are represented in it. The suitability of accessibility indicators for SASI therefore also depends on their contribution to the explanation of regional socio-economic development. From a substantive point of view non-transport factors and transport factors of regional development interact and cannot be separated (see Linneker, 1997); nevertheless it is useful to examine how much accessibility alone contributes to regional socio-economic development. Therefore the accessibility indicators implemented are – in a tentative bivariate analysis – correlated with indicators of regional economic performance and development.

This report D5 has a similar structure as D4. Therefore topics that have been dealt with in depth in D4 such as the discussion of policy goals of the European Union, are not repeated. However the tentative structure of the SASI model under development is repeated in the subsequent section for easier reference. Section 3 summarises theoretical concepts related to measuring accessibility, and Section 4 presents the most relevant implementations of accessibility used in other studies. In Section 5 selected accessibility indicators that might be applied in the SASI model are calculated and visualised for the system of model regions used. In Section 6 they are correlated with indicators of regional economic performance and development. The final Section 7 draws conclusions for further work in the project.

2.4. The SASI Model

This section contains a first outline of the structure of the SASI model under development. It is still tentative and reflects the discussion in the SASI project team to date. It is presented here to enable the reader to understand the selection of accessibility indicators proposed in the subsequent sections.

2.4.1. Design Principles

The model to be developed is to consistently forecast socio-economic and spatial impacts of transport infrastructure investment and transport system improvements in Europe. From this purpose the following requirements can be derived:

- The model must be responsive to changes in European transport policy, in particular to different scenarios and time schedules of expanding and improving the trans-European rail and road networks.

- The model must produce regional indicators of socio-economic development and cohesion that are relevant from the point of view of policy objectives of the European Union.

The first of these two requirements is addressed by calculating regional accessibility indicators expressing the location of each region within the strategic European rail and road networks defined for SASI. Changes in the trans-European networks affect the distribution of accessibility and the economic advantage across regions. However, regional socio-economic development cannot be explained by transport changes alone. Therefore other (non-transport) factors determining regional socio-economic development are included in the model. These factors include assumptions about European developments as well as factors expressing the endowment, or suitability and capacity for economic activities, of regions. When comparing different scenarios of transport network development, the non-transport factors have to be kept constant.

The second requirement determines the output and hence necessary submodels of the model. As indicated in Section 2.1 and SASI Deliverable D4, the goals of the European Union are the promotion of harmonious and balanced economic development, stable, non-inflationary and sustainable growth, convergence of economic performance, high levels of employment and social security, improvement of the quality of life and economic and social coherence and solidarity between the Member States. Since sustainability objectives are (for the time being) excluded from SASI, efficiency and equity objectives remain as the relevant goals. As it was argued in Deliverable D4, despite their acknowledged weaknesses the most commonly used indicators of regional economic efficiency are regional output and employment or, in operational terms, gross domestic product (GDP) per capita and rate of unemployment. This implies that not only economic output and employment but also population and labour force have to be modelled. Equity or cohesion indicators finally express the distribution of GDP per capita and unemployment across regions (see Deliverable D4).

Based on the above considerations, the SASI model will have six forecasting submodels: *European Developments*, *Regional Accessibility*, *Regional GDP*, *Regional Employment*, *Regional Population* and *Regional Labour Force*. A seventh submodel calculates *Socio-economic Indicators* with respect to efficiency and equity.

This defines the minimum scope of the SASI model. More submodels can be added later if so desired. However, to achieve the objectives of SASI as outlined in Section 2.2, the above submodels are necessary.

2.4.2. Submodels

In this section the seven submodels of the SASI model and the interrelationships between them are briefly described. Figure 1 is an attempt to visualise the interactions between the submodels.

European Developments
Here assumptions about European developments are entered that are processed by the subsequent submodels. European developments include assumptions about the future performance of the European economy as a whole and the level of immigration and outmigration across Europe's borders. They serve as constraints to ensure that the regional forecasts for economic development and population remain consistent with external developments not modelled. Given the expected rapid population growth and lack of economic opportunity in many origin countries, total European immigration by origin country will be largely a function of policy decisions by the European Union or national governments. Another relevant European policy field are transfer payments by the European Union via the Structural Funds to assist specific regions, which, because of their concentration on lagging regions, are responsible for a sizeable part of their economic growth. The last group of assumptions are those about policy decisions with respect to the trans-European networks. As these are of focal interest in SASI, they are modelled with considerable detail. They can include time-sequenced investment programmes for expansion or upgrading of the road and rail networks, for the closure of missing links or for improvements of the operation of networks with respect to intermodality and interoperability.

Regional Accessibility
This submodel calculates regional accessibility indicators expressing the relative locational advantage of each region with respect to relevant destinations in the region and in other regions as a function of travel time or travel cost (or both) to reach these destinations by the strategic road and rail networks. The interregional accessibility indicators calculated in the model are discussed in the following sections of this report. In addition, intraregional accessibility may be expressed by endowment indicators measuring density or connectivity of the networks within the region.

Regional GDP
This is the core submodel of the SASI model. It calculates a forecast of gross domestic product (GDP) generated in each region as a function of endowment indicators and accessibility. Endowment indicators are indicators measuring the suitability of the region for economic activity. Endowment indicators may include traditional location factors such as availability of skilled labour and business services, capital stock (i.e. production facilities) and intraregional transport

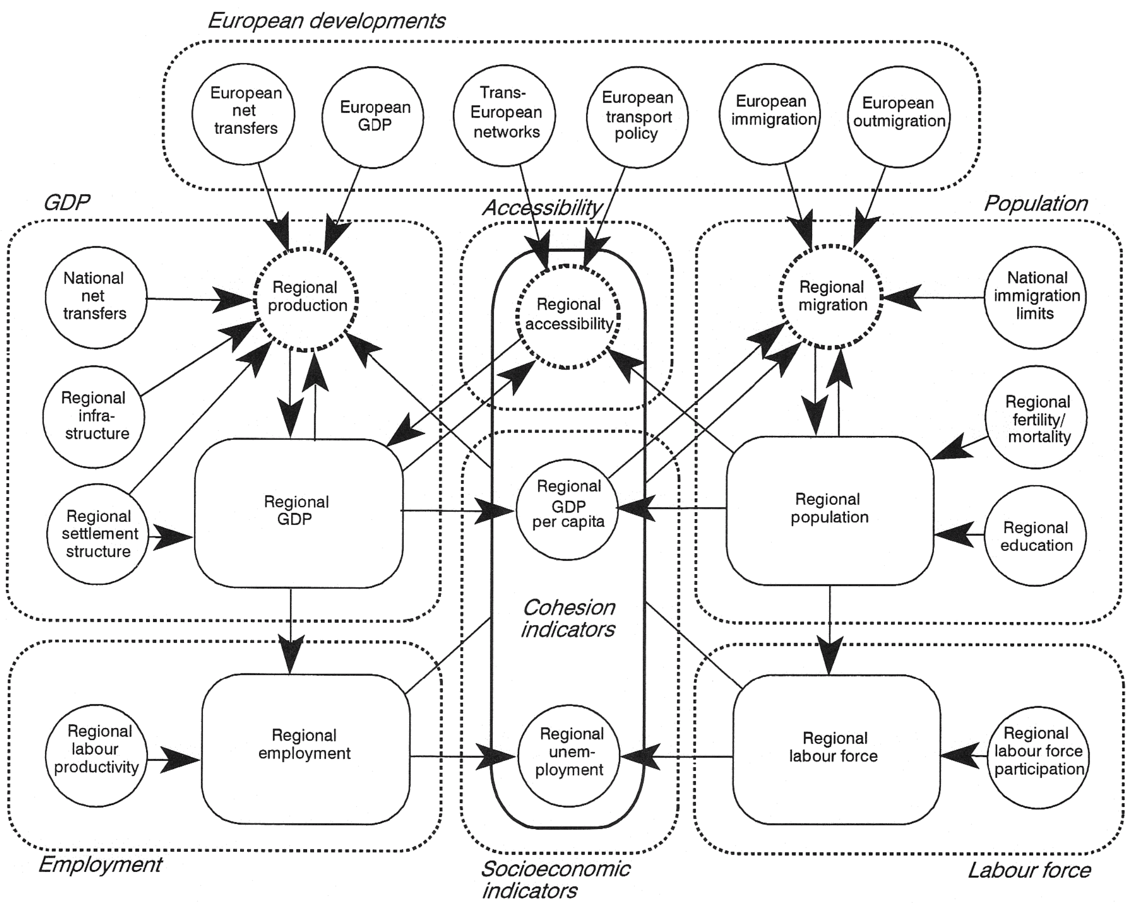


Figure 1. The SASI model (draft).

infrastructure as well as 'soft' location factors such as institutions of higher education, good housing and a pleasant climate and environment. Accessibility indicators are derived from the accessibility submodel. In addition to endowment and accessibility indicators, monetary transfers to regions by the European Union such as assistance from the Structural Funds are considered, as these may account for a sizeable proportion of the economic development of peripheral regions. The results of the regional GDP forecasts are adjusted such that the total of all regional forecasts meets the exogenous forecast of economic development (GDP) of Europe as a whole by the European Developments submodel.

Regional Employment
Regional employment is derived from regional GDP by external forecasts of regional labour productivity (GDP per worker per year). Employment is disaggregated by economic sector (agriculture, manufacturing, services). This requires exogenous forecasts of economic structural change, i.e. the changing shares of the three sectors in total employment.

Regional Population
The population side of the SASI model is needed to represent the demand side of the socio-economic indicators to be generated. Regional population changes due to natural change (fertility, mortality) and migration. In order to model fertility and mortality by a cohort-survival model, population must be disaggregated by age and sex. Age-specific fertility and mortality rates have to be provided as exogenous forecasts for each region and simulation period. Interregional migration will be modelled using a gravity type migration model in which origins and destinations are represented by population and the interaction term by a function of distance and the difference in wage level (GDP per capita) and job opportunities (unemployment). The results of this model are adjusted to comply with total European immigration and outmigration by country of origin/destination forecast by the European Developments submodel and the limits on immigration set by individual countries.

Regional Labour Force
Regional labour force is derived from regional GDP and exogenous forecasts of regional labour force participation rates.

Socio-economic Indicators
Total GDP and employment represent only the supply side of socio-economic development. To derive policy-relevant indicators, they have to be related to the demand side, i.e. to population and labour force. This is done in the final submodel by calculating regional GDP per capita and regional unemployment. From the socio-economic indicators so derived, equity or cohesion indicators describing their distribution across regions are calculated.

2.4.3. Space and Time

The SASI model forecasts socioeconomic development in the 201 regions at the NUTS-2 level defined for SASI for the fifteen EU countries (see Figure 2 and Annex Table A1). These are the 'internal' regions of the model. The 27 regions defined for the rest of Europe are the 'external' regions which are used only as additional destinations when calculating accessibility indicators. The four regions representing the rest of the world are not used.

The spatial dimension of the system of regions is established by their connection via networks. In SASI road, rail and air networks are considered. The 'strategic' road and rail networks used in SASI are subsets of the pan-European road and rail networks developed by IRPUD and recently adopted for the GISCO spatial reference database of Eurostat. The 'strategic' road and rail networks contain all TETN links laid down in Decision No. 1692/96/CE of the European Parliament and the Council (European Parliament, 1996) and the east European road and rail corridors identified by the Second Pan-European Transport Conference in Crete in 1994 as well as additional links selected for connectivity reasons (see Figures 3 and 4).

The SASI system of regions and the strategic networks used in SASI are also used in the concurrent DGVII projects STREAMS, EUNET and STEMM.

The temporal dimension of the model is established by dividing time into discrete time intervals or periods of one or two years. By modelling relatively short time periods both short- and long-term lagged impacts can be taken into account. The base year of the simulations will be 1980 in order to demonstrate that the model is able to reproduce the main trends of spatial development in Europe over a significant time period of the past with satisfactory accuracy. The forecasting horizon of the model will be 2010 or 2020.

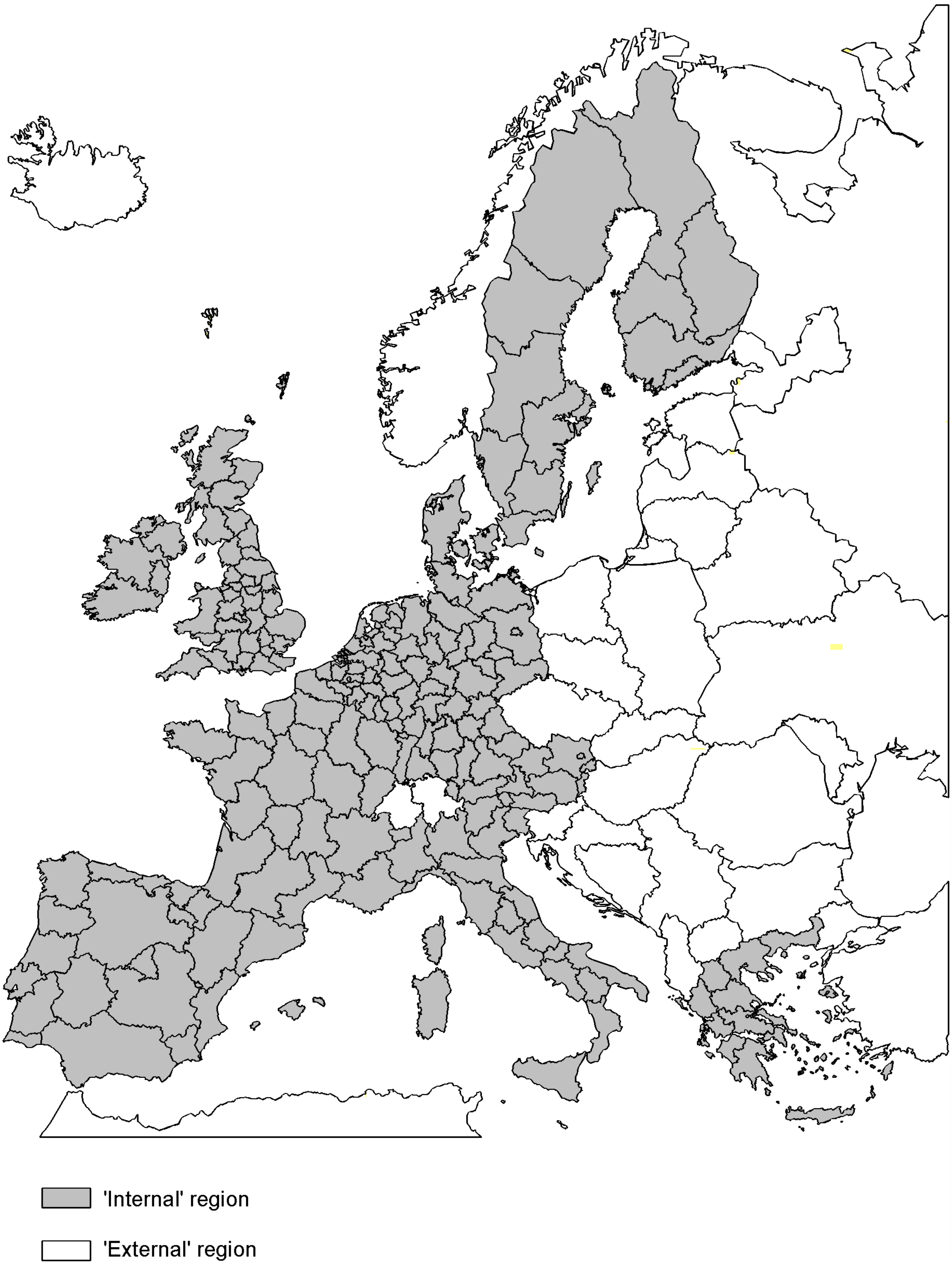


Figure 2. The SASI system of regions

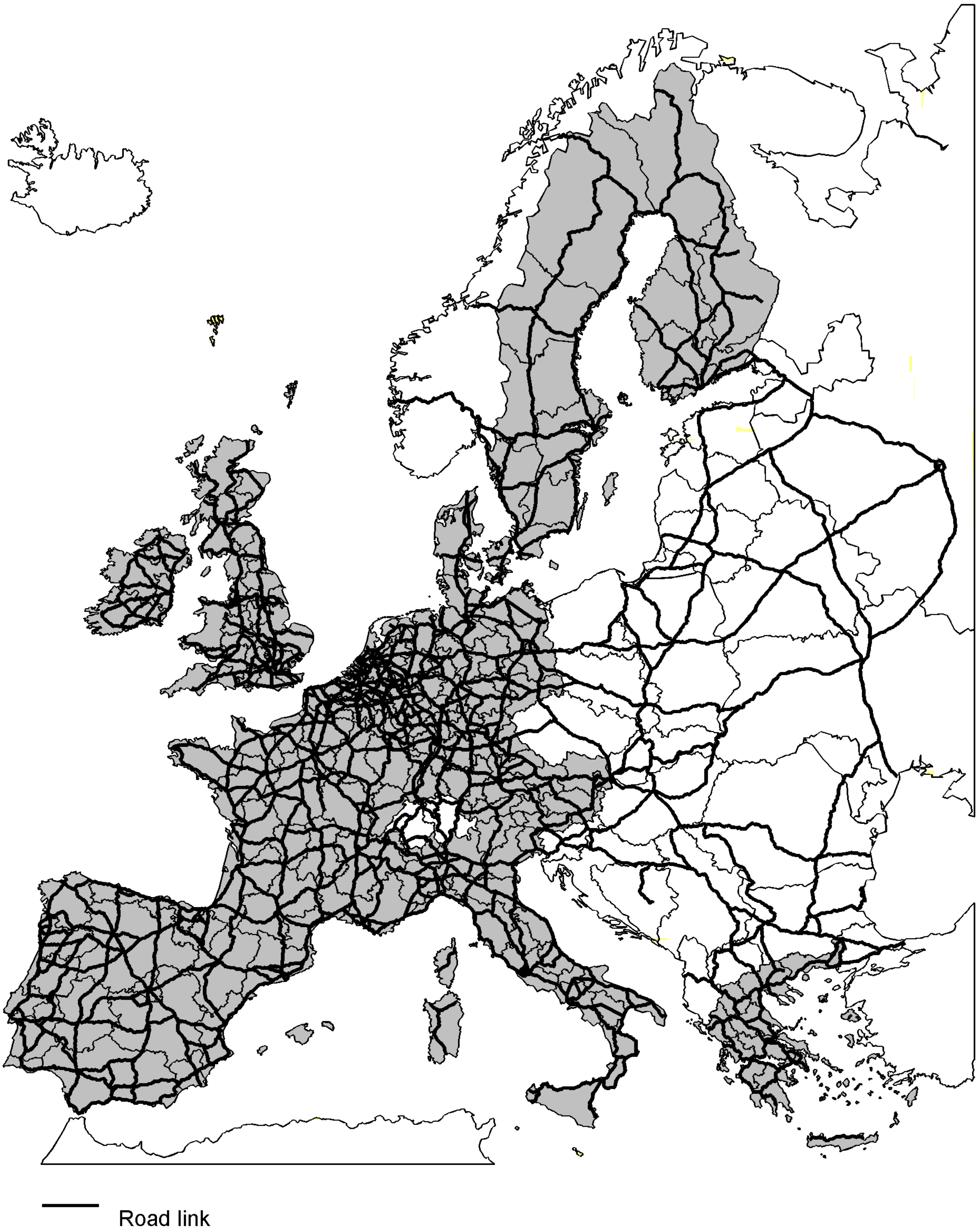


Figure 3. The SASI strategic road network

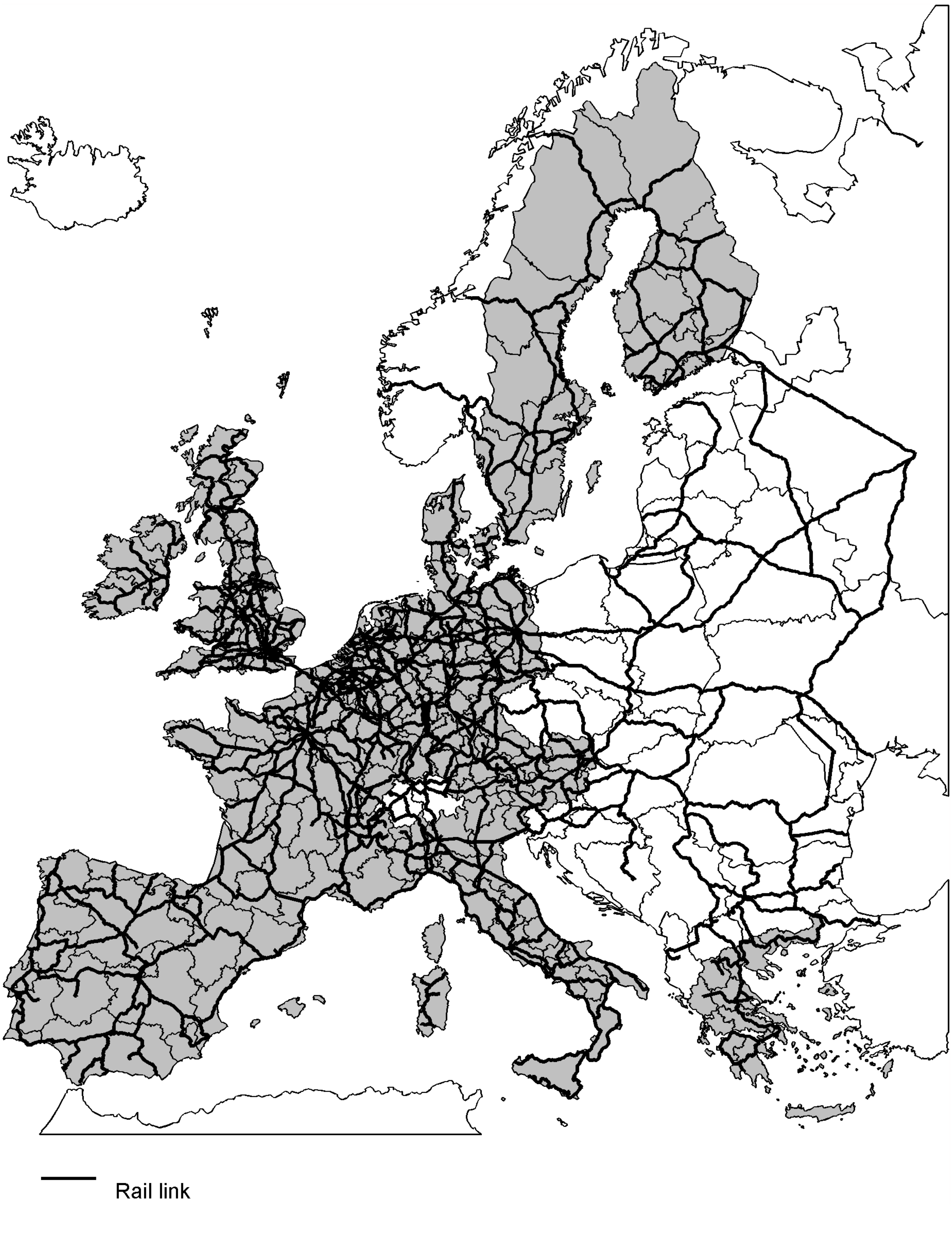


Figure 4. The SASI strategic rail network

3. Theoretical Foundations

3.1. Why Accessibility?

The important role of transport infrastructure for regional development is one of the fundamental principles of regional economics. In its most simplified form it implies that regions with better access to the locations of input materials and markets will, *ceteris paribus*, be more productive, more competitive and hence more successful than more remote and isolated regions (see Linneker, 1997).

However, the impact of transport infrastructure on regional development has been difficult to verify empirically. There seems to be a clear positive correlation between transport infrastructure endowment or the location in interregional networks and the *levels* of economic indicators such as GDP per capita (e.g. Biehl, 1986; 1991; Keeble et al., 1982, 1988). However, this correlation may merely reflect historical agglomeration processes rather than causal relationships effective today (cf. Bröcker and Peschel, 1988). Attempts to explain *changes* in economic indicators, i.e. economic growth and decline, by transport investment have been much less successful. The reason for this failure may be that in countries with an already highly developed transport infrastructure further transport network improvements bring only marginal benefits. The conclusion is that transport improvements have strong impacts on regional development only where they result in removing a *bottleneck* (Blum, 1982; Biehl, 1986; 1991).

While there is uncertainty about the magnitude of the impact of transport infrastructure on regional development, there is even less agreement on its direction. It is debated whether transport infrastructure contributes to regional polarisation or decentralisation. Some analysts argue that regional development policies based on the creation of infrastructure in lagging regions have not succeeded in reducing regional disparities in Europe (Vickerman, 1991a), whereas others point out that it has yet to be ascertained that the reduction of barriers between regions has disadvantaged peripheral regions (Bröcker and Peschel, 1988). From a theoretical point of view, both effects can occur. A new motorway or high-speed rail connection between a peripheral and a central region, for instance, makes it easier for producers in the peripheral region to market their products in the large cities, however, it may also expose the region to the competition of more advanced products from the centre and so endanger formerly secure regional monopolies (Vickerman, 1991b).

While these two effects may partly cancel each other out, one factor unambiguously increases existing differences in transport infrastructure. New transport infrastructure tends to be built not between core and periphery but within and between core regions, because this is where transport demand is highest (Vickerman, 1991a). It can therefore be assumed that the trans-European networks will largely benefit the core regions of Europe.

These developments have to be seen in the light of changes in the field of transport and communications which will fundamentally change the way transport infrastructure influences spatial development (see Masser et al., 1992). Several trends combine to reinforce the tendency to diminish the impacts of transport infrastructure on regional development:

- An increased proportion of international freight comprises high-value goods for which transport cost is much less than for low-value bulk products. For modern industries the *quality* of transport services has replaced transport *cost* as the most important factor.

- Transport infrastructure improvements which reduce the variability of travel times, increase travel speeds or allow flexibility in scheduling are becoming more important for improving the competitiveness of service and manufacturing industries and are therefore valued more highly in locational decisions than changes resulting only in cost reductions.

- Telecommunications have reduced the need for some goods transports and person trips, however, they may also increase transport by their ability to create new markets.

- With the shift from heavy-industry manufacturing to high-tech industries and services other less tangible location factors have come to the fore and have at least partly displaced traditional ones. These new location factors include factors related to leisure, culture, image and environment, i.e. quality of life, and factors related to access to information and specialised high-level services and to the institutional and political environment.

On the other hand, there are also tendencies that increase the importance of transport infrastructure:

- The introduction of totally new, superior levels of transport such as the high-speed rail system may create new locational advantages, but also disadvantages for regions not served by the new networks.

- Another factor adding to the importance of transport is the general increase in the volume of goods movements (due to changes in logistics such as just-in-time delivery) and travel (due to growing affluence and leisure time).

Both above tendencies are being accelerated by the increasing integration of national economies by the Single European Market, the ongoing process of normalisation between western and eastern Europe and the globalisation of the world economy.

The conclusion is that the relationship between transport infrastructure and economic development has become more complex than ever. There are successful regions in the European core confirming the theoretical expectation that location matters. However, there are also centrally located regions suffering from industrial decline and high unemployment. On the other side of the spectrum the poorest regions, as theory would predict, are at the periphery, but there are also prosperous peripheral regions such as the Scandinavian countries. To make things even more difficult, some of the economically fastest growing regions are among the most peripheral ones.

The central task of SASI is therefore to identify the way transport infrastructure contributes to regional economic development in different regional contexts. This means to develop indicators measuring not infrastructure investments as such but the benefit they bring to firms and households in the regions by more capacity, higher speeds, better quality and more reliable transport. These indicators are called *accessibility*.

3.2. Basic Accessibility Indicators

Accessibility is the main 'product' of a transport system. It determines the locational advantage of a region relative to all regions (including itself). Indicators of accessibility measure the benefits households and firms in a region enjoy from the existence and use of the transport infrastructure relevant for their region.

Accessibility indicators can be defined to reflect both within-region transport infrastructure and infrastructure outside the region which affect the region.

Simple accessibility indicators consider only intraregional transport infrastructure expressed by such measures as total length of motorways, number of railway stations (e.g. Biehl, 1986; 1991) or travel time to the nearest nodes of interregional networks (e.g. Lutter et al., 1993). While this kind of indicator may contain valuable information about the region itself, they fail to recognise the network character of transport infrastructure linking parts of the region with each other and the region with other regions.

More complex accessibility indicators take account of the connectivity of transport networks by distinguishing between the network itself, i.e. its nodes and links, and the activities or opportunities that can be reached by it (cf. Bökemann, 1982). In general terms, accessibility then is a construct of two functions, one representing the activities or opportunities to be reached and one representing the effort, time, distance or cost needed to reach them:

$$A_i = \sum_j \mathrm{g}(W_j)\,\mathrm{f}(c_{ij}) \qquad (1)$$

where A_i is the accessibility of region i, W_j is the activity W to be reached in region j, and c_{ij} is the generalised cost of reaching region j from region i. The functions $\mathrm{g}(W_{ij})$ and $\mathrm{f}(c_{ij})$ are called *activity functions* and *impedance functions*, respectively. They are associated multiplicatively, i.e. are weights to each other. That is, both are necessary elements of accessibility. A_i is the accumulated total of the activities reachable at j weighted by the ease of getting from i to j.

It is easily seen that this is a general form of potential, a concept dating back to Newton's law of gravitation and introduced into regional science by Stewart (1947). According to the law of gravitation the attraction of a distant body is equal to its mass weighted by a decreasing function of its distance. Here the attractors are the activities or opportunities in regions j (including region i itself), and the distance term is the impedance c_{ij}.

The interpretation here is that the greater the number of attractive destinations in regions j is and the more accessible regions j are from region i, the greater is the accessibility of region i. This definition of accessibility is referred to as destination-oriented accessibility. In a similar way an origin-oriented accessibility can be defined: The more people live in regions j and the easier they can visit region i, the greater is the accessibility of region i. Because of the symmetry of most transport connections, destination-oriented and origin-oriented accessibility tend to be highly correlated.

Different types of accessibility indicators can be constructed by specifying different forms of functions g(W_j) and f(c_{ij}). Table 1 shows the three most frequently applied combinations of g(W_j) and f(c_{ij}):

Table 1. Typology of accessibility indices

Type of accessibility	Activity function g (W_j)	Impedance function f (c_{ij})
1 *Travel cost* Accumulated travel cost to a set of activities	$W_j \mid 1$ if $W_j \geq W_{\min}$ 0 if $W_j < W_{\min}$	c_{ij}
2 *Daily accessibility* Accumulated activities in a given travel time	W_j	1 if $c_{ij} \leq c_{\max}$ 0 if $c_{ij} > c_{\max}$
3 *Potential* Accumulated activities weighted by a function of travel cost	W_j^{α}	$\exp\left(-\beta\, c_{ij}\right)$

where $W_{\min}$ and $c_{\max}$ are constants and α and β parameters. The different forms of functions used for g(W_j) and f(c_{ij}) are shown in graphical form in Figure 5. It can be seen that the three types of accessibility indicators are derived from different combinations of *rectangular*, *linear* and *nonlinear* (power or exponential) functions:

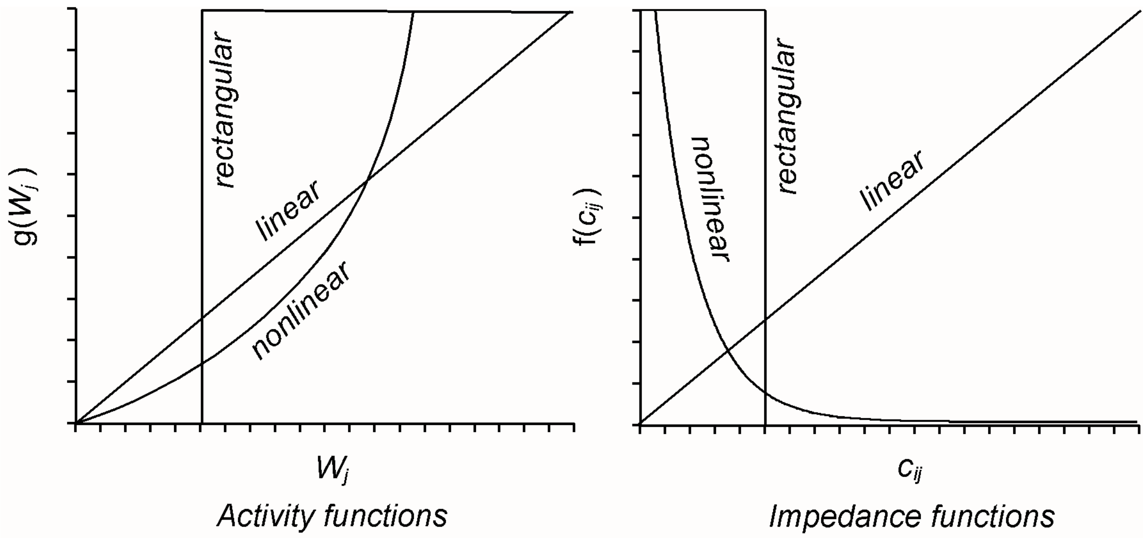


Figure 5. Activity and impedance functions used in accessibility indicators.

Travel cost

This indicator is based on the assumption that not all possible destinations are relevant for the accessibility of a region but only a specified set. This set may, for instance, consist of all cities over a specified size or level of attraction $W_{\min}$. The indicator measures the accumulated generalised travel costs to the set of destinations. In the simplest case no distinction is made between larger and smaller destinations, i.e. all destinations in the set get equal weight irrespective of their size and all other destinations are weighted zero (the activity function is rectangular). In many applications, however, destinations are weighted by size (the activity function is linear). The impedance function is always linear, i.e. does not take into account that more distant destinations are visited less frequently.

$$A_i = \sum_j g(W_j)\, c_{ij} \qquad \text{with} \quad g(W_j) = \begin{cases} W_j \mid 1 & \text{if } W_j \geq W_{\min} \\ 0 & \text{if } W_j < W_{\min} \end{cases} \tag{2}$$

To make the index easier to compare, the accumulated generalised cost so generated is frequently divided by the number of destinations or the total of attractions g(W_j), respectively. The indicator then represents the average travel cost to the set of destinations:

$$A_i = \frac{\sum_j g(W_j)\, c_{ij}}{\sum_j g(W_j)} \qquad \text{with} \quad g(W_j) = \begin{cases} W_j \mid 1 & \text{if } W_j \geq W_{\min} \\ 0 & \text{if } W_j < W_{\min} \end{cases} \tag{3}$$

In both cases the indicator expresses a *disutility*, i.e. the lower its value the higher the accessibility.

Travel cost indicators are popular because they are easy to interpret, in particular if they are expressed in familiar units such as average travel cost or travel time. Their common disadvantage is that they lack a behavioural foundation because they ignore that more distant destinations are visited less frequently and that therefore their values depend heavily on the selected set of destination, i.e. the arbitrary cut-off point of the W_j included.

Daily accessibility

This indicator is based on the notion of a fixed budget for travel, generally in terms of a maximum time interval in which a destination has to be reached to be of interest. The rationale of this accessibility indicator is derived from the case of a business traveller who wishes to travel to a certain city, conduct business there and return home in the evening (Törnqvist, 1970). Maximum travel times of between three and five hours one-way are used. Because of its association with a one-day business trip this type of accessibility is often called 'daily accessibility'.

$$A_i = \sum_j W_j \ \mathrm{f}\left(c_{ij}\right) \qquad \text{with} \ \ \mathrm{f}\left(c_{ij}\right) = \begin{cases} 1 \ \text{if} \ c_{ij} \leq c_{\max} \\ 0 \ \text{if} \ c_{ij} > c_{\max} \end{cases} \tag{4}$$

where $c_{\max}$ is the travel time limit. The daily accessibility indicator is equivalent to a potential accessibility (see below) with a linear activity function and a rectangular impedance function, i.e. within the selected travel time limit destinations are weighted only by size, whereas beyond that limit no destinations are considered at all.

Daily accessibility indicators, like the travel time indicators above, have the advantage of being expressed in easy to understand terms, e.g. the number of people one can reach in a given number of hours. However, they also share their disadvantage that they heavily depend on the arbitrarily selected maximum travel time beyond which destinations are no more considered.

Potential accessibility

This indicator is based on the assumption that the attraction of a destination increases with size *and* declines with distance or travel time or cost. Therefore both size and distance of destinations are taken into account. The size of the destination is usually represented by regional population or some economic indicator such as total regional GDP or total regional income. The activity function may be linear or nonlinear. Occasionally the attraction term W_j is weighted by an exponent α greater than one to take account of agglomeration effects, i.e. the fact that larger facilities may be disproportionally more attractive than smaller ones. One example is the attractiveness of large shopping centres which attract more customers than several smaller ones that together match the large centre in size. The impedance function is nonlinear. Generally a negative exponential function is used in which a large parameter β indicates that nearby destinations are given greater weight than remote ones.

$$A_j = \sum_j W_j^{\alpha} \ \exp\left(-\beta \ c_{ij}\right) \tag{5}$$

Earlier versions of the potential accessibility used an inverse power function reminiscent of Newton's gravity model:

$$A_i = \sum_j \frac{W_j}{c_{ij}^{\alpha}} \tag{6}$$

This form was proposed by Hansen as early as 1959 and is therefore called 'Hansen' accessibility. Later improvements led to the empirically similar but behaviourally derived negative exponential function used above (Wilson, 1967).

Potential accessibility indicators are superior to travel time accessibility indicators and daily accessibility indicators in that they are founded on sound behavioural principles of stochastic utility maximisation. Their disadvantage is that they contain parameters that need to be calibrated and that their values cannot be easily interpreted in familiar units such as travel time or number of people. Therefore potential indicators are frequently expressed in percent of average accessibility of all regions or, if changes of accessibility are studied, in percent of average accessibility of all regions in the base year of the comparison.

3.3. Refinements

From the above three basic accessibility indicators, an almost unlimited variety of derivate indicators can be developed (cf. Ruppert, 1975). The most important ones are discussed here.

Multimodal accessibility

All three types of accessibility indicator can be calculated for any mode. On a European scale, accessibility indicators for road, rail and air are most frequently calculated. In most studies accessibility indicators were calculated for passenger travel only; only few studies calculating freight accessibility indicators are known.

Differences between modes are usually expressed by using different 'generalised' cost functions. A frequently used generalised cost function is:

$$c_{ijm} = v_m\, t_{ijm} + c_m\, d_{ijm} + u_m\, k_{ijm} \tag{7}$$

where t_{ijm}, d_{ijm} and k_{ijm} are travel time, travel distance and convenience of travel from location i to destinations j by mode m, respectively, and v_m, c_m and u_m are value of time, cost per kilometre and disutility of inconvenience of mode m, respectively. In addition, there may be a fixed travel cost component as well as cost components taking account of network access at either end of a trip, waiting and transfer times at stations, waiting times at borders or congestion in metropolitan areas.

Modal accessibility indicators may be presented separately in order to demonstrate differences in accessibility between modes. Or they may be integrated into one indicator expressing the combined effect of alternative modes for a location. There are essentially two ways of integration. One is to select the fastest mode to each destination, which in general will be air for distant destinations and road or rail for short- or medium-distance destinations, and to ignore the remaining modes. Another way is to calculate an aggregate accessibility measure combining the information contained in the three modal accessibility indicators by replacing the generalised cost c_{ij} in (5) by the 'composite' generalised cost $\bar{c}_{ij}$:

$$\bar{c}_{ij} = -\frac{1}{\lambda} \ln \sum_m \exp\left(-\lambda\, c_{ijm}\right) \tag{8}$$

where c_{ijm} is the generalised cost of travel by mode *m* between *i* and *j* of (7) and λ is a parameter indicating the sensitivity to travel cost (Williams, 1977). This formulation of composite travel cost is superior to average travel cost because it makes sure that the removal of a mode with higher cost (i.e. closure of a rail line) does not result in a - false - reduction in aggregate travel cost. This way of agg regating travel costs across modes is theoretically consistent only for potential accessibility. No consistent ways of calculating multimodal accessibility indicators for travel cost and daily accessibility exist.

Intermodal accessibility

A further refinement is to calculate *intermodal* accessibility. Intermodal accessibility indicators take account of intermodal trips involving two or more modes. Intermodal accessibility indicators are potentially most relevant for logistic chains in freight traffic such as rail freight with feeder transport by lorry at either end. Intermodal accessibility indicators in passenger travel involve mode combinations such as rail-and-fly or car rentals at railway stations and airports.

The calculation of intermodal accessibility indicators requires, of course, the capability of minimum path search in a multimodal network. The intermodal generalised cost function consequently contains further additional components to take account of intermodal waiting and transfer times, cost and inconvenience.

Intraregional accessibility

Intermodality is also an issue when calculating *intraregional* accessibility. Most accessibility studies so far have concentrated on the accessibility of cities, i.e. network nodes which are assumed to represent the whole metropolitan area or region. This presents two problems. Accessibility indicators calculated for network nodes only ignore that accessibility is continuous in space. The decline of accessibility from the central node (centroid) of a region to smaller towns and less urbanised parts of the region is not considered. Also the quality of the interconnections between the high-speed interregional and the low-speed intraregional transport networks cannot be taken account of. Yet the ease of getting from home or office to the nearest station of the high-speed rail network or the next international airport may be more important for a location than the speed of the long-distance connection from there. In addition the estimation of access times from locations within the region to the regional centroid as well as of travel times between activities within the region itself ('self-potential'), which greatly influence the accessibility of a region, increase in difficulty with spatial aggregation.

However, calculating intraregional accessibility indicators is not straightforward as it requires high-resolution data on the spatial distribution of activities in the region. If also the quality of the intraregional transport network and its connection with the long-distance interregional networks are to be assessed, detailed information on the intraregional road and public transport networks and the transfer possibilities at railway stations and airports are required.

Activities and actors

Accessibility indicators are also to be used in SASI as explanatory variables contributing to the prediction of location decisions by households and firms. However, there are a variety of households and firms with different requirements with respect to their location and with different sensitivity with respect to travel time, travel cost or other trip characteristics. It would therefore be surprising if one single accessibility indicator would be sufficient to explain say the migration decision by a worker household and the investment decision by a company.

Because of this, it may be necessary to develop different accessibility indicators for different activities and types of actors. In the EUNET project associated with SASI 20 'trip purposes' were proposed for which accessibility indicators might be calculated (INRETS, 1997):

- daily consumption
- visits to relatives (day return, short period, long period, emigration)
- entertainment (day return, short period, long period)
- access to input (labour, low value, high value, distribution)
- access to markets (consumer goods, consumer sales, intermediate low value goods, intermediate to high value goods, intermediate business trips, services)
- tourists (short period, long period)

It was proposed to classify households by social status and age, car ownership, revenues and specific characteristics, individuals as business travellers or service personnel and freight by value per ton, system of storage, hazardous or perishable goods, type of conditioning, size of the load and type of trade.

The problems associated with this kind of disaggregation are clearly lack of data and difficulty of calibration. Moreover, it is likely that many of the accessibility indicators so generated will be highly correlated with each other.

3.4. Accessibility Indicators Used in Other Studies

There is a large variety of approaches to measuring accessibility in the geographic and economic literature. However, as indicated in Section 3.1, there are only few attempts to empirically demonstrate that accessibility, as economic theory suggests, has had significant influence on regional economic development. Most of the studies reported have proposed and demonstrated a specific approach to measuring differences or changes in accessibility in a particular spatial context or year and then *speculated* on the their possible or likely effects on regional economic development.

Travel cost

Total or average travel time to a specified set of destinations has received increasing recognition as accessibility indicator in recent studies because of its straightforward interpretability.

In 1993 the Bundesforschungsanstalt für Landeskunde und Raumordnung (BfLR) (Lutter et al., 1993) in a study for DG XVI of the European Commission calculated accessibility of NUTS-3 regions in the formerly twelve member countries of the European Community (EUR12) as average travel time by fastest mode (road, rail, air) to 194 economic centres. The selection of centres was based on RECLUS (1989) and Zumkeller and Herry (1992). The results with and without planned infrastructure investments are summarised by country in Figure 6. Similar accessibility indicators were developed for the reunited Germany by Eckey and Horn (1992) and Lutter et al. (1992).

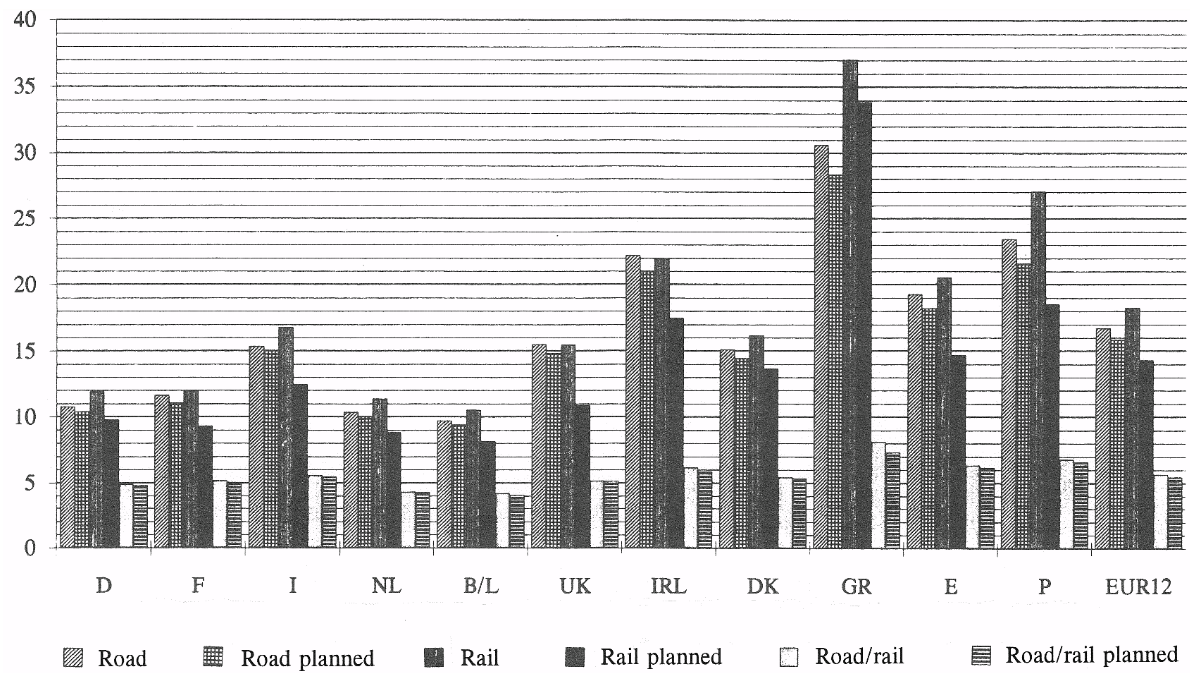


Figure 6. Average travel time to 194 economic centres (Source: Lutter et al., 1993).

Gutiérrez (1995) and Gutiérrez and Urbano (1996) calculated average travel time by road and rail from about 4,000 nodes of a multimodal European transport network to 94 agglomerations with a population of more than 300,000 with and without planned infrastructure improvements. Road travel times included road and car ferry travel times modified by a link-type specific coefficient and a penalty for crossing nodes representing congested population centres (maximum 30 minutes for Paris). Rail travel times included time-table travel time plus road access time and penalties for changes between road and rail (60 minutes), rail and ferry (180 minutes) and change of rail gauge between Spain and France (30 minutes). The map of road accessibility in Figure 7 shows the highest accessibility concentrated around Paris.

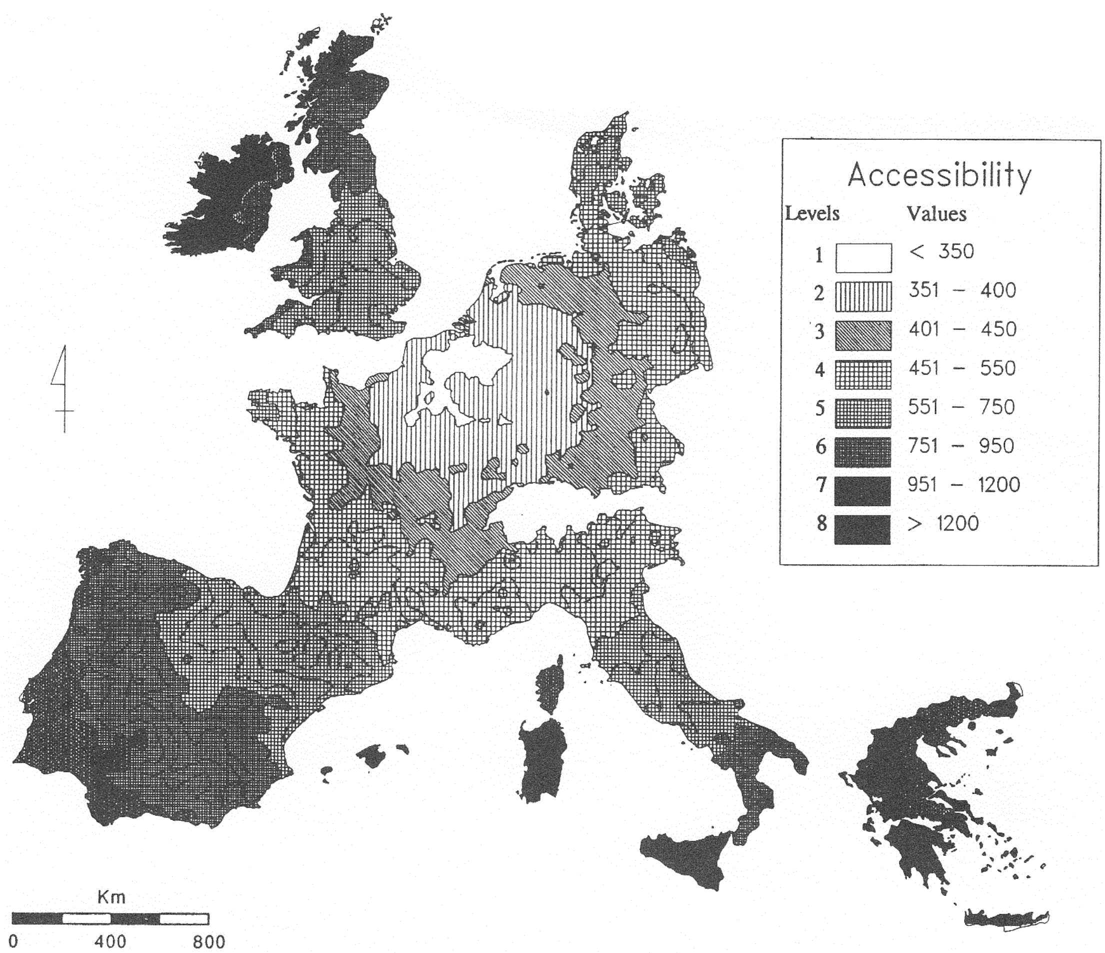


Figure 7. Accessibility to 94 economic centres (Source: Gutiérrez and Urbano, 1996).

A road freight accessibility index expressing total road transport cost to a market of size M is the FreR(M) index used in the UTS study (Chatelus and Ulied, 1995). The indicator accumulates road transport cost to NUTS-2 regions in EUR15 plus Norway and Switzerland multiplied with regional population. Road transport cost include cost of the driver's time, cost per kilometre and a fixed cost component.

Average travel time to selected destinations was also proposed as accessibility indicator for the EUNET study associated with SASI (INRETS, 1997).

Daily accessibility

As indicated above, the concept of daily accessibility is due to Törnqvist who as early as 1970 developed the notion of 'contact networks' hypothesising that the number of interactions with other cities by visits such as business trips would be a good indicator of the position of a city in the urban hierarchy.

Figure 8 illustrates the results of a more recent application of this method to cities in Europe (Cederlund et al., 1991). The size of the circles on the map corresponds to the number of people that can be reached from each city by a return trip during a work day with four hours minimum stay.

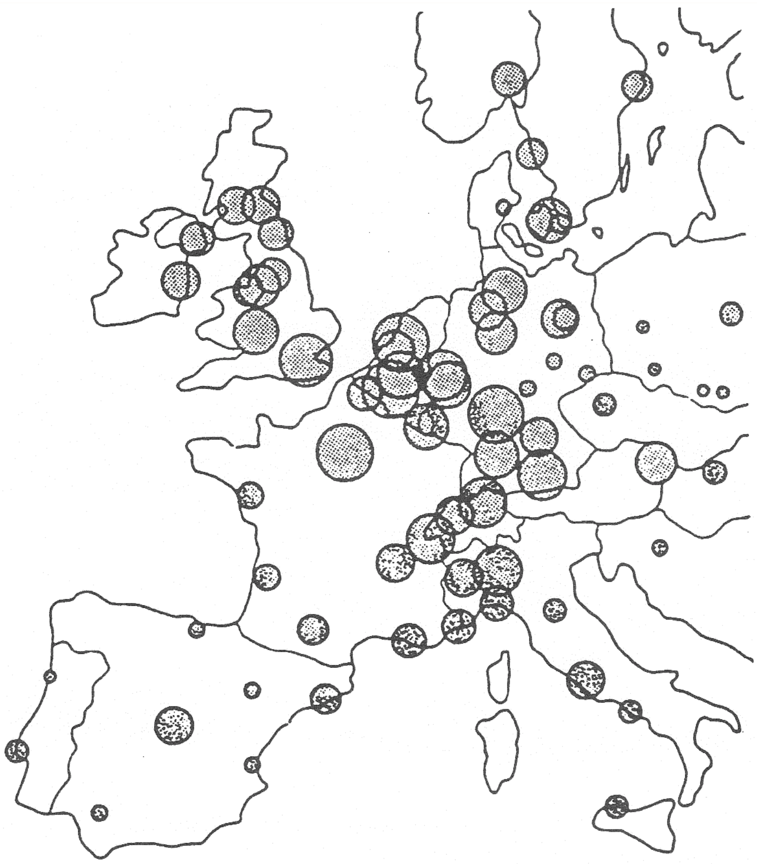


Figure 8. Daily accessibility of European cities (Source: Cederlund et al., 1991).

In the accessibility study of the BfLR for DG XVI mentioned above (Lutter et al., 1993) daily accessibility was calculated in terms of the number of people that can be reached in three hours by the fastest mode. Modes considered included road, rail and air with and without planned infrastructure investments (new motorways, high-speed rail lines and more frequent flight connections). Figure 9 summarises the resulting accessibility indicators by country highlighting the central location and population density of the Benelux countries.

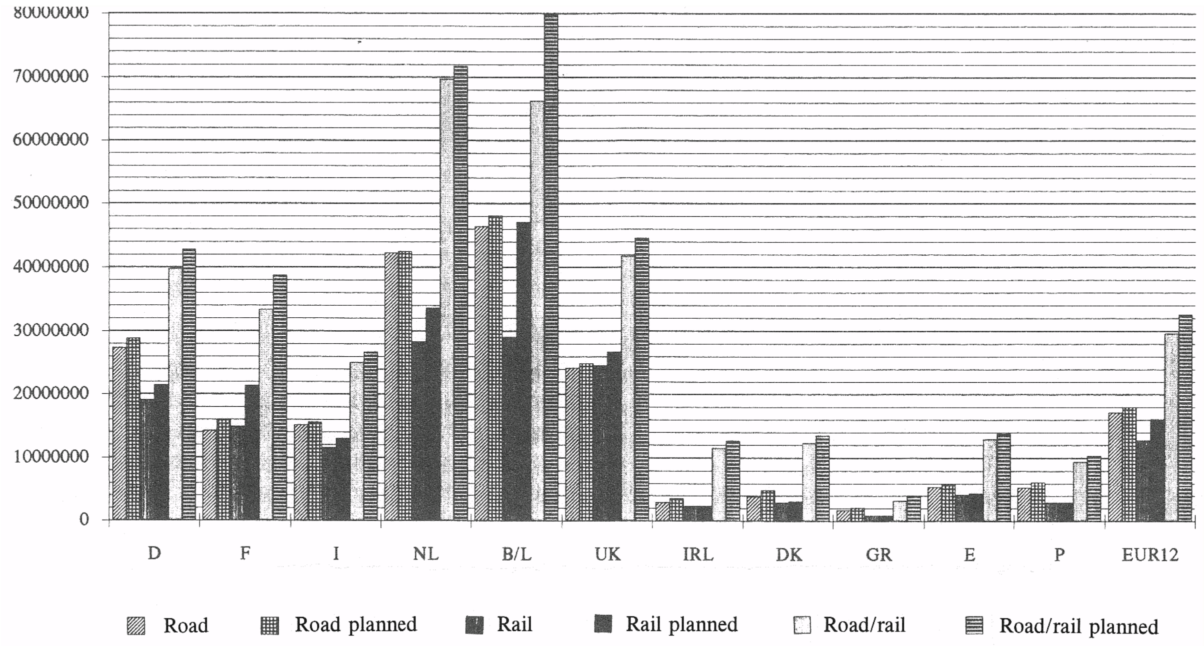


Figure 9. Population reached within three hours (Source: Lutter et al., 1993).

Also three hours was the time limit set for the CON(T) accessibility indicator used in the UTS study (Chatelus and Ulied, 1995). The indicator accumulated population of NUTS-2 regions of EUR15 plus Norway and Switzerland reachable within three hours by any combination of car, rail and air with transfers times between modes explicitly considered. In the same study the FreR(T) index, a freight accessibility indicator expressing the size of the market that can be reached in T days was developed. The indicator accumulates the population that can be reached in one, two or three days by the fastest connection using road, rail or combined traffic with driving time restrictions observed.

Spiekermann and Wegener at IRPUD developed three-dimensional surfaces of daily rail accessibility for pan-Europe using raster-based GIS technology (Spiekermann and Wegener, 1994; 1996; Vickerman et al., 1997). The method used will be explained in Section 4.

Potential accessibility

The most popular type of accessibility indicator found in the literature continues to be potential accessibility.

Keeble et al. (1982; 1988) analysed the centrality of economic centres in Europe using a gravity potential with regional GDP as destination activity; the resulting centrality contours are shown in Figure 10. The figure clearly shows two central areas of high accessibility in Europe: one between London and northern Italy and one between Paris and Berlin.

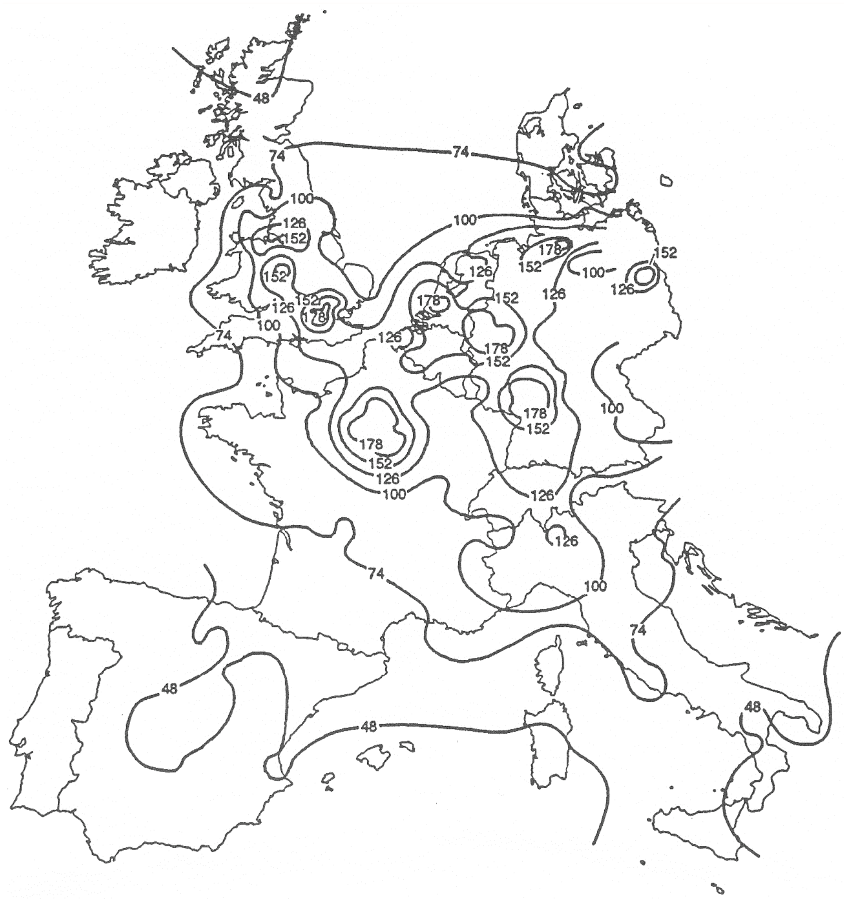


Figure 10. Economic potential in Europe (Source: Keeble et al., 1986).

Bruinsma and Rietveld (1992) calculated potential accessibility of European cities with respect to population. The resulting map, in which the size of the circles indicates not population but accessibility of cities, is shown in Figure 11. Not surprisingly, it closely resembles the contour map by Keeble et al. of Figure 10 and so demonstrates the spatial correlation between economic and population centres.

In a study of rail accessibility in Italy Capineri (1996) used population weighted by per-capita income as destination activity. The study used digital timetable information of the Italian railways to calculate average travel times of the three fastest train connections between each pair of cities in Italy arriving not later than 11.00 h including access, waiting, in-vehicle, transfer and egress times.

Potential accessibility indicators were calculated for the planned high-speed rail network in Germany by Steinbach and Zumkeller (1992).

Spiekermann and Wegener at IRPUD developed three-dimensional surfaces of potential rail accessibility for pan-Europe using raster-based GIS technology (Spiekermann and Wegener, 1994; 1996; Vickerman et al., 1997). The method used will be explained in Section 4.

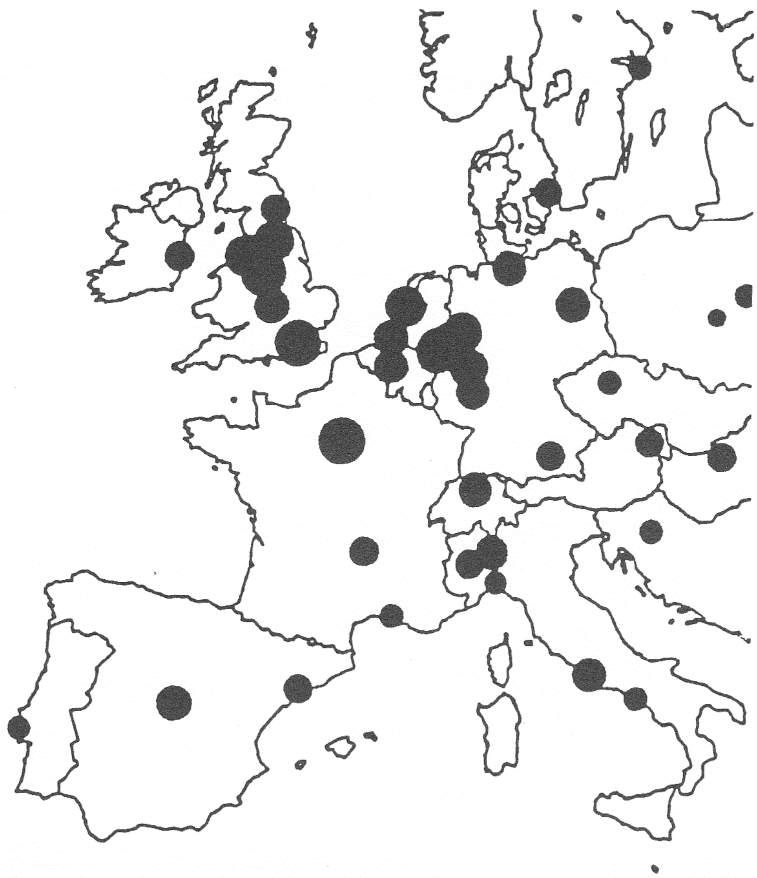


Figure 11. Population potential of European cities (Source: Bruinsma and Rietveld, 1992).

Comparative studies of accessibility

Bruinsma and Rietveld (1996) reviewed the state of the art in developing indicators of accessibility and compared indicators of accessibility in Europe calculated in recent studies.

In the theoretical part of their study they listed eleven types of accessibility indicators:
- acc1 access to network
- acc2 distance to the nearest network node
- acc3 number of direct connections
- acc4 number of lines arriving at node
- acc5 travel cost to one other node
- acc6 average travel cost to all nodes
- acc7 expected value of utility of visit to all nodes
- acc8 potential accessibility
- acc9 number of people reachable with a certain travel cost
- acc10 inverse of balancing factor in spatial interaction model
- acc11 accessibility assessed by expert judgment

It is obvious that indicators acc6, acc9 and acc8 correspond to the travel cost accessibility, daily accessibility and potential accessibility discussed in this paper, respectively.

In the empirical part of their study Bruinsma and Rietveld compared accessibility indicators calculated by seven groups of authors:

Erlandsson and Lindell (1993): daily accessibility (acc9) by fastest mode as in Figure 8.
Bruinsma and Rietveld (1993): potential accessibility (acc8) by fastest mode as in Figure 11.
Spiekermann and Wegener (1994): daily accessibility (acc9) and potential accessibility (acc8) by rail based on raster cells (see Section 4).
Gutiérrez (1995): travel cost accessibility (acc6) by rail as in Figure 7.
Cattan (1992): travel cost accessibility (acc6) of rail and air traffic.
RECLUS (1989): distance to nearest airport or port (acc2).
Healey & Baker (1994): expert judgment (acc11).

The result of their analysis was that within a given travel mode the correlation between the accessibility indicators examined is rather high despite significant differences in implementation. They concluded therefore that if one is mainly interested in the rank order of cities with respect to accessibility, the choice of indicator tends to be of less importance than the choice of mode(s) considered. However, if one is interested in inequalities between cities or regions, the way the indicators are implemented appears to have a much larger impact.

3.5. Accessibility Indicators and Cohesion

Accessibility differs from other socioeconomic indicators discussed in SASI Deliverable D4 (Bökemann et al., 1997) in that it is not only an output of the SASI model but also a key input to the model because it represents the linkage between transport and economic development, which is after all the main focus of the model. However, accessibility is also itself an important factor of quality of life. It is therefore an essential element of the 'cohesion' objective of the European Union to provide a fair distribution of accessibility to all its regions and to reduce existing disparities in accessibility between regions.

So as for other socioeconomic indicators, also for accessibility indicators 'cohesion' indicators measuring the distribution of accessibility across regions can be developed. Cohesion indicators are macroanalytical indicators combining the accessibility values of individual regions into one single measure of spatial concentration or dispersion of accessibility. Changes in the cohesion indicators predicted by the model for future transport infrastructure investments reveal whether these policies are likely to reduce or increase existing disparities in accessibility between the regions.

SASI Deliverable D4 in Section 3.2.3 provided a comprehensive list of possible cohesion indicators, which are also applicable here:

- Statistical measures such as maximum, mean, minimum, standard deviation of regional accessibility values and ratios between the highest and lowest (or the five, ten or twenty highest and lowest) regional accessibility values give an impression of the distribution of accessibility values between regions.

- The graphical representation of a rank-size distribution of regions sorted by decreasing or increasing order of accessibility visualises the degree of inequality between regions. If two rank-size distributions of different years or modes are compared, decreasing or increasing inequality in accessibility or differences in the distribution of accessibility by mode can be detected.

- The rank correlation coefficient by Spearman compares two rank orders of regions by decreasing or increasing accessibility. If two rank orders of two different years are compared, the coefficient informs about the degree of stability of the rank positions of the regions. A Spearman correlation coefficient of one indicates that there has been no change in the rank order of regions, a coefficient of minus one indicates that the rank order has been reversed. In the context of transport infrastructure policy a high rank correlation between the situation without and with policy implementation is desirable for equity reasons (see Deliverable D4, Bökemann et al., 1997).

- The Lorenz curve compares a rank-ordered cumulative accessibility distribution of regions with a distribution in which all regions have the same accessibility. This is done graphically by sorting regions by increasing accessibility and drawing their cumulative distribution against a cumulative equal distribution (an upward sloping line). The area between the two cumulative distributions indicates the degree of polarisation of the accessibility distribution of regions.

- The GINI coefficient calculates the ratio between that area and the triangle under the upward sloping line of the equal distribution. The equation for the GINI coefficient is

$$G = 1 + 1/n - 2/\left(n^2 + \overline{A}\right) \sum_i i\, A_i \tag{9}$$

where the A_i are accessibility of regions sorted in *decreasing* order. The equation is used here to measure the inequality in accessibility between regions, with A_i being accessibility of region i, $\overline{A}$ the average accessibility of all regions, and n the number of regions. A GINI coefficient of zero indicates that the distribution is equal-valued, i.e. that all regions have the same accessibility. A GINI coefficient close to one indicates that the distribution of accessibility is highly polarised, i.e. few regions have a very high accessibility and all other regions are relatively isolated. The GINI coefficient will be used in SASI to compare the inequality in accessibility between regions for two different years. A growing GINI coefficient indicates that inequality in accessibility between regions has increased, a declining coefficient indicates that disparities in accessibility have been reduced. It is possible to take account of the different size of regions by treating each region as a collection of individuals having the same accessibility.

In addition, disparities between regions can be visualised by choropleth maps or three-dimensional diagrams (see Section 5).

The cohesion indicators discussed so far are *macro* indicators expressing the distribution of accessibility across regions. However, the disaggregate method of calculating accessibility applied in SASI permits to calculate also microanalytic indicators of *intraregional* dispersion in accessibility (see Section 5). These microanalytic indicators can be used to analyse whether a particular infrastructure investment largely benefits the central nodes or whether its impacts are evenly distributed across all parts of the regions.

4. Implementation of Accessibility Indicators

As it has been demonstrated in the previous section, there exist three principal kinds of accessibility indicators differing in theoretical foundation and interpretability. It was also shown that there is a wide range of possible refinements with respect to multimodality, intermodality, intraregional connectivity and activities and actors. This variety makes the selection of appropriate indicators for SASI a difficult task.

A second conclusion of Section 3 was that virtually all accessibility indicators used so far have concentrated on network nodes or centroids representing cities or regions and so have ignored the internal spatial organisation within regions.

To overcome this problem, Spiekermann and Wegener at IRPUD developed spatially disaggregate accessibility indicators using raster-based GIS technology (Spiekermann and Wegener, 1994; 1996, Vickerman et al., 1997). By this method the raster structure is applied to represent a quasi-continuous activity surface of Europe. As no raster data for Europe are available, synthetic raster data are generated using microsimulation in combination with a raster-based GIS. For that purpose the European territory is disaggregated into some 70,000 raster cells of 10 kilometres width. Accessibility is calculated by using each raster cell both as origin and destination, i.e. by generating a 70,000 by 70,000 origin-destination matrix. The results are accessibility values for all raster cells, which are then aggregated to regions. In this respect the method follows the suggestion by Newman and Vickerman (1993) that accessibility models should be more disaggregate in spatial resolution, economic activities and transport modes.

This section presents the disaggregate accessibility model that will be used in the SASI model (see Section 2.4). First the input data base, i.e. the generation of disaggregate spatial distributions of activities and travel times, are explained. Second the accessibility indicators calculated are defined. Third the accessibility model is presented.

4.1 Generation of Input Data Base

For the presentation of the method in this report, two sets of input data were prepared, the disaggregate spatial distribution of activities and past, current and future travel times for different modes in Europe. For the destination term in the accessibility equation both population and economic production in terms of gross domestic product (GDP) are used.

Population

For the disaggregate representation of population the European territory was subdivided into about 70,000 raster cells each representing an area of 10 by 10 km. Each raster cell contains information on which region it belongs to. Regions were selected according to the availability of population data, i.e. 1,025 NUTS-3 regions for the European Union and 341 regions for the other European countries ranging in size between NUTS-2 and NUTS-3 regions.

Population data for 1995 were extracted from Eurostat (1996) and statistics on European countries by the German Federal Statistical Office (Statistisches Bundesamt, several years). In order to generate intraregional distributions of population density a second population data set containing the location and population of 1,690 cities in Europe with more than 50,000 inhabitants was prepared (Source: Rand McNally Westermann, 1994).

Raster-based population data were generated by allocating the population of each region to the raster cells belonging to the region (Figure 12). For each region first the population of large cities was allocated to cells at and close to their geographical location. The number of cells for each city and the number of population allocated to each cell was determined as a function of total population of the city using the model of urban density gradients by Clark (1951). After the distribution of the population of large cities, the remaining population of each region was evenly distributed across the rest of the region, i.e. a homogenous density of the population living in smaller settlements was assumed. The method applied will be described in detail in Deliverable D8.

The method developed leads to a plausible intraregional distribution of population taking account of population centres and meeting the constraint that the sum of the population of all raster cells is equal to the regional population total. The result is a data file with estimated population for each of the about 70,000 raster cells of Europe. Figure 13 shows a map of population density generated from the population data base so generated.

Economic production

As an alternative to population, economic production in terms of GDP in Purchasing Power Standard (PPS) units may be used for the destination term of the accessibility model. GDP was allocated to raster cells by multiplying the population of each raster cell with the GDP per capita recorded for the region to which it belongs. The underlying assumption is that economic production is distributed like the regional population.

GDP data were available for NUTS-2 regions for the European Union from Eurostat's regional database and were extracted for other European countries from UN data (UN/ECE, 1997). Missing regional GDP data, e.g. for the new German Länder for 1981, had to be estimated. A more thorough discussion of the data problems encountered will be presented in SASI Deliverable D7.

Figure 14 presents the disaggregate spatial distribution of economic production (GDP) in pan-Europe so generated.

Travel times

In this report only two transport modes, road and rail, are considered. For the SASI model air travel will be added later; the development of the air network is in progress.

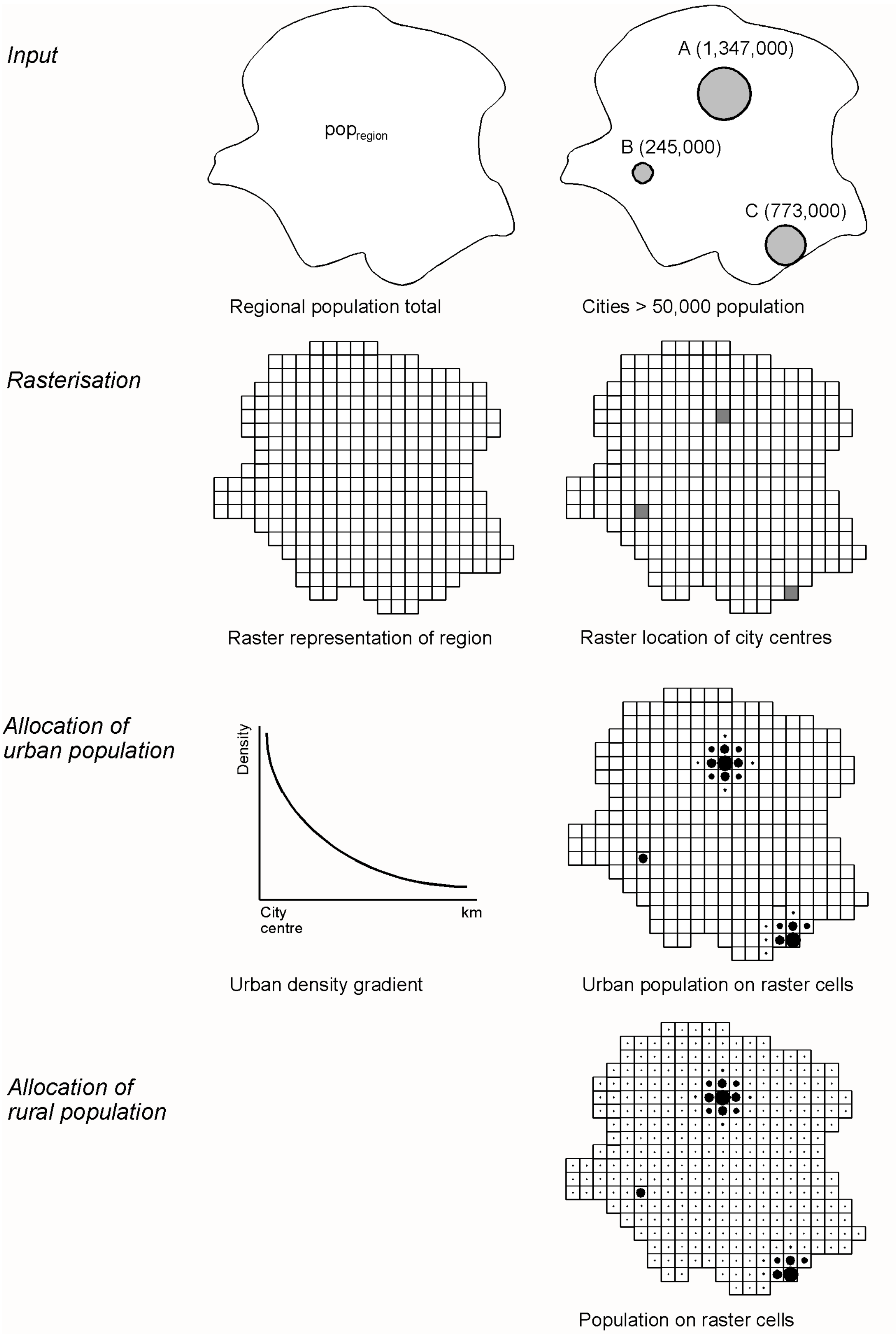


Figure 12. Disaggregation of population

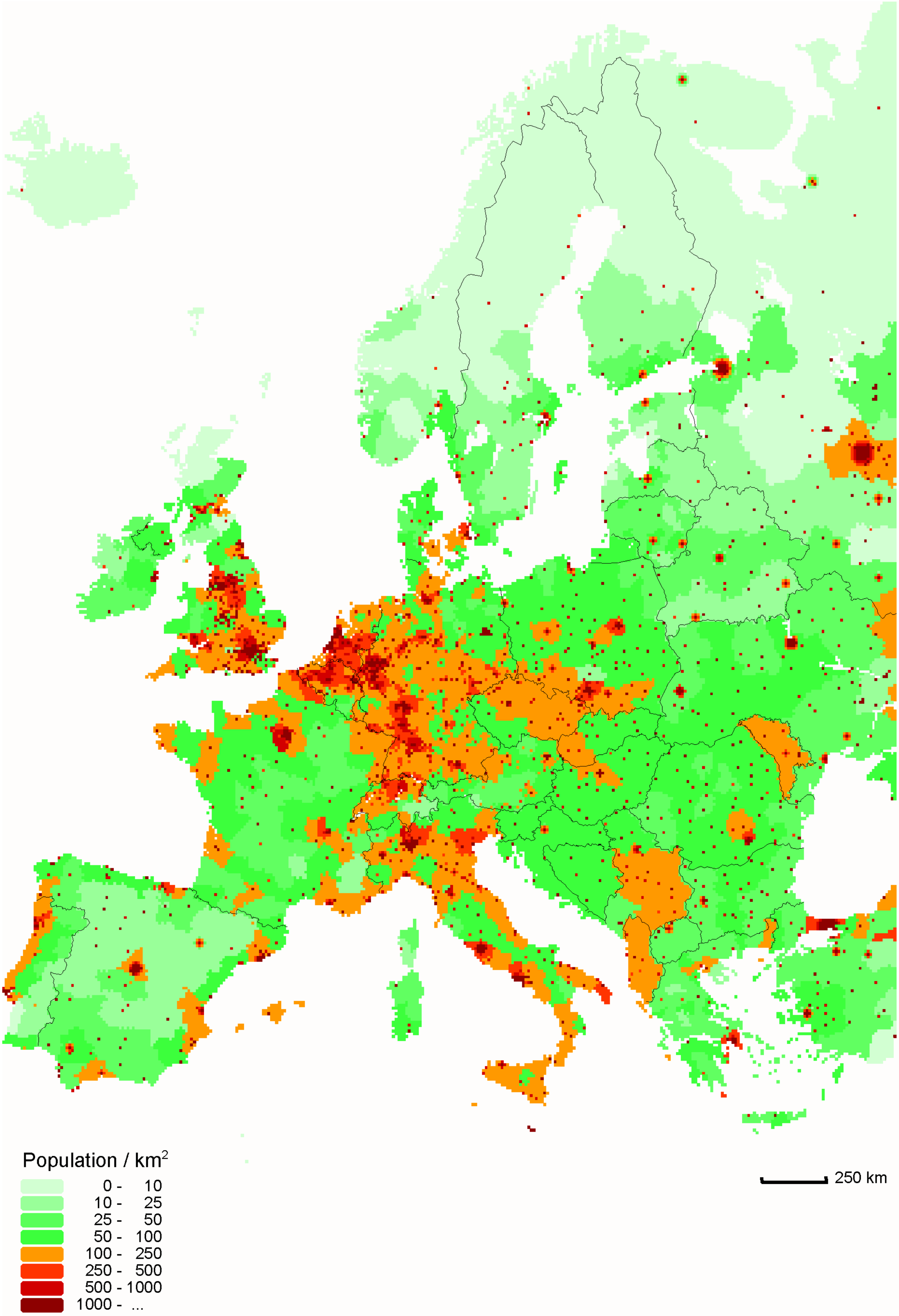


Figure 13. Population density by raster cell.

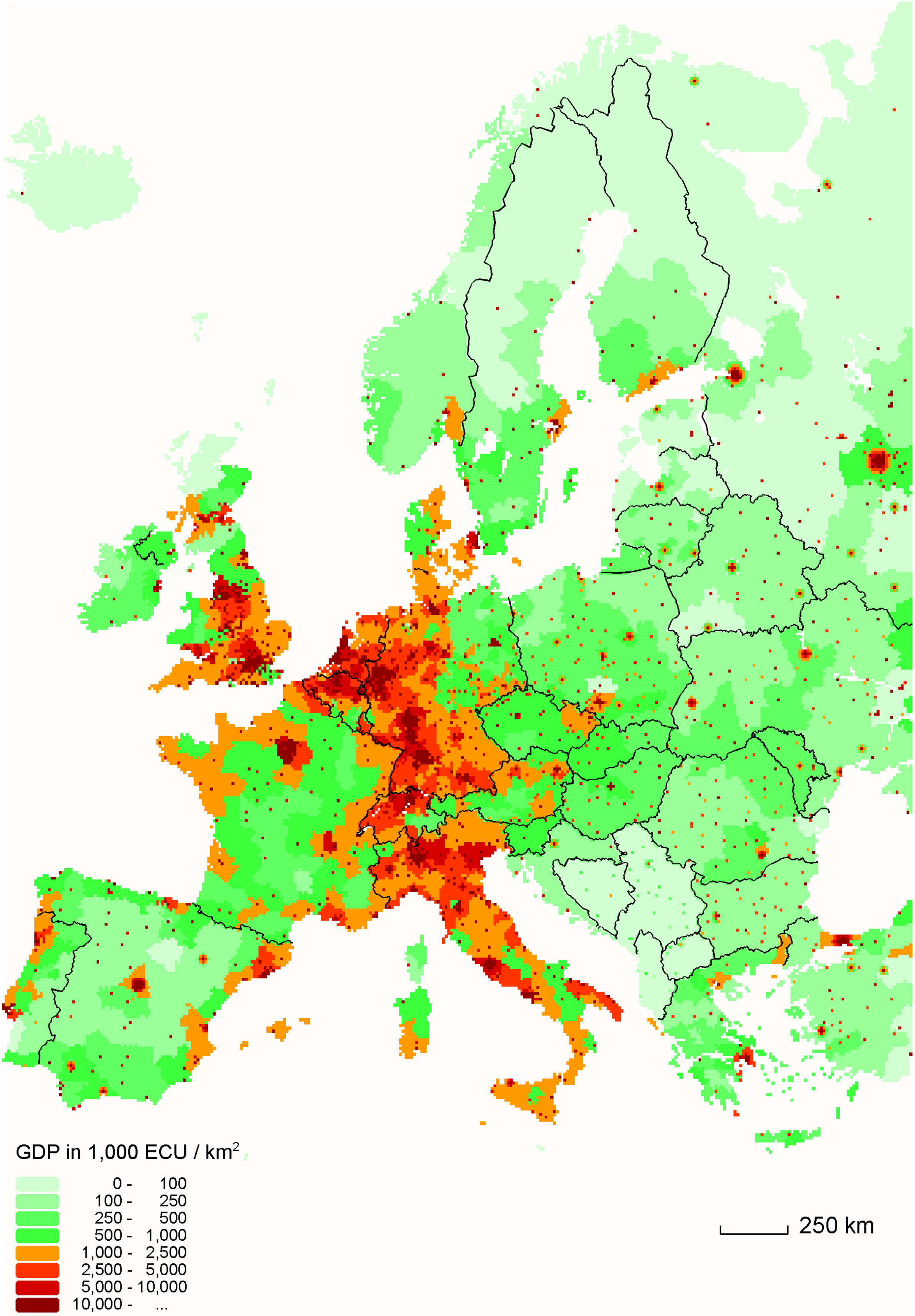


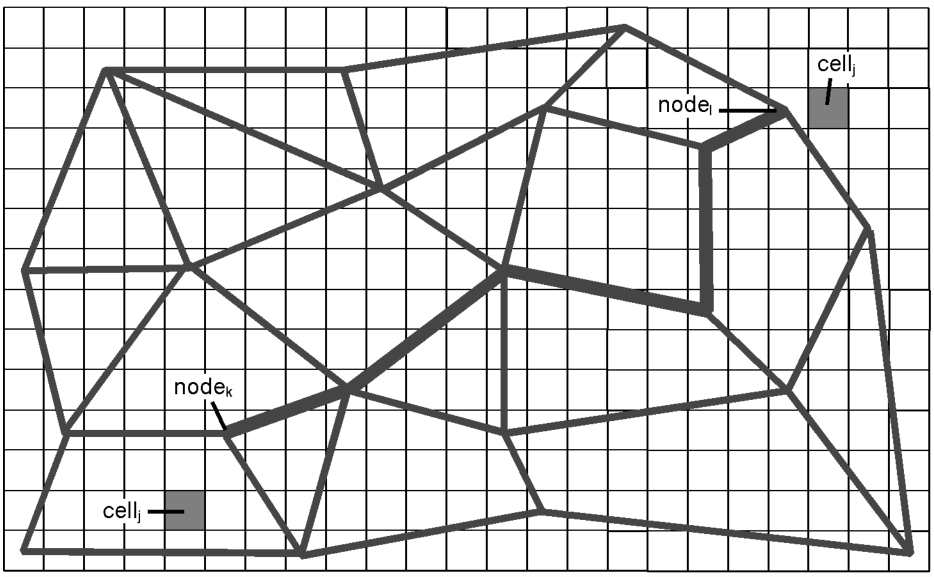
Figure 14. GDP density by raster cell.

For road and rail travel times the networks presented in Figures 3 and 4 were used and loaded with appropriate travel times:

- Road travel times were compiled for the years 1996 and 2010. Travel times were associated with links as a function of link type. Assumed average speeds are 100 km/h for motorways, 80 km/h for dual carriageway national roads, 60 km/h for other national roads and 40 km/h for other roads. For 2010 road travel times also the TEN outline plan of the European Union as specified in Decision 1692/96/EC of the European Parliament and of the Council was taken as reference.

- Rail travel times were compiled for the years 1981, 1996 and 2010. Past and current travel times were extracted from Thomas Cook (1981; 1996) European rail time tables for all of the 2,250 rail links. For 2010 rail travel times the TEN outline plan of the European Union as above was taken as reference. Future travel times were estimated by using average travel speeds for new or upgraded links and assuming an acceleration of ten percent for links without physical change.

The networks were coded as vectors between nodes. The networks were linked to the raster representation of activities by associating each node with a raster cell as reference. The travel time between two raster cells consists of five parts (see Figure 15): intra-cell travel time of 15 minutes each at start and end of the trip, access time from the origin cell to the nearest network node, minimum-path travel time on the network and egress time to the destination cell from the nearest node. If direct air-line travel between two cells was shorter than travel over the network, the direct travel time was used. For off-network movement within and between raster cells an air-line travel speed of 30 km/h was assumed.



$$t_{ij} = tcell_i + t(cell_i , node_k) + t_{min} (node_k , node_l) + t(node_l , cell_j) + tcell_j$$

Figure 15. Travel time components between two cells.

4.2 Accessibility Indicators Modelled

This section examines which types of accessibility indicator might be most suitable for being included in the SASI model. Here three, possibly conflicting, objectives are relevant. First, the indicators used should contribute as much as possible to explaining regional economic development. At this stage of the analysis it is assumed that accessibility indicators that show a high correlation with economic indicators such as GDP per capita are likely to be most useful even if other non-transport factors are included in the analysis. Second, the accessibility indicators should be meaningful also by itself as indicators of regional quality of life. Third, the indicators should be consistent with theories and empirical knowledge about human spatial perception and behaviour.

In the light of these objectives, the three principal types of accessibility indicator identified in Section 3.2 were tested:

Travel cost

This indicator measures average travel cost to a predefined set of destinations (see Section 3.2). Two sets of destinations were used: 192 cities with a population of more than 250,000 and 29 cities with a population of more than 1,000,000. One indicator was implemented by accumulating for each of the 70,000 origin cells r travel times $c_{rs(j)}$ to the centre cell of each destination city j and dividing by the number $n(\mathbf{C})$ of cities in $\mathbf{C}$, where $\mathbf{C}$ is the set of cities with population P_j greater or equal to $P_{\min}$ of 250,000 or 1,000,000.

$$A_r = \sum_{j \in \mathbf{C}} \frac{c_{rs(j)}}{n(\mathbf{C})} \qquad \text{with } \mathbf{C} = \left\{ j, P_j \geq P_{\min} \right\} \tag{10}$$

Another indicator was implemented as average travel time weighted by population P_j:

$$A_r = \sum_{j \in \mathbf{C}} \frac{P_j \; c_{rs(j)}}{\sum_j P_j} \qquad \text{with } \mathbf{C} = \left\{ j, P_j \geq P_{\min} \right\} \tag{11}$$

Daily accessibility

This indicator counts the number of people that can be reached from a location by a return trip during a work day with a minimum stay of a certain time (see Section 3.2). Here five hours one-way travel time was assumed to be the maximum for allowing five hours of activities at the destination. The indicator was implemented by accumulating for each of the about 70,000 origin cells population or GDP as destination activity W_s of all destination cells that can be reached within five hours (or 300 minutes):

$$A_r = \sum_s W_s \, k_s \qquad \text{with } k_s = \begin{cases} 1 \text{ if } c_{rs} \leq 300 \\ 0 \text{ if } c_{rs} > 300 \end{cases} \tag{12}$$

Potential accessibility

The potential model assumes that the attraction of a destination increases with size and declines with distance or travel time or cost (see Section 3.2). The potential accessibility indicator used here was implemented by calculating the negative exponential of Equation 5 for each of the 70,000 origin cells. Destination activities W_s are population or GDP in all 70,000 destination cells, and the impedance function c_{rs} is travel time between origin and destination cells.

$$A_r = \sum_s W_s^{\alpha} \exp\left(-\beta\, c_{rs}\right) \qquad (13)$$

Whereas the parameters of the previous accessibility indicators can be derived from theoretical or plausibility considerations, the parameters of potential accessibility have to be calibrated. This was done by experimentally changing the α and β of the activity and impedance functions and correlating the results with economic activity (GDP).

Figure 16 shows the consequences of changing β stepwise from 0.0002 to 0.025. The resulting impedance curves are scaled in such a way that the accessibility of the origin cell counts as 1.0. With these values of β rail accessibility was calculated for 1981 and 1996, and the results were correlated with GDP levels of 1981 and 1991. The corresponding r^2 are presented in Table 2. It can be seen that the higher the β the lower the correlation with GDP. However, by non-linear transformation of accessibility the differences between the r^2 are reduced. This is shown in the last column of Figure 16 indicating the best achievable r^2. Based on this result, a low β might be most suitable for the SASI model as it seems to explain a larger part of the variation of GDP. However, low β make potential accessibility more similar to daily accessibility with a very high $c_{\max}$. This leads to almost identical accessibility everywhere. Moreover, a 'flat' impedance function such as Curve 6 in Figure 16 postulating that a destination 20 hours away is visited one tenth as many times as the origin itself is highly questionable. Therefore a more plausible impedance function with a β of 0.01 was tentatively selected for the subsequent empirical analysis despite the loss in explanatory power.

In a similar way also the activity function was calibrated. The parameter α was stepwise increased from 1.0 to 2.0 in order to take account of agglomeration effects as discussed in Section 3.2. However, increasing the parameter led to decreasing correlation with GDP, i.e. $\alpha = 1$ resulted in the best fit. Decreasing α stepwise towards zero, i.e. assuming agglomeration disutilities, also reduced r^2. Therefore, an α of 1 was retained for the subsequent analysis.

With these parameters α and β the final accessibility function is

$$A_r = \sum_s W_s^{1} \exp\left(-0.01\, c_{rs}\right) \qquad (14)$$

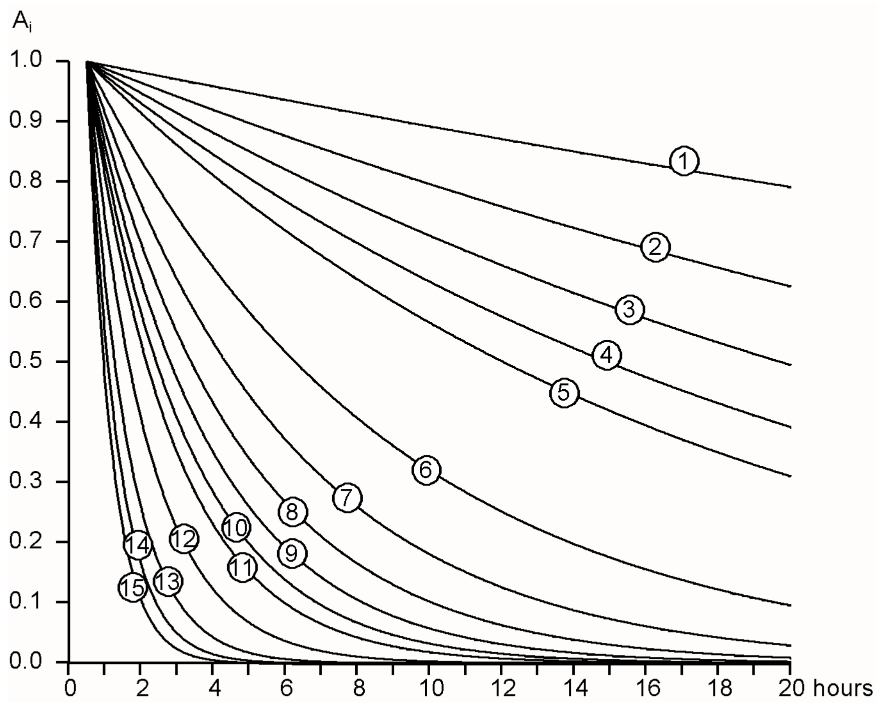


Figure 16. Calibration of β for potential accessibility.

Table 2. Calibration of β for potential accessibility.

Curve (see Figure 16)	β	Correlation (r^2)		
		Accessibility 1981 GDP 1981	Accessibility 1981 GDP 1981	Non-linear correlation (best fit)
1	0.0002	0.58	0.54	0.56
2	0.0004	0.59	0.57	0.59
3	0.0006	0.61	0.57	0.61
4	0.0008	0.61	0.56	0.61
5	0.0010	0.62	0.56	0.62
6	0.0020	0.61	0.52	0.62
7	0.0030	0.58	0.47	0.61
8	0.0040	0.55	0.43	0.60
9	0.0050	0.52	0.40	0.58
10	0.0060	0.49	0.37	0.56
11	0.0070	0.46	0.34	0.54
12	0.0100	0.40	0.29	0.49
13	0.0150	0.34	0.23	0.43
14	0.0200	0.31	0.19	0.41
15	0.0250	0.29	0.12	0.39

Figure 17 summarises the three accessibility indicators tentatively implemented for the SASI model. Each indicator is used in two versions: for daily and potential accessibility the destination activity is either population or GDP; for the travel cost indicator two sets of destinations depending on the size of cities are employed.

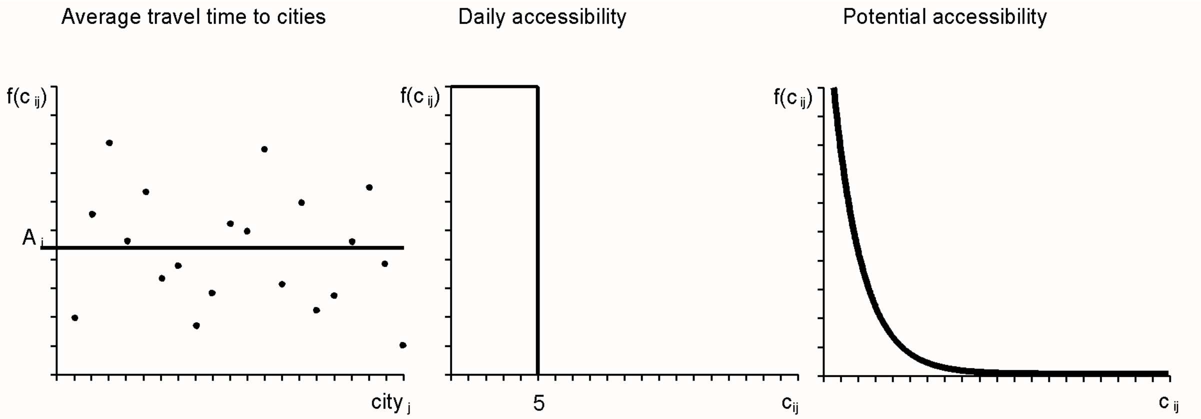


Figure 17. Accessibility impedance functions implemented.

These six accessibility indicators were calculated each for two modes (road and rail) and two or three years (see Table 3):

Table 3. Accessibility indicators calculated.

Accessibility indicator	Without high-level network	Road		Rail		
		1996	2010	1981	1996	2010
Average travel time to cities > 250,000 population		X	X	X	X	X
Average travel time to cities > 1,000,000 population		X	X	X	X	X
Weighted average travel time to cities > 250,000 population		X	X	X	X	X
Weighted average travel time to cities > 1,000,000 population		X	X	X	X	X
Daily accessibility (population)	X	X	X	X	X	X
Daily accessibility (GDP in PPS)	X	X			X	
Potential accessibility (population)	X	X	X	X	X	X
Potential accessibility (GDP in PPS)	X	X			X	

In addition, a third network alternative was introduced. In the 'without high-level network' alternative, it is assumed that no interregional network exists, i.e. that all trips are made on local or regional networks. This was achieved by calculating travel times between cells similar to the calculation of access travel times based on air-line distances with an average speed of 30 km/h. Accessibility based on these travel times can be seen as local potential and might be used to estimate the effect of geographical location alone compared with network effects.

All indicators were calculated for each of the 70,000 raster cells taking account of the travel time to all 70,000 cells and, for potential and daily accessibility, of population or GDP in all 70,000 cells.

4.3 Accessibility Model

The above indicators were calculated using a first version of the accessibility model to be used in the SASI model. The accessibility model comprises data inputs, the accessibility model itself and output options (see Figure 18):

- The input consists of two elements. The generation of activities provides the disaggregate distribution of destination activities for the accessibility model. These inputs are exogenous at present and will later be derived from forecasts of the SASI model (see Figure 1). The network part provides link travel times by mode extracted from railway time tables or calculated from average speeds by link type. Air network data and travel times are under preparation.

- The accessibility model calculates access times from raster cells to the networks and minimum paths, i.e. minimum travel times between all nodes of the networks. Based on this it calculates for each raster cell the values of the accessibility indicators for different modes and years.

- The output of the model can be of three kinds. The first output option provides accessibility indicator for raster cells in graphical form. The second output option presents aggregated regional accessibility indicators. Regional accessibility is expressed in three ways: as maximum value in the region, as average value per capita and as average value per cell. For averages also standard deviations are presented to indicate intraregional disparities in accessibility. The third output option provides 'cohesion' indicators of disparities in accessibility between regions (see Section 3.4).

The next section will present and discuss accessibility indicators specified in the preceding sections and calculated with the SASI accessibility model.

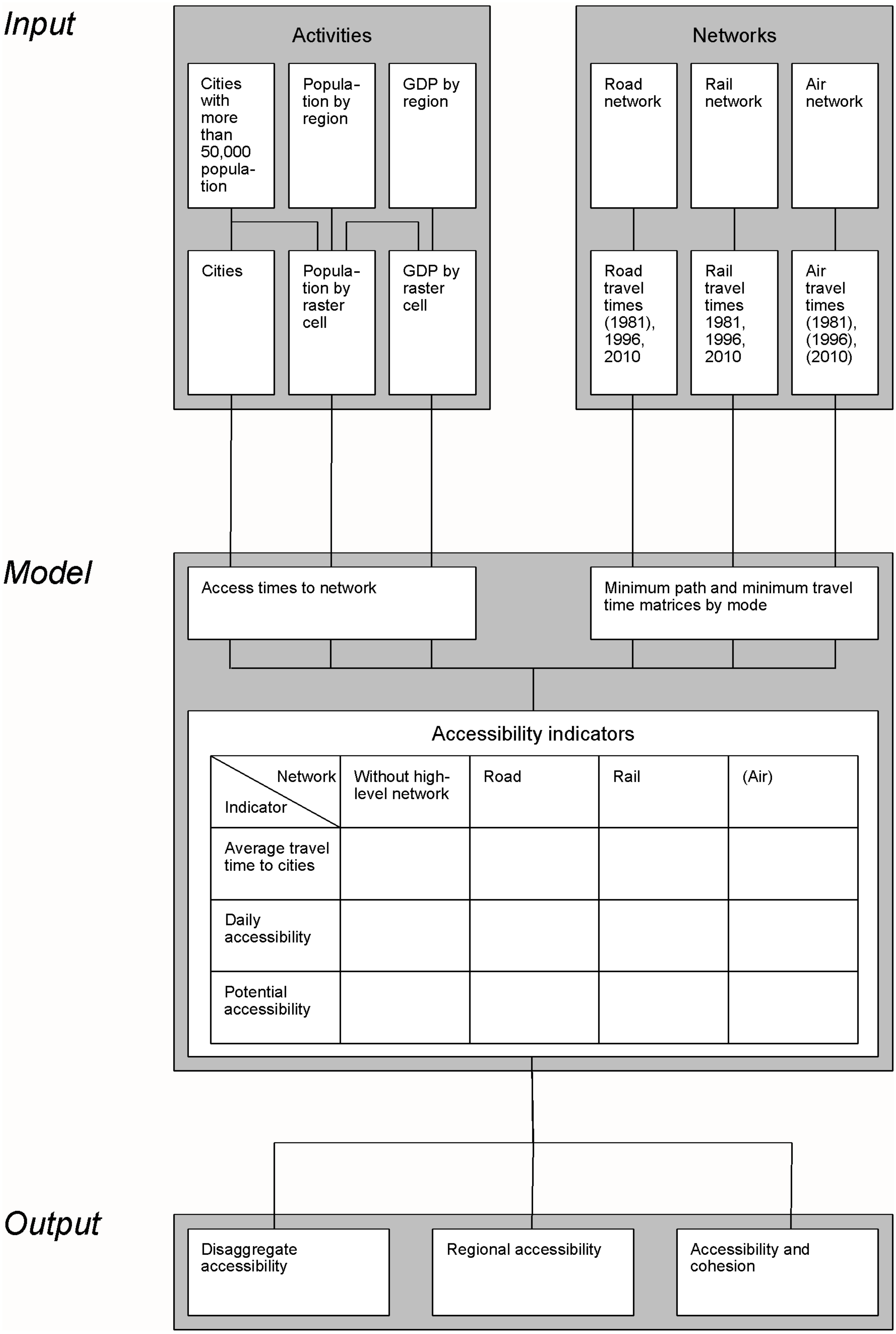


Figure 18. Accessibility model.

5. Accessibility Indicators: Sample Output and Comparison

In this section selected results of the accessibility model are presented and discussed. The purpose is to demonstrate the different output options in spatial resolution and graphical presentation and to compare the accessibility indicators implemented. The discussion is to help to assess the suitability of the indicators for the SASI model.

5.1 Disaggregate Accessibility

Based on the disaggregate input data the accessibility model calculates accessibility values for some 70,000 raster cells each representing an area of 10 km x 10 km. In this way accessibility can be displayed and analysed quasi continuously over space. This chapter presents the three accessibility indicators implemented by different types of graphical output.

Average travel times to large cities

Figure 19 shows average rail travel times to large cities in the years 1996 (top) and 2010 (bottom). 192 cities with a population of more than 250,000 serve as destinations. In 1996 the European average of all average travel times was about 30 hours. The shortest average travel times can be found in areas located in Austria and Germany. Not surprisingly regions at the periphery of the European Union and in the southern and northern parts of eastern Europe have the longest average travel times. The increase in average travel times from the core to the edge is smooth. There are no great differences between neighbouring regions because the large number of destinations and their even distribution across the continent have an equalising effect on average travel times.

In 2010, the European average of regional average rail travel times decreased to 22 hours as can be seen from the growth of the green areas. The spatial distribution of shortest and longest average travel times has not changed, i.e. the dissimilarities between different locations in Europe remain more or less the same. The shortest average travel times are about 12 hours, the longest ones are nearly 50 hours.

Daily accessibility

Daily accessibility was implemented by assuming that all destinations that can be reached within five hours contribute equally to the accessibility of the origin region.

One effective way of representing accessibility indicators is to display them as three-dimensional accessibility surfaces. The elevation of the surface at each point indicates the magnitude of accessibility at that point. To allow comparisons between different surfaces, surfaces to be compared are drawn to the same vertical scale. Accessibility surfaces are presented here for daily accessibility by rail to population and to GDP

Figure 20 (top) shows daily accessibility without high-level networks. As indicated above, in this case an average speed for air-line distances of 30 km/h is assumed. This means that in the maximum travel time of five hours destinations within a radius of 150 km are included.

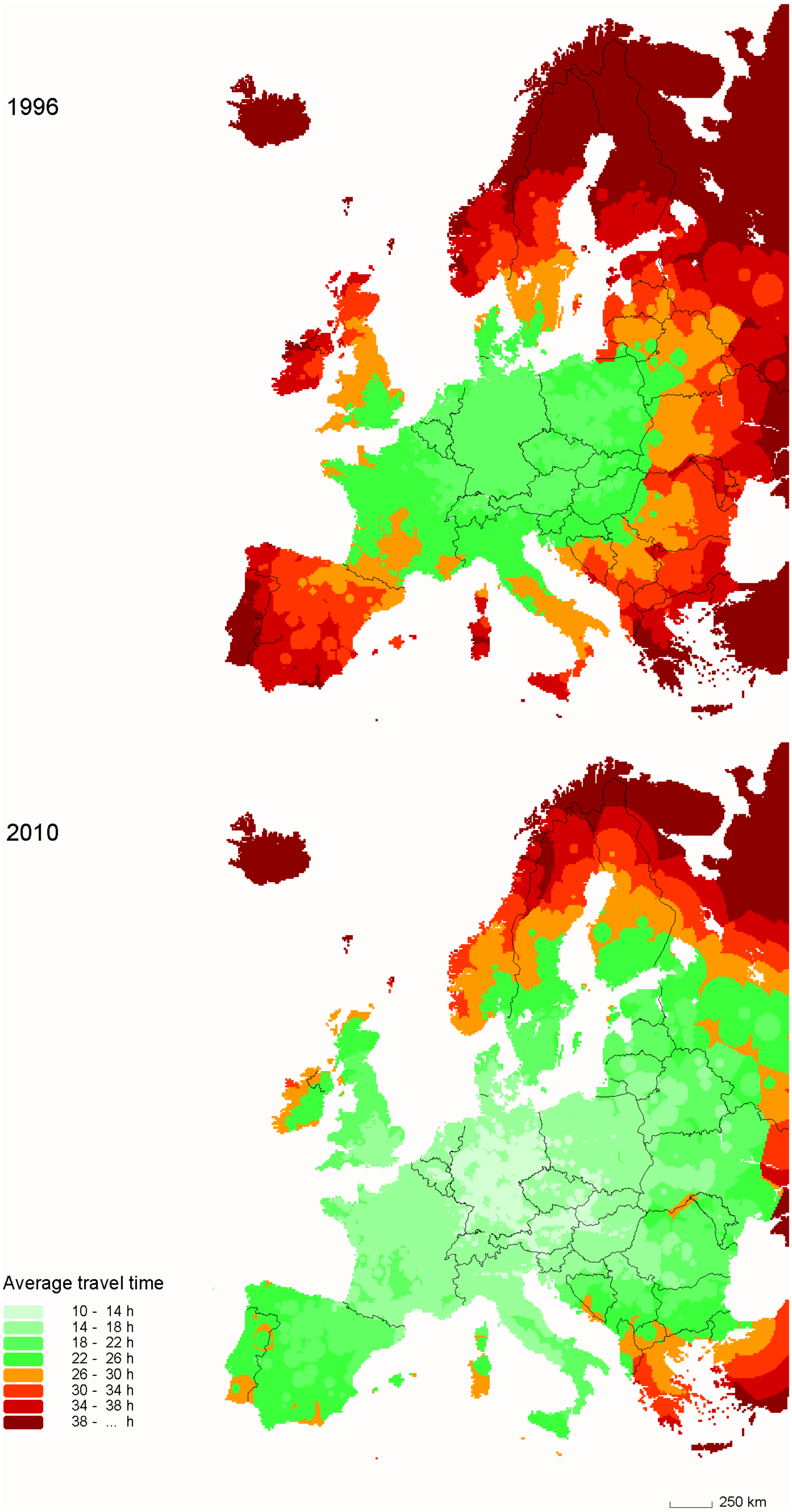


Figure 19. Average travel time by rail to cities with a population of more than 250,000 in 1996 (top) and in 2010 (bottom).

The no-network alternative can be considered as *local* or *regional* potential which has to be distinguished from *self-potential*. The destination activity is population. Consequently high-density regions, e.g. regions in south-east England, Belgium and the Netherlands, the western parts of Germany and the northern parts of Italy have the highest local potential. Remarkably not London or Paris but Belgium and the Rhine-Ruhr region seem to have the highest daily accessibility. But also the local potentials of spatially isolated but large agglomerations such as Madrid, St. Peterburg or Moscow and their hinterlands seem to be substantial.

Figure 20 (bottom) presents daily accessibility by rail for 1996. Now the combined effects of high density and interregional infrastructure become visible. Significant disparities in accessibility appear. The highest daily accessibility values are found in France, southern England, Belgium and the Netherlands, Germany, Switzerland, Austria and northern Italy. Again not London or Paris but Belgium and north-western Germany seem to have the highest daily accessibility. There is a sharp decline from these areas towards Scandinavia, eastern and south-eastern Europe, southern Italy, the Iberian peninsula and Ireland. However, even in the high-accessibility regions there are large differences in daily accessibility between city centres (expressed as 'peaks' in the accessibility surface) and their hinterlands (expressed as 'valleys') as accessibility decreases from the nodes in the high-speed rail network to the more remote locations at the fringe of their catchment areas.

Figure 21 shows daily accessibility in which population is replaced by GDP as destination activity, without high-level network (top) and by rail in 1996 (bottom). The surfaces seem to be similar to those of Figure 20, but disparities in local accessibility have now become more pronounced. Because economic production is highly concentrated in north-west Europe (see Figure 14), the 'mountains', i.e. the locations with high accessibility appear even higher than in Figure 20. With a little imagination the 'Blue Banana', the European megalopolis stretching from south-east England along the Rhine to northern Italy, can be recognised. The most apparent difference between the two accessibility surfaces is the much sharper decline in accessibility to GDP towards eastern Europe, where GDP is still much lower.

The distribution of daily accessibility is even more concentrated if interregional networks are included (Figure 21, bottom). Now the rich regions in France, England, the Benelux countries, Germany, Austria and northern Italy form a 'central massif' of high accessibility in stark contrast to the rest of Europe. In particular in eastern and south-eastern Europe the accessibility surface is nearly flat indicating the isolation caused by the combined effect of low GDP and poor rail connections. However, within the high-accessibility area there are the same 'peaks' and 'valleys' as in Figure 20 (bottom) indicating the decline in accessibility from the nodes of the networks to their hinterlands.

The next two figures enable a comparison of daily accessibility over time. Figure 22 shows daily accessibility by rail to population in 1996 as in Figure 20 (bottom), but now as a two-dimensional map. The map reproduces the 'central massif' of daily accessibility of Figure 20 (bottom). It also confirms that the chain of medium-sized cities along the Rhine corridor from Frankfurt to the Ruhr, and not London or Paris, have the highest daily accessibility. Figure 23 presents daily accessibility by rail to GDP in 2010 drawn to the same colour scale. The map shows that the 'central massif' increases in height but does not spread out very much, i.e. it supports the hypothesis advanced earlier that high-speed rail predominantly benefits the central regions.

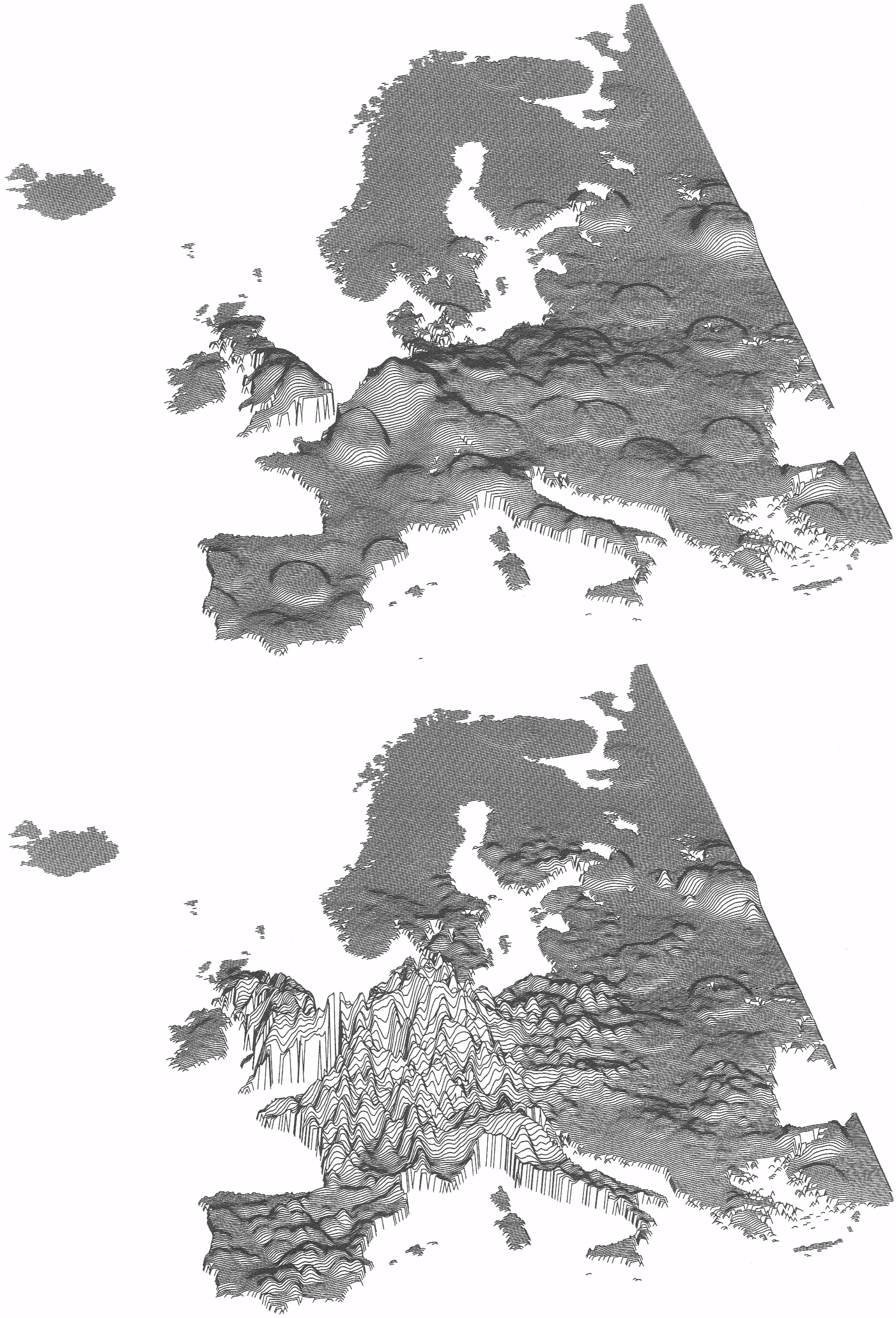


Figure 20. Daily accessibility to population, without high-level network (top), and by rail in 1996 (bottom).

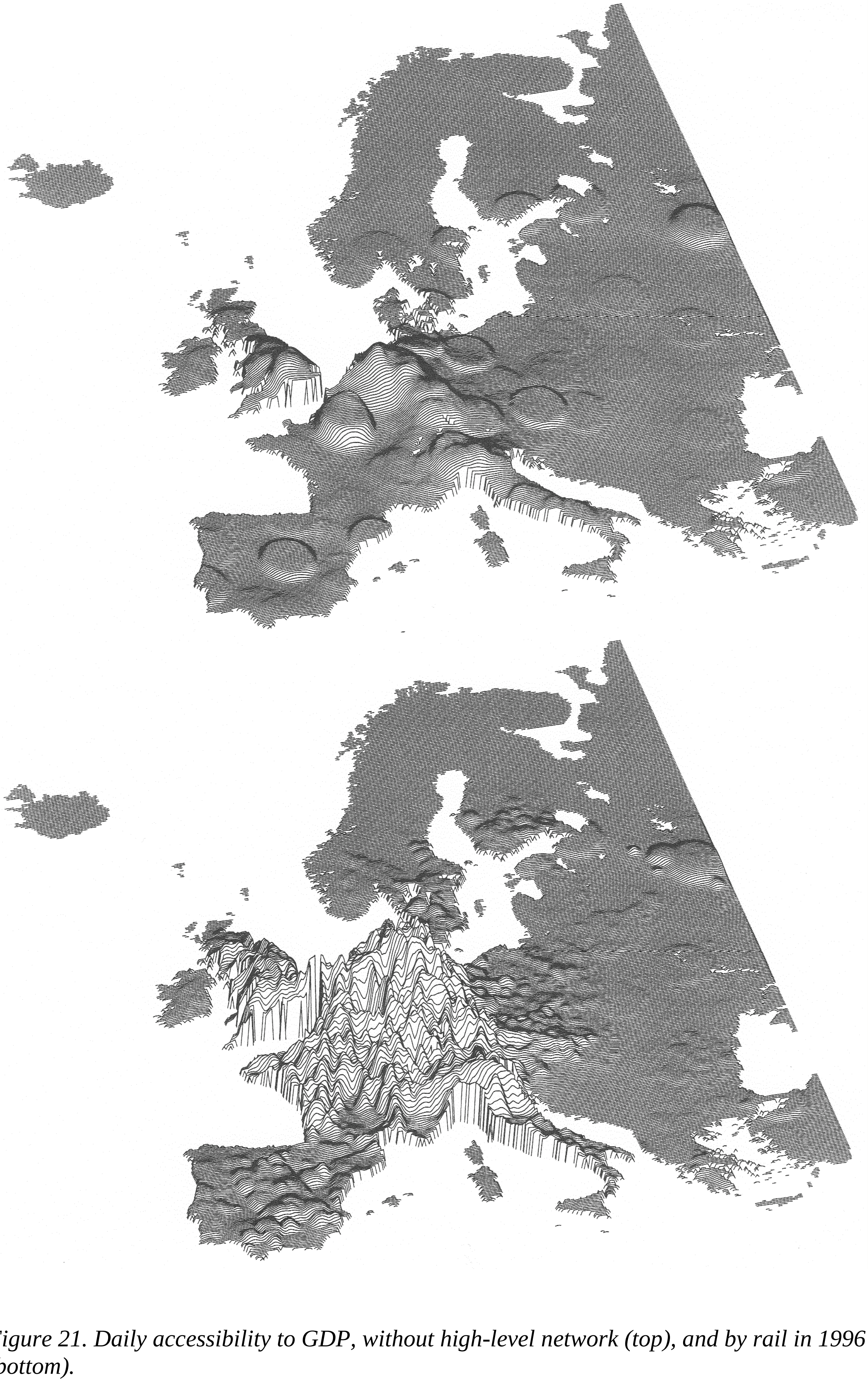


Figure 21. Daily accessibility to GDP, without high-level network (top), and by rail in 1996 (bottom).

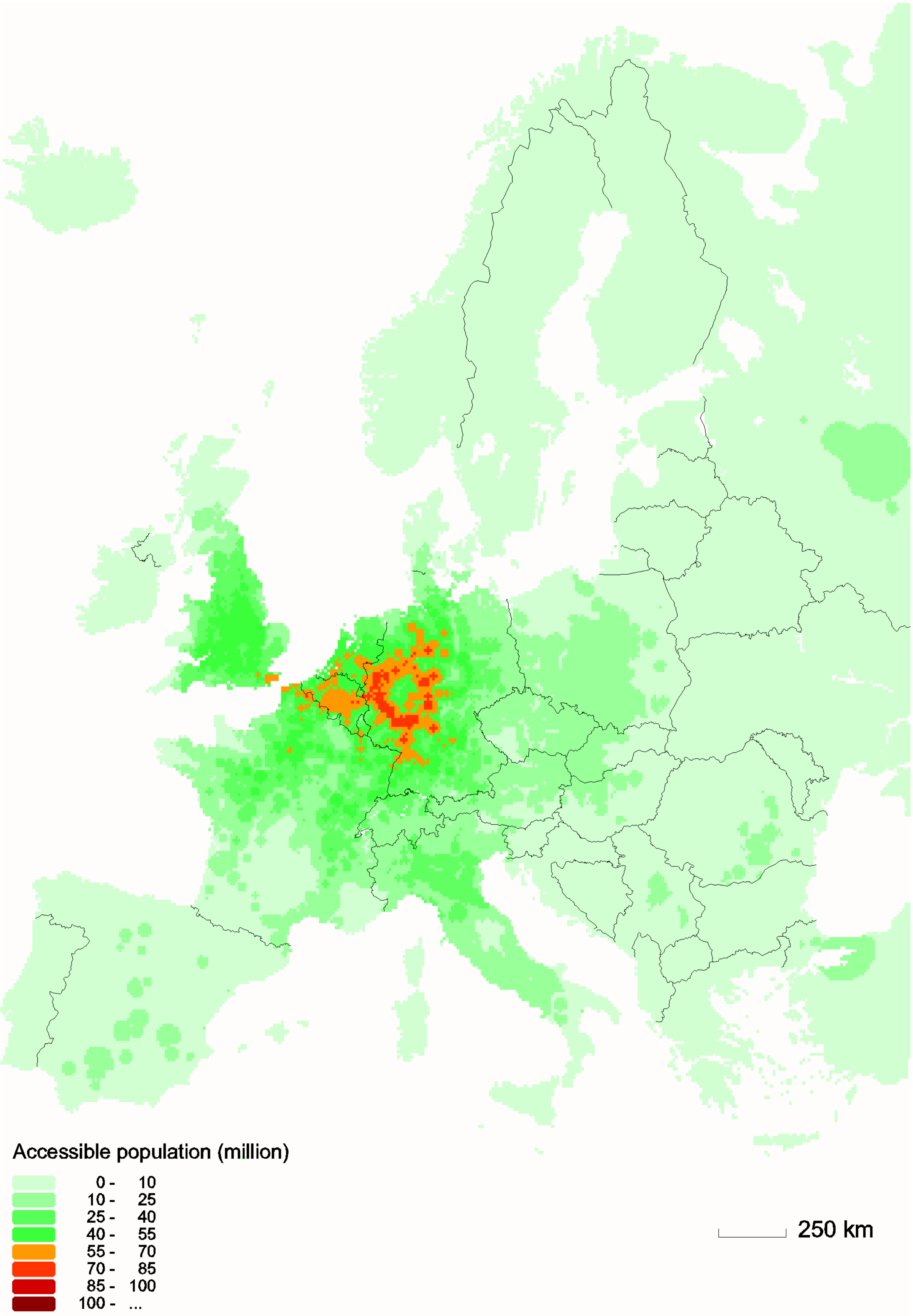


Figure 22. Daily accessibility by rail to population in 1996.

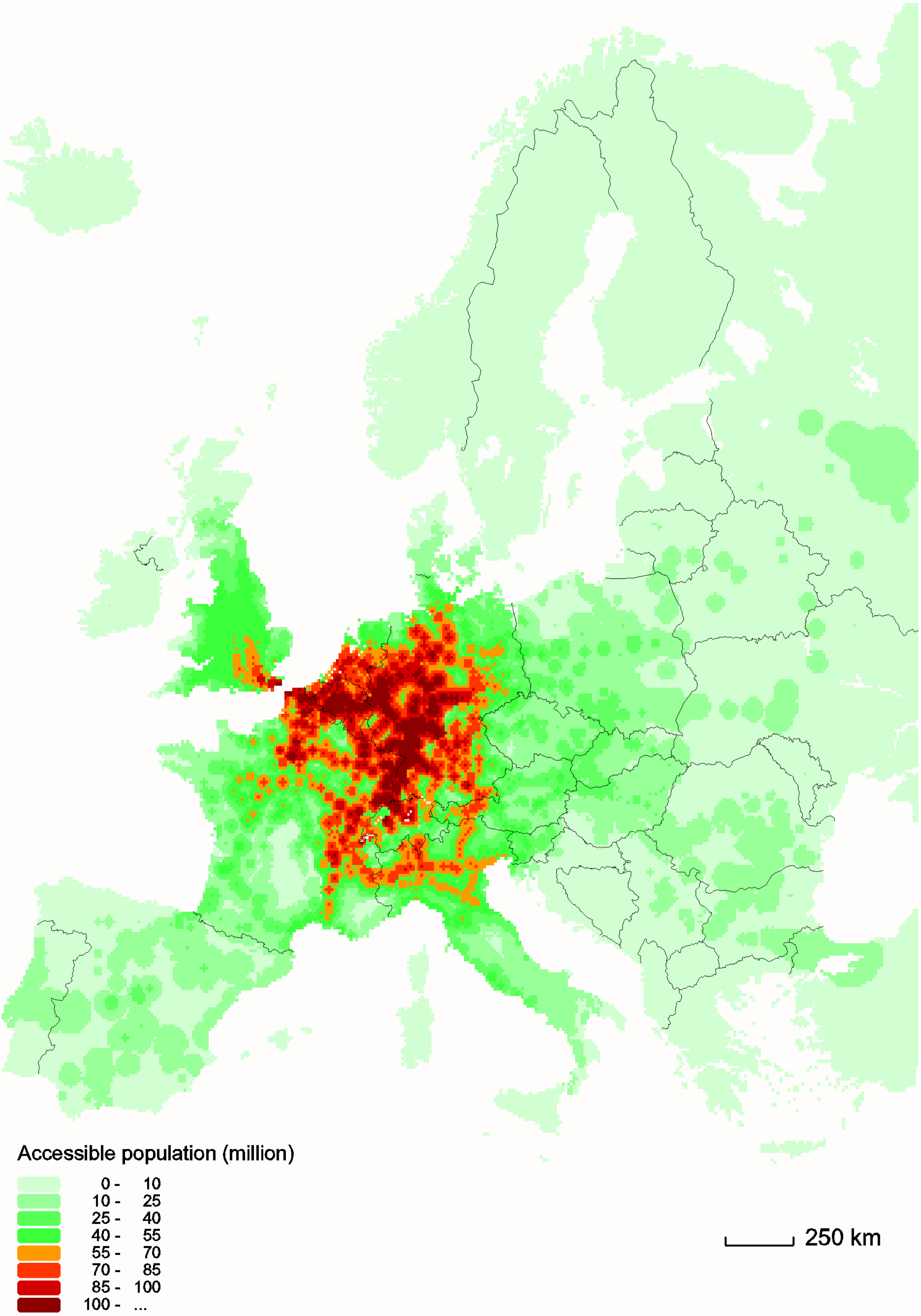


Figure 23. Daily accessibility by rail to population in 2010.

Potential accessibility

Potential accessibility is presented and discussed here for population as destination activity. Figure 24 (top) displays the surface of potential accessibility without high-level networks. This surface is a smoothed reproduction of the distribution of population in Europe (see Figure 13). Major agglomerations appear as peaks, whereas smaller cities disappear.

Figure 24 (bottom) shows the surface of accessibility by rail in 1981. Compared to the local potential, more peaks of higher potential emerge. As for daily accessibility, significant disparities in accessibility become visible. Urban regions have the highest and rural areas the lowest accessibility. Accessibility decreases from city centres to rural areas and central locations have higher accessibility than peripheral regions.

Figure 25 (top) shows the surface of potential accessibility by rail in 1996. This surface can be compared with the one of daily accessibility in Figure 20 (bottom). It can be seen that potential accessibility has smoother transitions. The 'valleys' between the 'peaks' (the differences between urban centres and their hinterlands) and the self-potential of large isolated cities such as Moscow are less pronounced. The surface of potential accessibility by rail in 1996 does not differ much from the surface of 1981 but a clear growth in accessibility has occurred until 2010 (Figure 25, bottom). Because it is assumed that the trans-European rail networks will be in operation, rail travel times decrease with the effect that accessibility increases everywhere. Also the impact of the Crete corridors in eastern Europe can be seen by the growth of the nodes along these corridors. However, the 'valleys' between the 'peaks' in the high-accessibility regions have become deeper, i.e. the disparities in accessibility between urban centres and their rural hinterlands have increased, whereas the disparities between central and peripheral regions and between the European Union and eastern Europe have remained constant.

This analysis is underlined by Figure 26 which shows absolute changes between local potential and potential accessibility by rail in 1981 (top) and absolute changes between 1996 and 2010 (bottom). Both the network effect in the top diagram and the development of the rail network between 1996 and 2010 in the bottom diagram primarily benefit the already advantaged regions and within the regions the nodes of the networks. However there are also regions that do not benefit at all: Greece, Ireland and Scandinavia are too remote from the population and economic centres of Europe that even high-speed rail could significantly improve their situation.

The next two figures enable a comparison between modes in the future. Figure 27 shows potential accessibility to population in 2010 by rail (as in Figure 25, bottom) in map form and Figure 28 potential accessibility in 2010 by road. Figure 27 is comparable to the map of daily accessibility by rail to population in Figure 23. Although the two colour scales are not comparable, it can be seen that potential accessibility is less concentrated and more evenly distributed also across eastern Europe. The comparison between Figure 27 and Figure 28 (both of which are drawn to the same colour scale) shows that after the completion of the trans-European high-speed rail network rail will be the far superior mode of travel in Europe. Whereas the two highest categories of accessibility by rail in Figure 27 cover most of the high-speed corridors in France, England, Benelux, Germany and Italy, the same level of accessibility by road in Figure 28 covers only a small region from south-east England through the Benelux countries into western Germany.

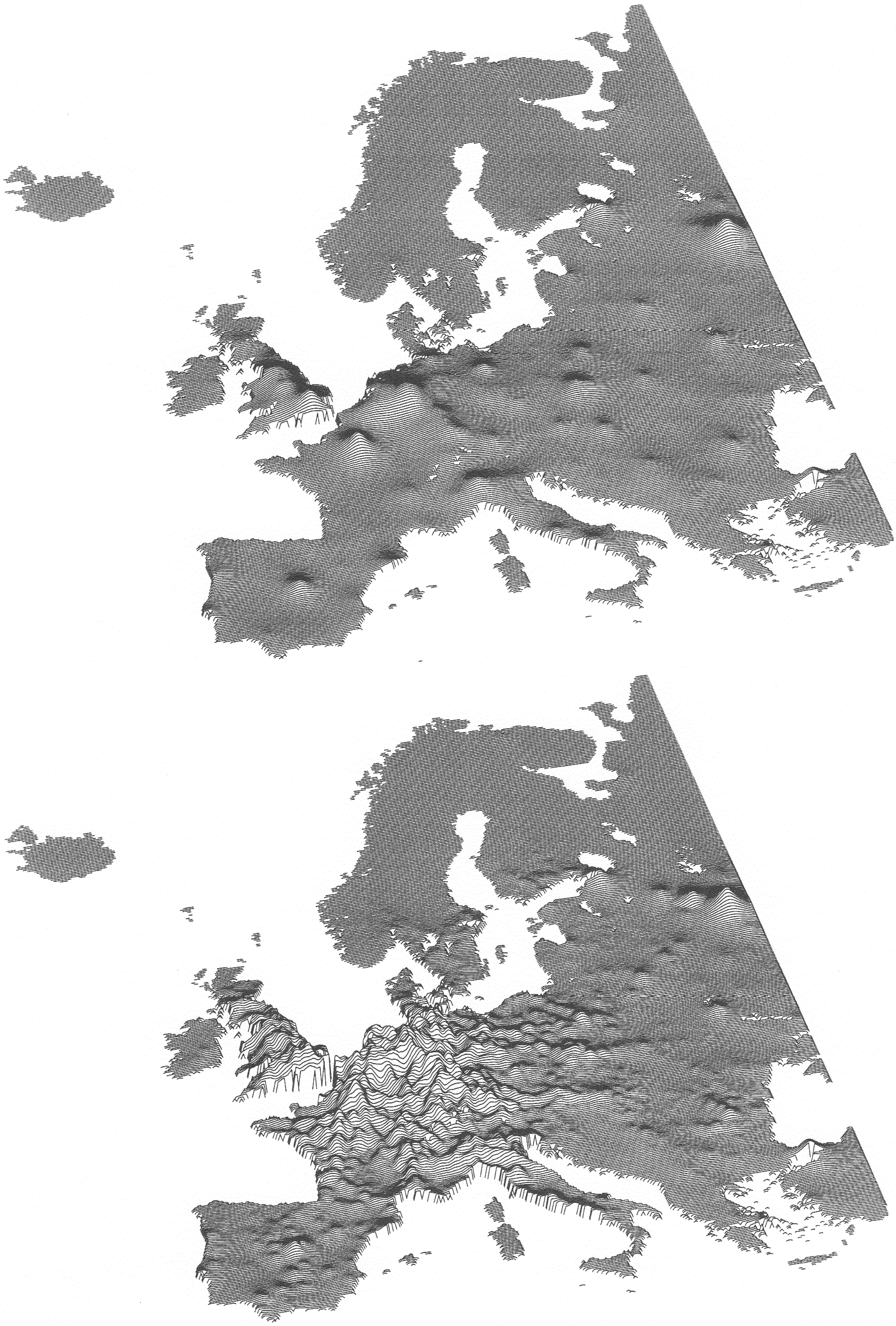


Figure 24. Potential accessibility to population without high-level network (top), and by rail in 1981 (bottom).

Figure 25. Potential accessibility to population by rail in 1996 (top) and in 2010 (bottom).

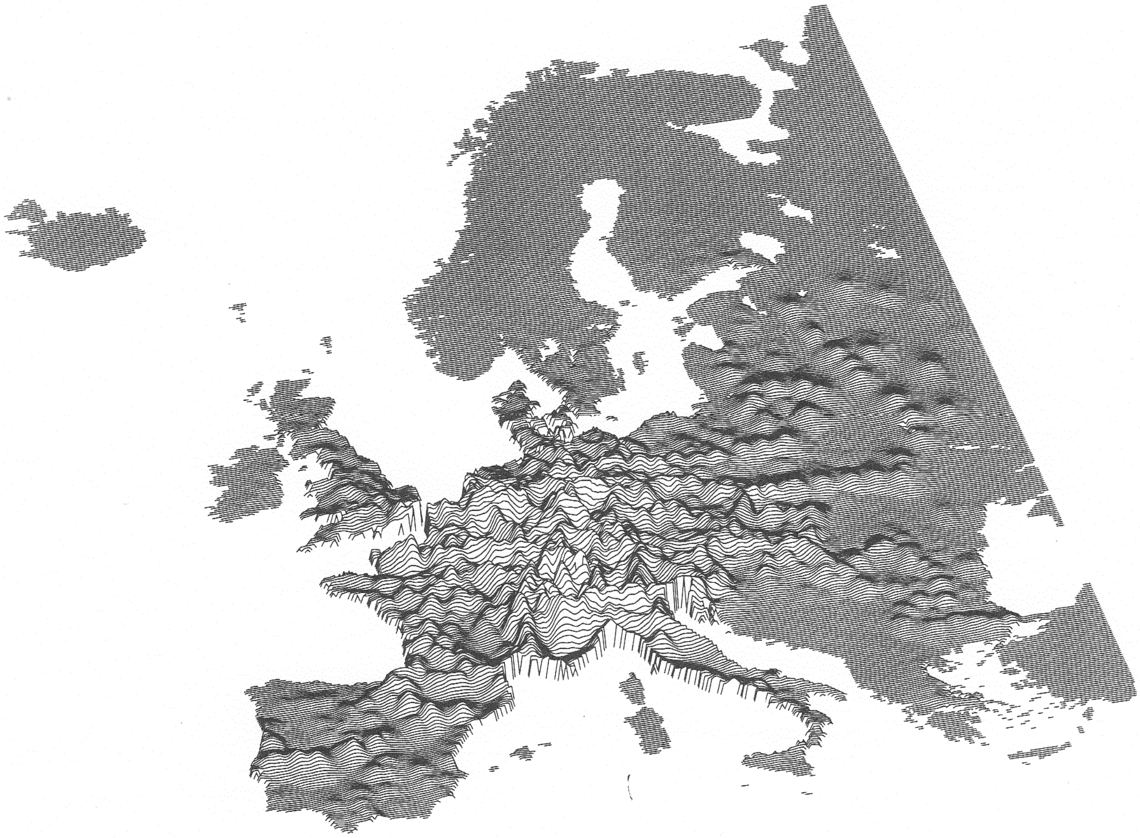


Figure 26. Potential accessibility to population by rail, absolute difference between no-high-level network and 1981 (top) and absolute change between 1996 and 2010 (bottom).

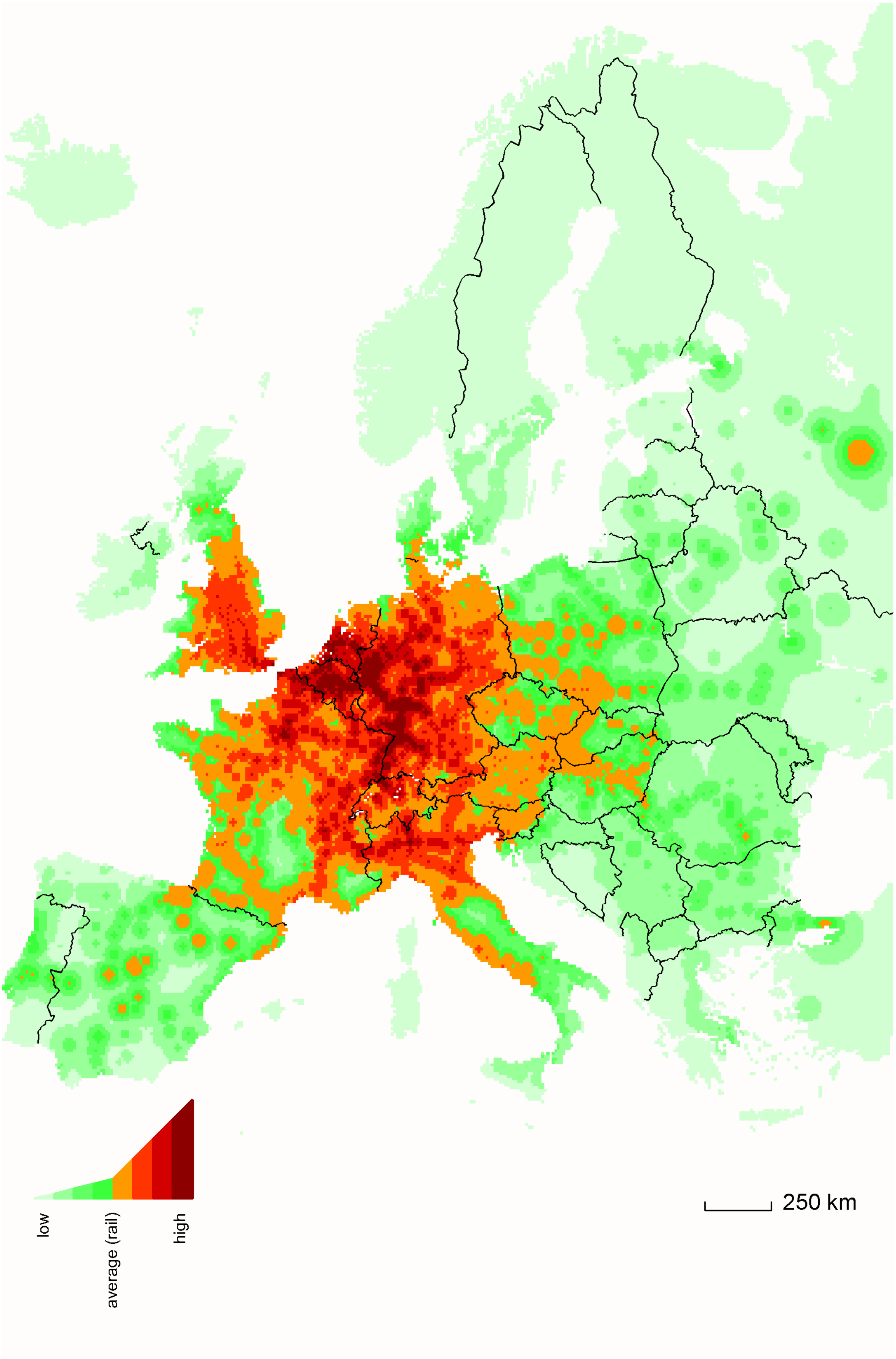


Figure 27. Potential accessibility to population by rail in 2010.

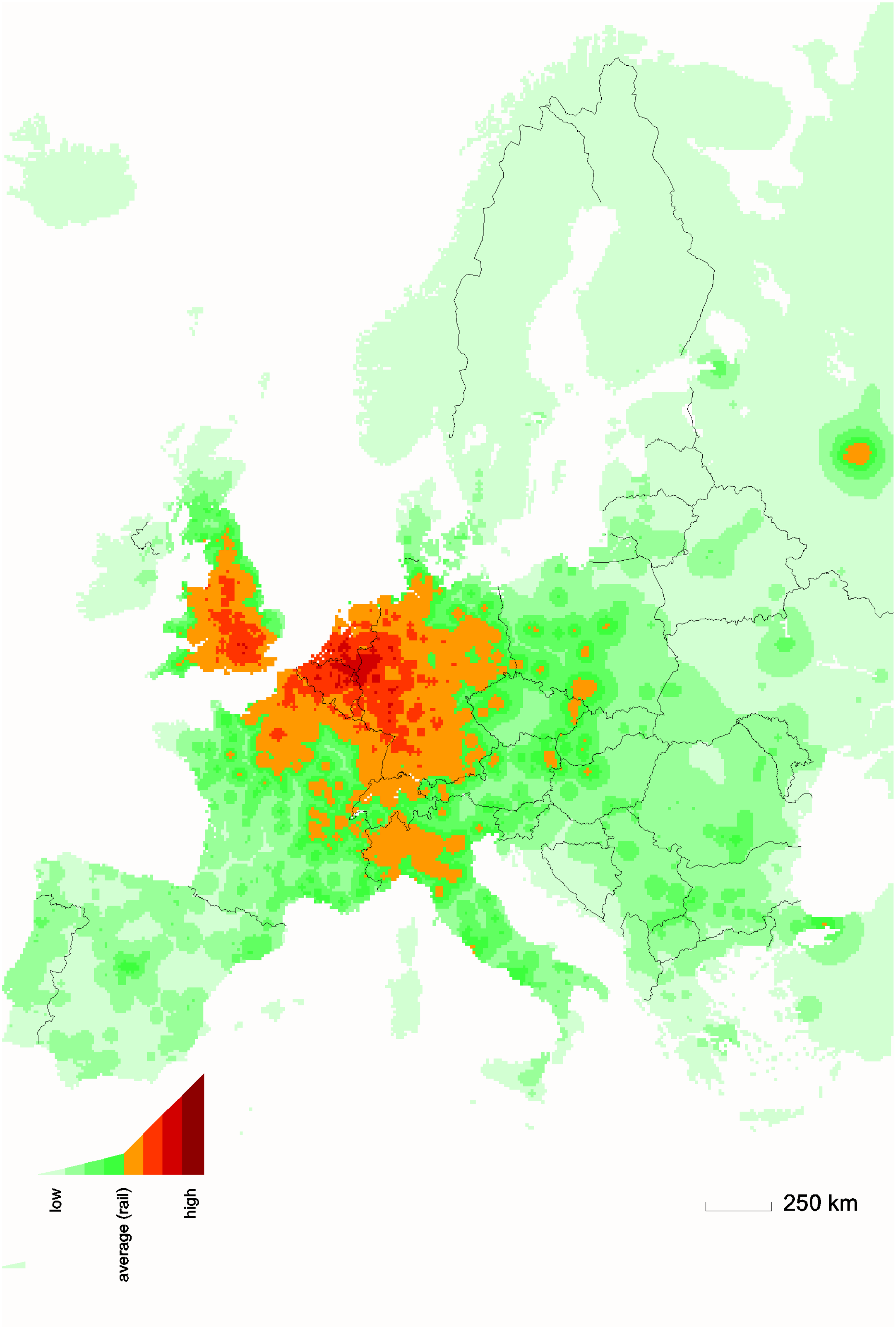


Figure 28. Potential accessibility to population by road in 2010.

5.2 Accessibility of Regions

The SASI model is designed to forecast socio-economic impacts of transport infrastructure for a system of 201 regions of the European Union (see Section 2.4). Therefore the regional accessibility indicators have to be aggregated from raster cells to regions. Regional accessibility is expressed in three ways: as maximum value in the region, as average value per capita and as average value per cell. For averages also standard deviations are presented to indicate intraregional disparities in accessibility. Regional accessibility indicators are the output of the accessibility model fed into the other modules of the SASI model.

By taking potential accessibility by road to population as an example, Figure 29 demonstrates the impact of the aggregation procedure from pixels (top) to regions (bottom). It can be seen that the aggregation leads to a loss of information with respect to spatial detail but that the overall distribution of accessibility over the European territory remains the same. One exception is eastern Europe. There the aggregation leads to a more pronounced loss of information because of the size of the regions, which are however external regions of the SASI model.

This section gives an overview on *regional* accessibility for the three types of accessibility implemented. It starts by comparing the changes of regional accessibility between years and modes. Then the three accessibility indicators are compared with each other in order to identify differences and similarities. In all analyses of this section regional accessibility is defined as average accessibility per cell, i.e. as the average accessibility of all cells belonging to a region. All comparisons are performed for all 201 regions of the European Union.

5.2.1 Comparison between Years and Modes

The first part of the analysis looks at the development of regional accessibility between two years or compares regional accessibility by different modes. Only selected comparisons are discussed. Tables A2 to A5 of the Annex show correlation coefficients between all possible combinations of indicators.

Average travel times to large cities

Figure 30 presents correlation diagrams of regional average travel times and weighted average travel times. All indicators are standardised to their European mean, i.e. overall growth or decline of accessibility has been eliminated. Because the travel cost indicator represents a disutility, the higher the travel costs the lower the accessibility. In each diagram two accessibility indicators differing by year, mode, minimum city size or way of aggregation (unweighted v. weighted) are compared:

- Diagram *a* compares average travel times by road to cities with a population of more than 250,000 in 1996 and in 2010. Not surprisingly in both years the highest travel times are found in remote regions such as the Mediterranean islands or in northern Finland. Belgian, German, Dutch and Austrian regions have the lowest average travel times. Future motorway construction leads to a significant reduction of average travel time (which cannot be seen because of the standardisation of indicators), but the relative position of regions remains about the same.

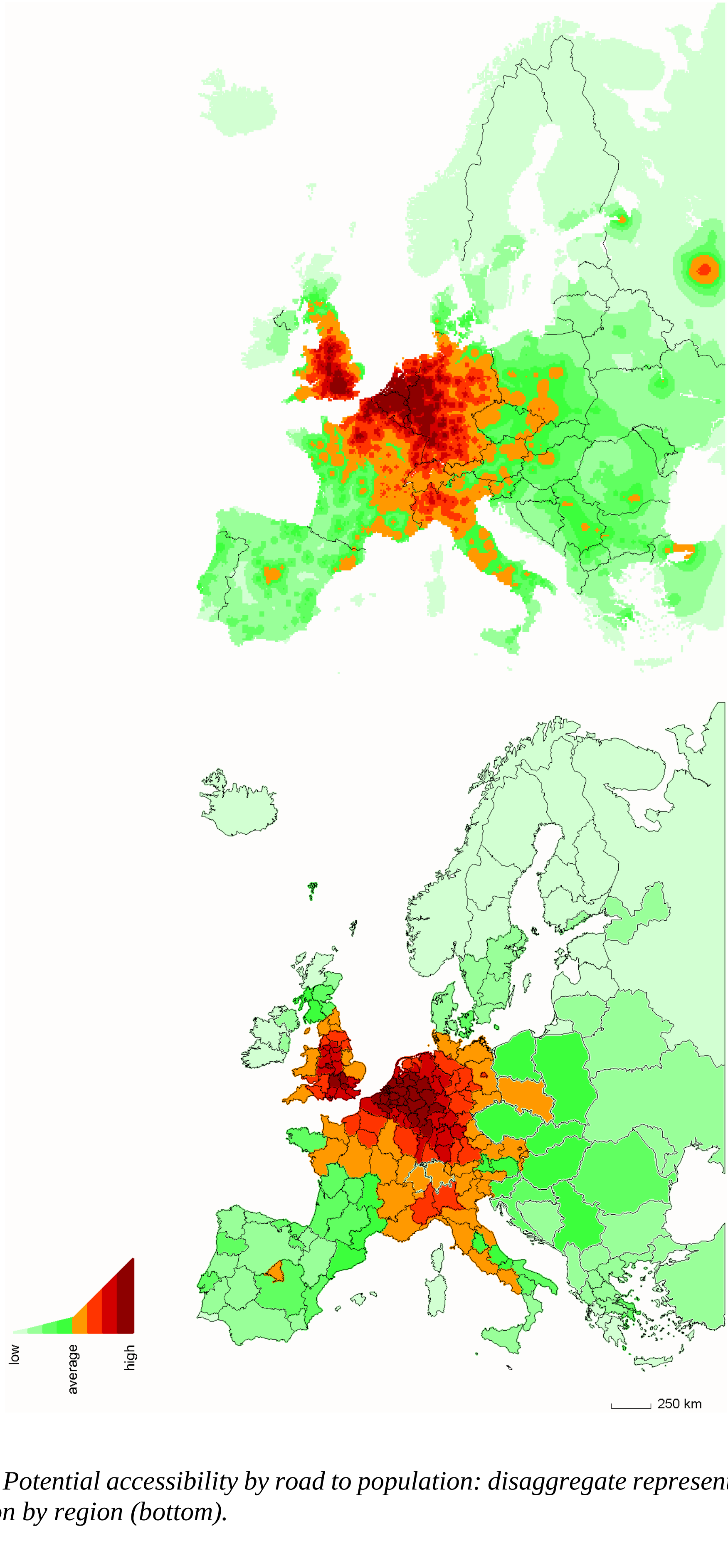


Figure 29. Potential accessibility by road to population: disaggregate representation (top) and aggregation by region (bottom).

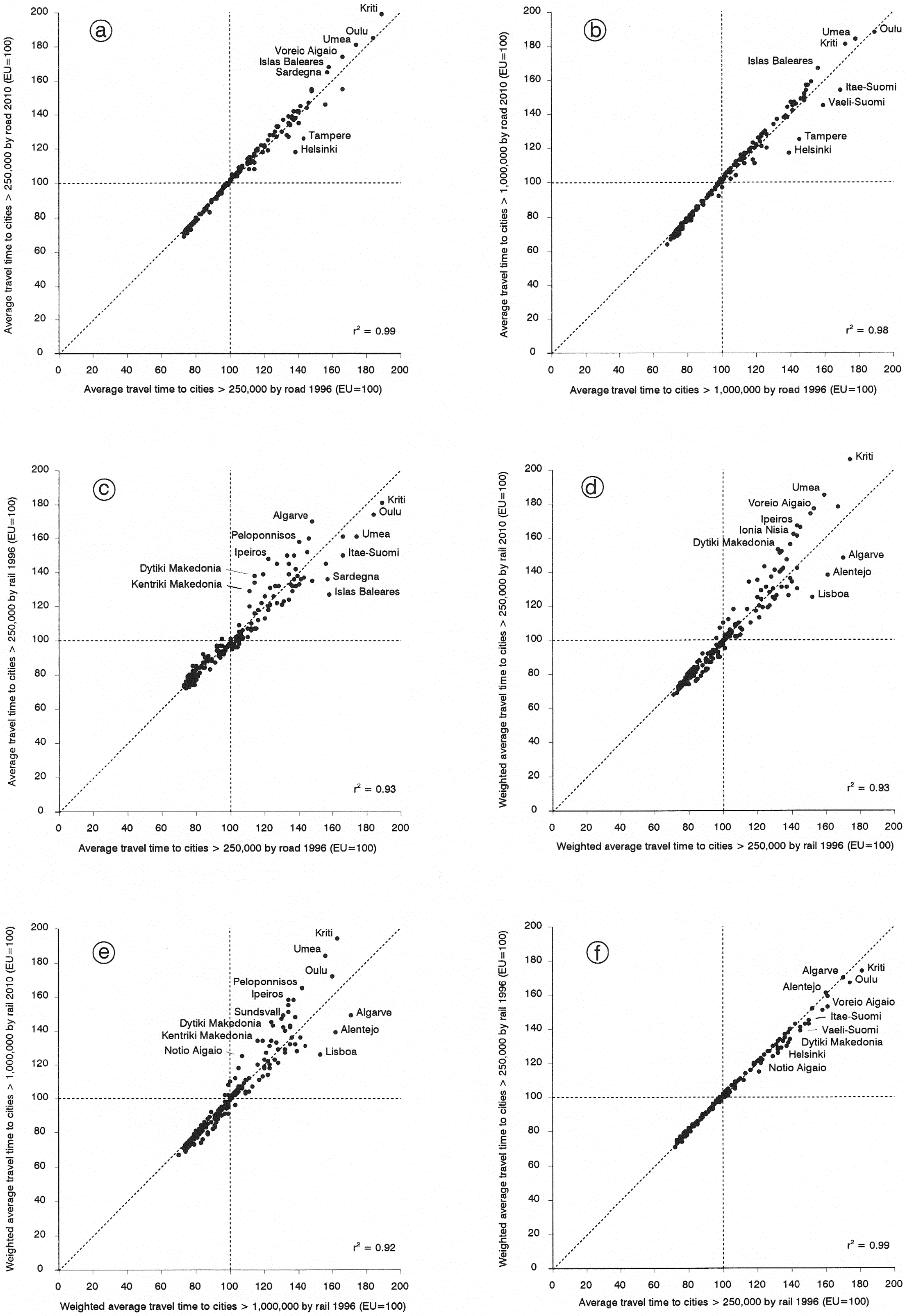


Figure 30. Average travel time to cities: correlation between different years, modes, minimum city sizes and ways of aggregation.

- Diagram *b* shows that the effect of changing the minimum size of the destination cities is small. Only remote regions have different average travel times. This is so because the larger cities are distributed less evenly over the European territory.

- Diagram *c* compares road and rail travel times relative to the European mean. The only differences visible are associated with remote regions. Greek regions have shorter travel times by road, whereas regions in northern Finland and the Mediterranean islands have shorter travel times by rail.

- Diagram *d* compares weighted average travel times by rail in 1996 and 2010. Again differences are found only in remote regions.

- Diagram *e* confirms that also for weighted average travel times changing the minimum size of the destination cities does not significantly alter the results.

- Diagram *f* demonstrates that is does not matter whether average or weighted average travel times are used.

To summarise, average travel times are not very sensitive to changes in the transport network nor to changing the minimum destination activity or the way of aggregation. Not even the dramatic changes of the rail network expected in the future result in significant changes in the relative position of the regions.

Daily accessibility

Figure 31 presents correlation diagrams for daily accessibility. All indicator values are standardised to the European mean as in Figure 30. Now accessibility represents a utility, i.e. the higher the indicator value the better the accessibility.

- Diagram *a* compares daily accessibility without high-level networks with accessibility by rail in 1981. As in Figure 20, the highest daily accessibility is found in regions of Belgium and north-west Germany. The rail network results in significant differences compared to the no-network situation. Peripheral regions lose whereas most central regions gain.

- Diagram *b* shows that the development of the rail network between 1981 and 1996 results in only small changes in the relative position of regions. Exceptions from this are some regions in Germany which benefit from the German ICE and the unification of Germany. A similar impact of the French TGV cannot be identified.

- Diagram *c* shows that the expected future development of the rail network will lead to further polarisation in accessibility between regions. Regions with already high accessibility benefit most. Some regions in central and northern parts of the United Kingdom lose because rail development in the United Kingdom besides the Channel Tunnel Rail Link is assumed to be minimal.

- Diagram *d* suggests that the future development of the road network will not result in significant changes of the relative position of regions. The regions with the highest accessibility are found again in north-western Europe.

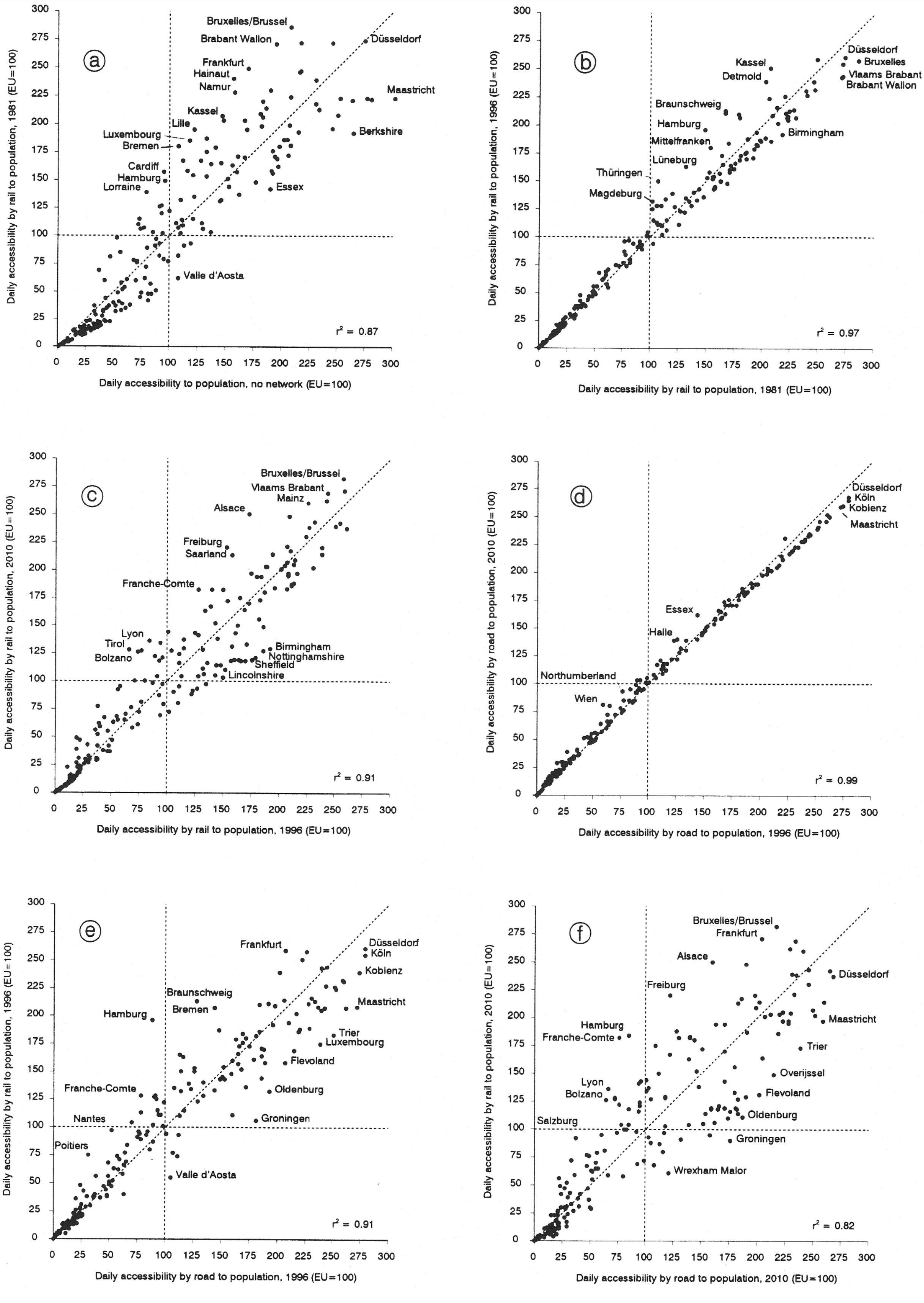


Figure 31. Daily accessibility to population: correlation between different years and modes.

- Diagram *e* displays that there are large differences between road and rail accessibility for many regions in 1996. In general large agglomerations have better daily accessibility by rail than by road, and rural regions between the large agglomeration have higher accessibility by road.

- As seen in Diagram *f*, the differences in accessibility by road and by rail remain relatively constant despite large changes in the networks.

To summarise, daily accessibility is rather sensitive to changes of the transport system. Also differences between central and peripheral regions are much greater than for average travel cost. This is so mainly because some of the remote regions have accessibilities of less than 25 percent of the European average. The development of the networks does not significantly change the distribution of daily accessibility in Europe.

Potential accessibility

Figure 32 presents a comparable set of correlation diagrams for potential accessibility. As the diagrams are more or less identical to those for daily accessibility, no detailed discussion is necessary. However it can be observed that the differences in potential accessibility between the alternatives are somewhat smaller than those in daily accessibility.

5.2.2 Correlation Between Accessibility Indicators

The previous discussion presented differences between accessibility indicators by year and mode and by size of destination city (only for travel cost accessibility). This subsection examines differences between types of indicator and between destination activities.

Daily and potential accessibility v. travel cost

In Figure
33 daily (*a*) and potential (*b*) accessibility are compared with weighted average travel time. Both diagrams are similar. Regions with high daily or potential accessibility in general have short travel times, and regions with low daily or potential accessibility in general have long travel times.

However, the relationship is highly nonlinear. Because of its strict cut-off criterion, weighted average travel time does not differentiate between regions with good or very good accessibility in the European core; they all have very similar average travel times of about 75 percent of the European average, whereas their daily and potential accessibility range between 75 and 300 of the mean. Only the more remote regions show a distinct relationship between daily or potential accessibility and average travel time. This nonlinearity leads to the relatively low correlation coefficients r^2 of 0.52 for both cases.

Other correlations between daily and potential accessibility and travel costs are in the same range (see Annex Tables A2 to A5). It seems that these indicators measure something different.

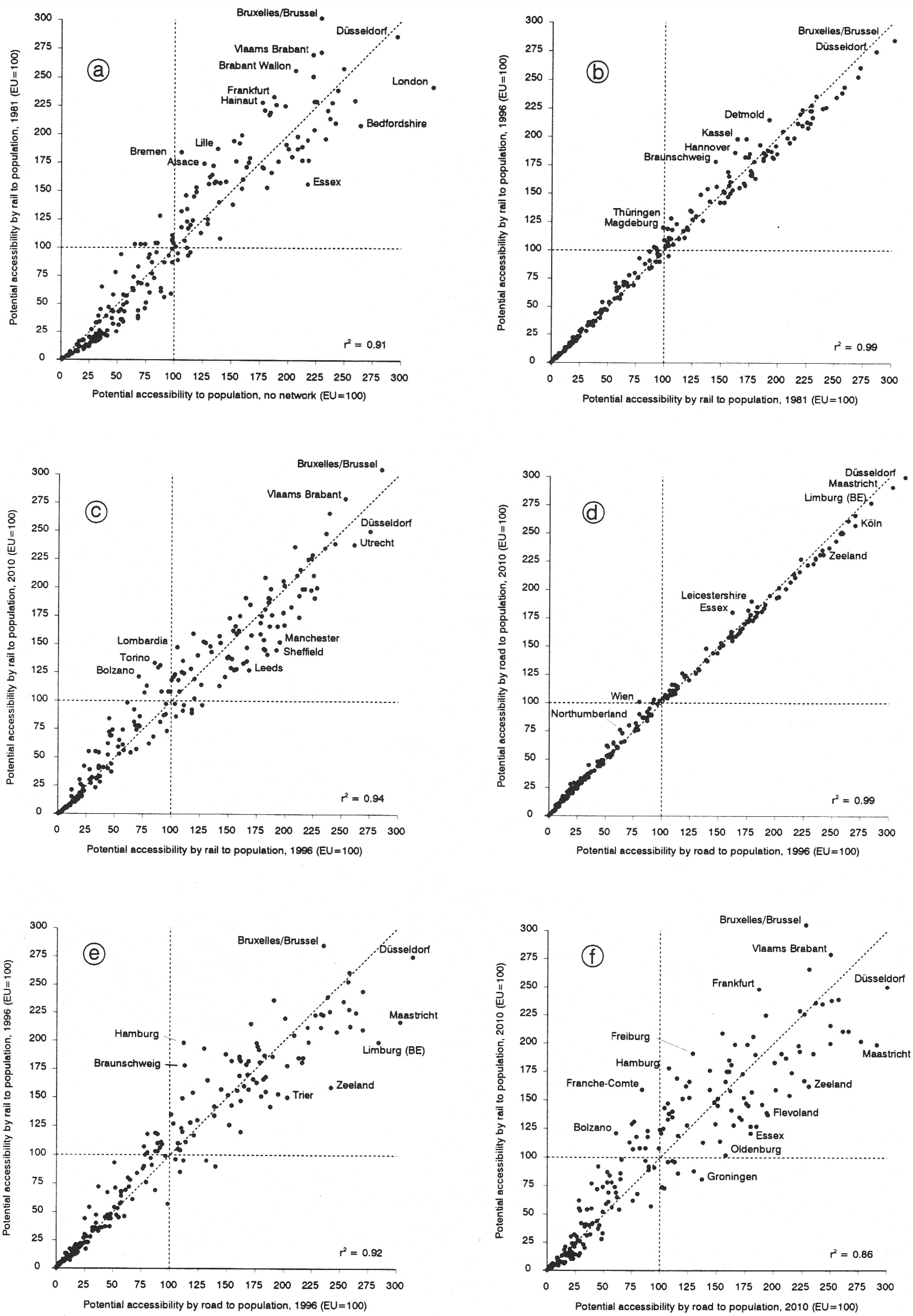


Figure 32. Potential accessibility to population: correlation between different years and modes.

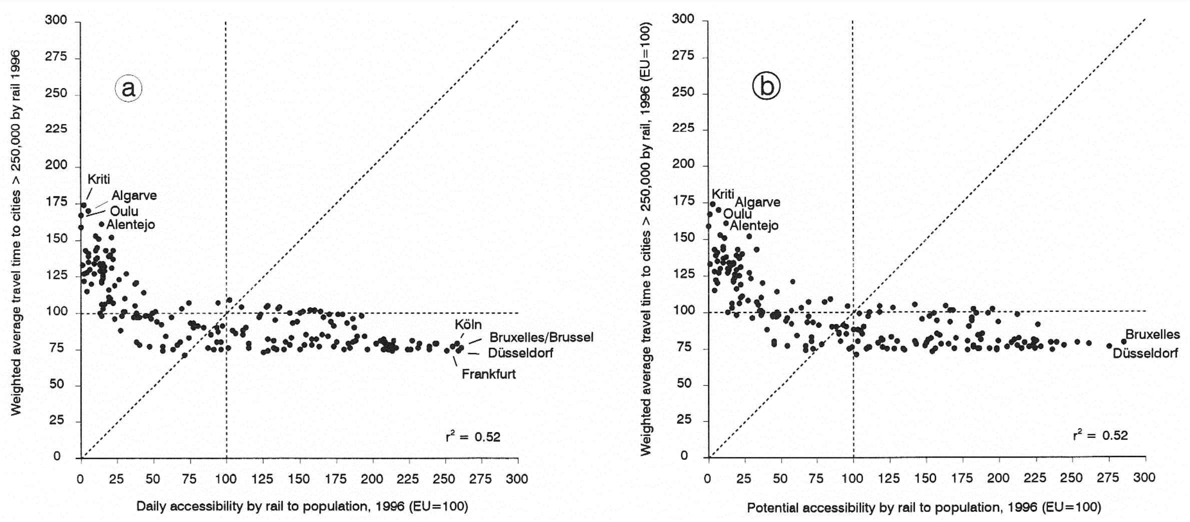


Figure 33. Correlation between daily (a) and potential (b) accessibility and weighted average travel time by rail.

Daily v. potential accessibility

Figure 34 presents correlation diagrams of daily and potential accessibility for different years and modes. Generally the correlation between the two indicators is rather high expressed by r^2 between 0.94 and 0.97.

Diagrams *a* to *f* are very similar with respect to the position of regions. In particular for the below-average regions there are no significant differences between the two indicators. However for the above-average regions a pattern emerges. Large agglomerations have higher potential than daily accessibility. More rural regions in the high-accessibility area have higher daily accessibility. One explanation for this might be that the local potential of large agglomerations (as reflected in the no-network alternative) contributes to their potential accessibility, whereas for daily accessibility every agglomeration counts the same for itself as for its hinterland region because of the rectangular impedance function.

Accessibility to population v. accessibility to GDP

Finally accessibility to population is compared with accessibility to GDP. Because daily and potential accessibility are similar, only potential accessibility to population and GDP is presented in Figure
 35 for rail (*a*) and road (*b*). It can be seen that changing the destination activity does not make a great difference: the correlations are very high with r^2 of 0.98 and 0.97. The obvious reason is that population and economic activity are very similarly distributed in space, although the distribution of GDP is more peaked because of higher GDP per capita in the more central regions (see Figure 14).

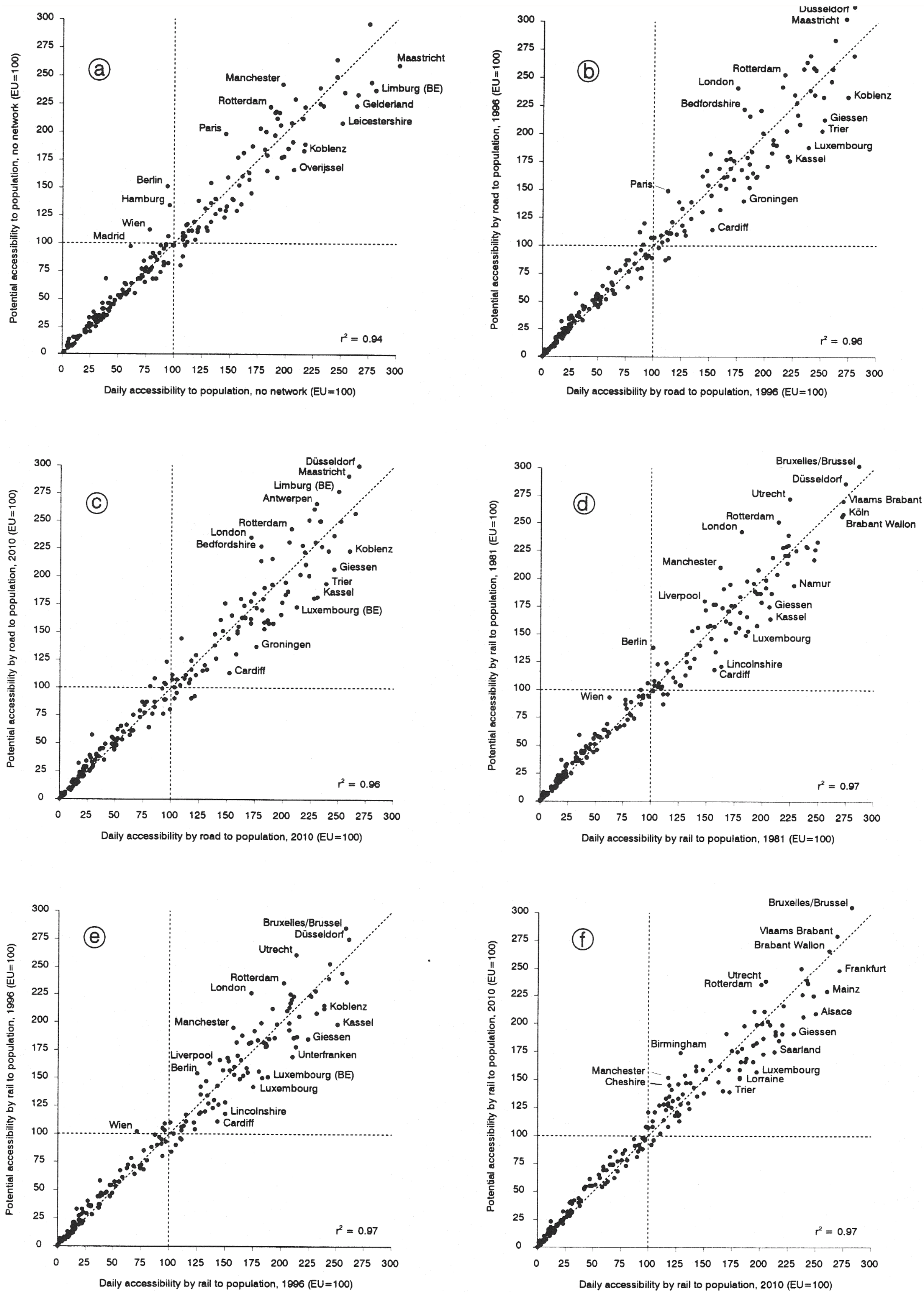


Figure 34. Correlation between daily and potential accessibility.

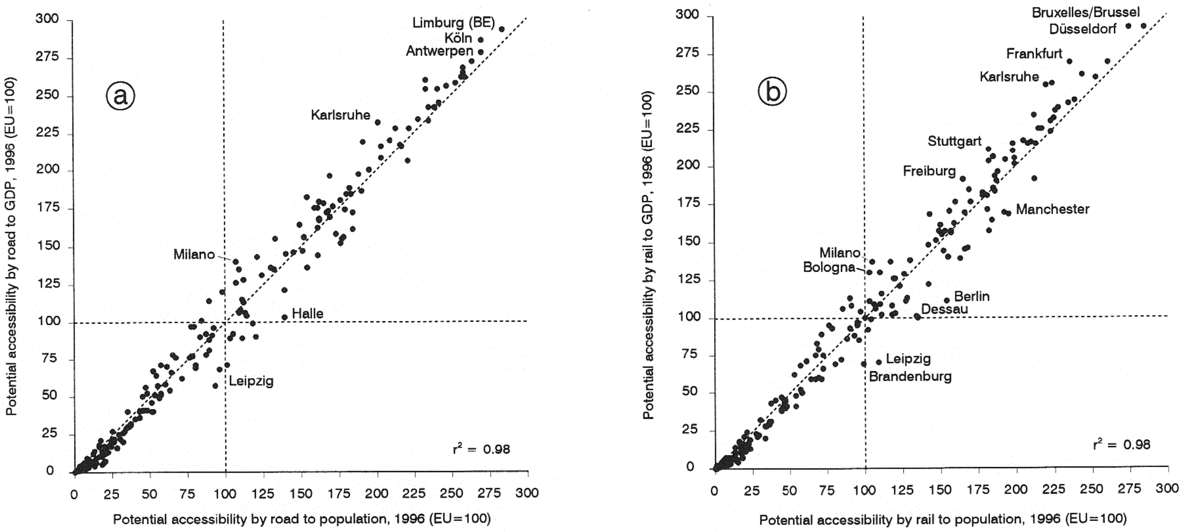


Figure 35. Correlation between potential accessibility to population and to GDP, road 1996 (a), rail 1996 (b).

Nevertheless, some differences appear. For the more central regions accessibility to GDP is slightly higher than to population, whereas for the more remote regions the opposite is true. This means that GDP as destination activity increases the disparities in accessibility because of the uneven distribution of GDP per capita in the European Union. The New German Länder play a specific role. Whereas they have above-average accessibility to population, they fall behind in accessibility to GDP because of their current economic problems and their vicinity to the poorer regions in eastern Europe.

5.3 Accessibility and Cohesion

The third output option of the accessibility model provides macro indicators of accessibility, i.e. assesses the model results in terms of cohesion. Three groups of cohesion indicator are applied here (see Section 3.5): statistical measures such as maximum, mean, minimum, standard deviation and ratios between 'best' and 'worst' regions, rank-size distributions of regions and Lorenz distributions and GINI coefficients.

Statistical measures

Statistical measures such as maximum, mean, minimum, standard deviation of regional accessibility values and ratios between the highest and lowest (or the five, ten or twenty highest and lowest) regional accessibility values give an impression of the distribution of accessibility values between regions.

Table 4 presents basic statistical measures for all accessibility indicators implemented: maximum, mean and minimum, standard deviation and several ratios between the regions with the highest and lowest accessibility.

Table 4. Statistical measures of accessibility indicators

		Maxi-mum	Mean	Minimum	Standard deviation	Ratio best / worst regions	Ratio best 5 / worst 5 regions	Ratio best 10 / worst 10 regions	Ratio best 20 / worst 20 regions
Average travel time to cities > 250,000	Road 1996	189.1	100	73.1	25.3	2.6	2.4	2.0	2.1
	Road 2010	199.3	100	69.7	26.7	2.9	2.6	2.2	2.2
	Rail 1981	181.3	100	72.8	25.7	2.5	2.4	2.0	2.1
	Rail 1996	182.0	100	72.9	25.0	2.5	2.3	2.0	2.1
	Rail 2010	214.1	100	70.4	28.7	3.0	2.7	2.3	2.3
Average travel time to cities > 1,000,000	Road 1996	189.4	100	68.2	25.3	2.8	2.5	2.1	2.1
	Road 2010	188.2	100	64.2	26.7	2.9	2.6	2.2	2.2
	Rail 1981	182.7	100	66.5	24.9	2.7	2.4	2.1	2.1
	Rail 1996	175.0	100	67.0	23.9	2.6	2.4	2.0	2.0
	Rail 2010	196.5	100	64.3	27.0	3.1	2.6	2.2	2.2
Weighted average travel time to cities > 250,000	Road 1996	183.0	100	73.4	24.4	2.5	2.3	2.0	2.0
	Road 2010	191.6	100	69.8	25.9	2.7	2.5	2.1	2.1
	Rail 1981	174.9	100	72.0	24.4	2.4	2.3	2.0	2.0
	Rail 1996	174.2	100	71.9	23.7	2.4	2.3	1.9	2.0
	Rail 2010	206.1	100	69.0	27.5	3.0	2.6	2.2	2.2
Weighted average travel time to cities > 1,000,000	Road 1996	175.2	100	71.4	23.2	2.5	2.2	1.9	2.0
	Road 2010	180.1	100	67.3	24.9	2.7	2.5	2.1	2.1
	Rail 1981	175.9	100	70.0	23.1	2.5	2.3	1.9	2.0
	Rail 1996	171.1	100	70.1	22.2	2.4	2.2	1.9	1.9
	Rail 2010	194.6	100	67.1	25.8	2.9	2.5	2.1	2.1
Daily accessibility to population	No network	302.9	100	1.6	73.9	186.9	85.1	44.7	24.9
	Road 1996	280.0	100	0.7	82.7	390.1	190.2	96.1	46.2
	Road 2010	268.1	100	0.7	79.1	390.7	191.3	96.0	39.9
	Rail 1981	286.7	100	0.8	79.6	342.8	170.1	81.8	40.8
	Rail 1996	261.3	100	0.8	77.8	337.9	177.8	79.3	42.5
	Rail 2010	282.3	100	0.5	77.4	575.4	273.4	119.0	63.0
Daily accessibility to GDP	No network	323.4	100	1.6	81.0	203.2	113.2	62.4	37.5
	Road 1996	294.1	100	0.7	87.3	435.4	257.1	135.9	73.4
	Rail 1996	285.1	100	0.7	82.3	383.6	241.6	123.7	72.3
Potential accessibility to population	No network	328.8	100	1.6	73.4	203.7	73.2	38.6	22.7
	Road 1996	314.1	100	0.8	81.1	415.7	154.8	80.5	44.0
	Road 2010	300.6	100	0.7	78.1	415.9	154.5	81.3	38.5
	Rail 1981	302.6	100	0.9	78.1	350.4	124.4	62.5	36.3
	Rail 1996	285.5	100	0.8	76.0	351.3	119.0	60.4	37.0
	Rail 2010	305.4	100	0.5	73.6	559.2	172.0	83.7	49.9
Potential accessibility to GDP	No network	378.1	100	1.6	80.5	235.9	106.8	55.0	34.2
	Road 1996	330.2	100	0.7	85.5	454.8	216.8	112.9	66.7
	Rail 1996	292.7	100	0.8	80.3	348.2	178.6	96.8	60.6

Looking first at the average and weighted average travel time indicators, the hypothesis developed in the previous sections is confirmed that these indicators are not sensitive to changes in infrastructure. There is not much change in the statistical measures between years and modes. In particular the ratio between the 20 'best' and 20 'worst' regions remains more or less stable regardless of mode and network development.

The spread of daily and potential accessibility is much wider. Accordingly the ratios between the regions with highest and lowest accessibilities increase considerably. However, within one indicator group, the standard deviations, though much larger, remain in the same range for all years and modes. By standard deviation alone, the completion of the trans-European networks will lead to a slight decrease of regional disparities in accessibility in Europe. However by the ratios between best and worst regions, disparities in accessibility tend to increase, in particular through the completion of the planned high-speed rail lines.

Figure 36 gives a graphical representation of these statistical measures for potential accessibility as an example. The range of the 20 'best' and 20 'worst' regions and the standard deviation from the mean are shown for the different network alternatives. In the upper diagram, as in Table 4, the results of all network alternatives are standardised to their own mean, i.e. the overall increase in accessibility is ignored. With this standardisation the standard deviations become slightly smaller. However, only in the road network this leads to a gain in relative accessibility of the 20 regions with the lowest accessibilities and a corresponding relative loss of the 20 regions with the highest accessibilities. In the rail network, despite the lower standard deviation, the 20 most remote regions lose and the 20 most central regions gain significantly.

In the lower diagram of Figure 36 the results are standardised to the mean of the no-network alternative, i.e. the general increase in accessibility becomes visible. As discussed earlier, there is not much change between the present and the future road network. There was some change between the rail network in 1981 and the rail network of 1996. The largest increase in accessibility is caused by the completion of the future trans-European high-speed rail network. It can be seen that in absolute terms even the standard deviation increases significantly. In absolute terms the 20 most remote regions gain only very little, whereas the 20 most central regions gain even more in absolute than in relative terms.

Rank-size distributions

The graphical representation of a rank-size distribution of regions sorted by decreasing or increasing order of accessibility visualises the degree of inequality between regions. If two rank-size distributions of different years or modes are compared, decreasing or increasing inequality in accessibility or differences in the distribution of accessibility by mode can be detected.

Figure 37 is an example of such a comparison. The top diagram shows the rank-size distribution of daily accessibility to population by rail in 1996 (solid line) and 2010 (dotted line). The distribution confirms the information already presented in Table 4 that the difference in accessibility between the most central regions and the most peripheral regions is immense.

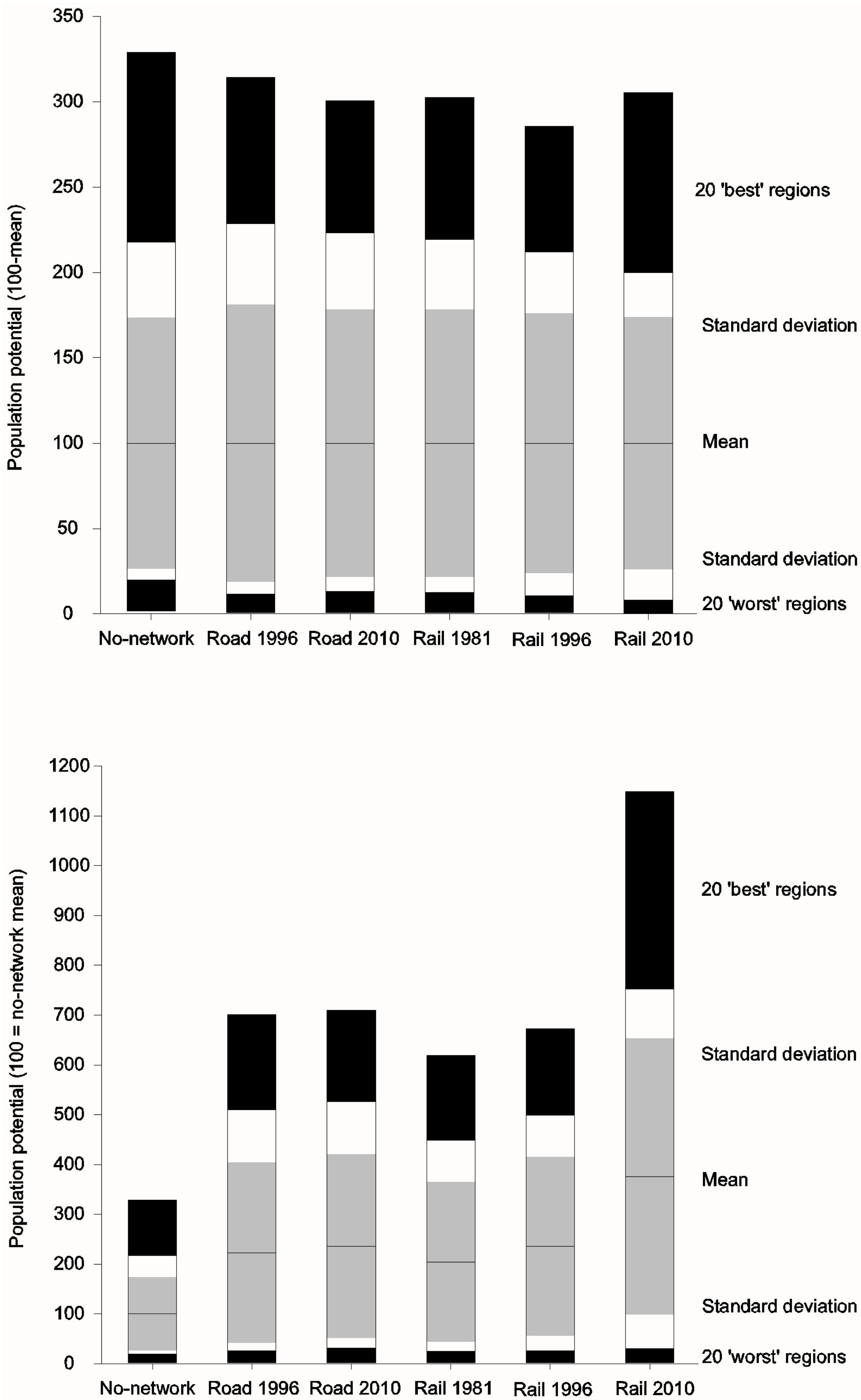


Figure 36. Potential accessibility standardised to the mean of each alternative (top) and to the mean of the 'no-network' alternative (bottom).

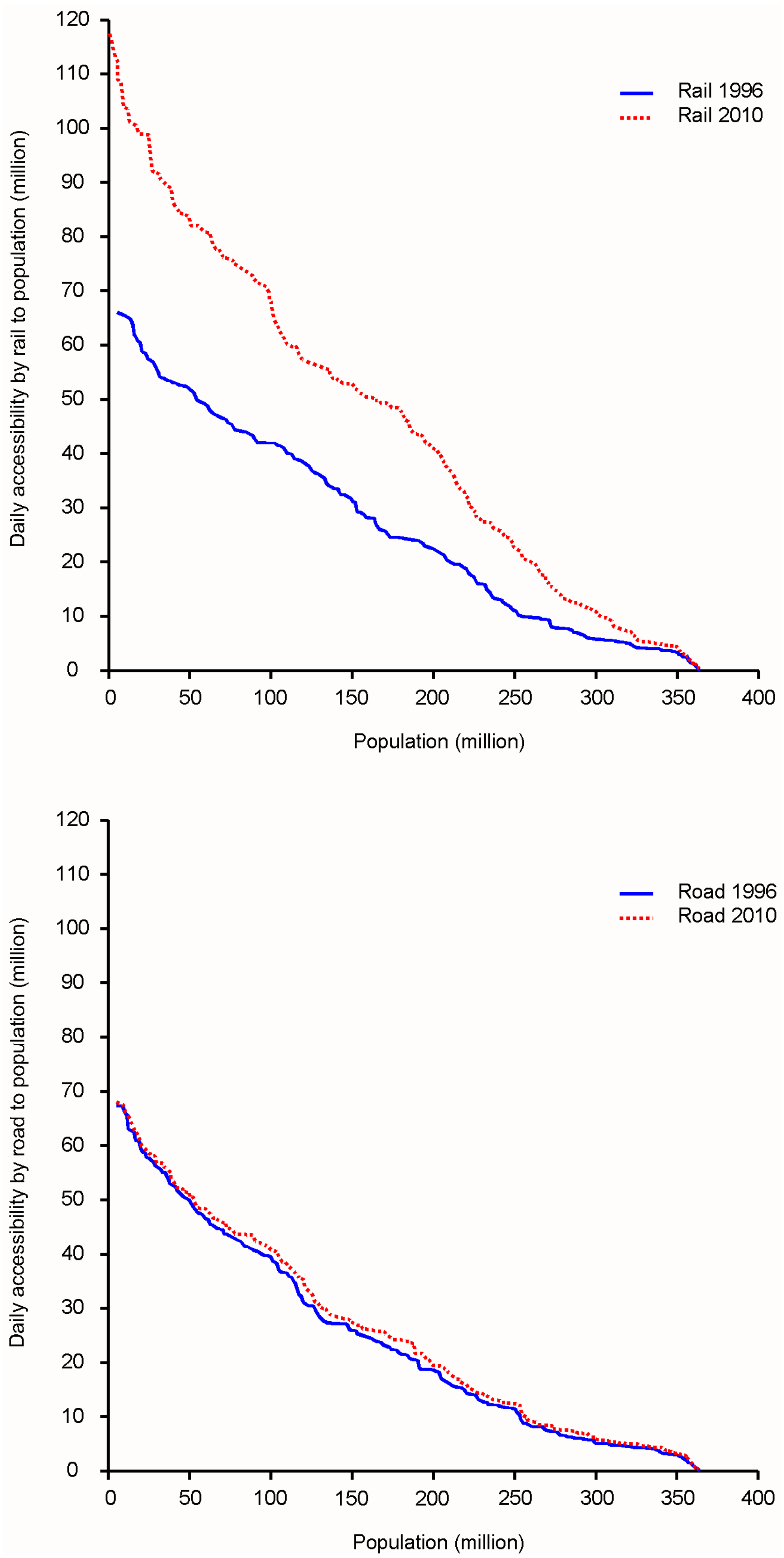


Figure 37. Rank-size distribution of daily accessibility in 1996 and 2010, by rail (top) and by road (bottom).

The diagram also shows the vast gain in daily accessibility to be expected if the high-speed rail network will be implemented. Whereas in 1996 people or firms in the regions with the highest daily accessibility in Belgium and north-west Germany were able to reach between 70 and 60 million people or customers within five hours travel time, they will be able to reach, in the same five hours, between 110 and 120 million people in the year 2010. The diagram also confirms the observation that in absolute terms the largest gains in accessibility will occur in the regions with the already highest accessibility, whereas the peripheral regions at the far end of the rank-size distribution will gain only very little.

The bottom diagram of Figure 37 shows the same for daily accessibility by road. It can be observed that in 1996 the rank-size distribution of daily accessibility by road is very similar to the rank-size distribution of daily accessibility by rail, but that there will be only marginal changes until 2010. This confirms the observation made earlier that in the future rail will be by far the superior mode of travel in Europe.

Rank correlation

The rank correlation coefficient by Spearman compares two rank orders of regions by decreasing or increasing accessibility. If two rank orders of two different years are compared, the coefficient informs about the degree of stability of the rank positions of the regions. A Spearman correlation coefficient of one indicates that there has been no change in the rank order of regions, a coefficient of minus one indicates that the rank order has been reversed. In the context of transport infrastructure policy a high rank correlation between the situation without and with policy implementation is desirable for equity reasons (see Deliverable D4, Bökemann et al., 1997).

Table 5 presents Spearman correlation coefficients comparing different network alternatives or years for the three accessibility indicators implemented both for rail and road. In all cases the Spearman correlation coefficient is higher than 0.95, i.e. the network effect or the development of the networks over time have only relatively little impact on the position of the regions in the rank order of regions in accessibility. Virtually no changes in the rank order of regions is introduced by the modest changes in the rail network between 1981 and 1996 (the Spearman coefficients are close to one). The same applies to future changes in the road network. However, the future implementation of the trans-European high-speed rail network will cause certain changes in the relative position of regions in Europe with respect to accessibility, irrespective of the indicator chosen.

Table 5. Spearman correlation coefficient

	Rail			Road	
	No network v. 1981	1981 v. 1996	1996 v. 2010	no network v. 1996	1996 v. 2010
Average travel time to cities > 250,000		0.998	0.985		0.996
Daily accessibility to population	0.960	0.991	0.962	0.954	0.998
Potential accessibility to population	0.974	0.995	0.977	0.970	0.998

Lorenz-curve (GINI coefficient)

The Lorenz curve compares a rank-ordered cumulative accessibility distribution of regions with a distribution in which all regions have the same accessibility. A GINI coefficient of zero indicates that the distribution is equal-valued, i.e. that all regions have the same accessibility. A GINI coefficient close to one indicates that the distribution of accessibility is highly polarised, i.e. few regions have a very high accessibility and all other regions are relatively isolated. The GINI coefficient is used here to compare the inequality in accessibility between regions for two different years. A growing GINI coefficient indicates that inequality in accessibility between regions has increased, a declining coefficient indicates that disparities in accessibility have been reduced.

Figure 38 is an example of such a comparison using the same data as Figure 37. The top diagram shows Lorenz curves for daily accessibility to population by rail in 1996 (solid line) and 2010 (dotted line). It can be seen that the Lorenz curve standardises all cumulative distributions to the same total so that the overall growth in accessibility seen in Figure 37 disappears. With this standardisation the curves for 1996 and 2010 are very similar. Close inspection reveals that at the very low and at the very high accessibility ends the curve of 2010 lies below the one of 1996, whereas in the middle range it lies above (cf. Figure 36). This means that regions in the lower middle range and at the top end of the accessibility scale gain most, whereas regions at the bottom end and in the upper middle range gain least. The GINI coefficients of 0.441 for 1996 and 0.439 for 2010 indicate that the net effect of this polarisation and equalisation is slight convergence of accessibility. This result is somewhat different from the one published in Spiekermann and Wegener (1996), where the line of 2010 always was below the line of 1996, i.e. polarisation occurred everywhere. The difference is probably due to the much more detailed network used in the present analysis, which gives greater weight to medium-size cities in the lower middle-range of accessibility.

The bottom diagram of Figure 38 shows the corresponding Lorenz curves for road. The planned trans-European motorway projects result in a slight convergence of accessibility as indicated by the GINI coefficients of 0.464 for 1996 and 0.447 for 2010.

Table 6 presents GINI coefficients for all accessibility indicators, years and modes calculated. As already indicated in Table 4, average travel time is much less polarised than daily and potential accessibility and so has much lower GINI coefficients.

Table 6. GINI coefficients.

	No network	Rail			Road	
		1981	1996	2010	1996	2010
Average travel time to cities > 250,000		0.138	0.135	0.150	0.136	0.144
Daily accessibility to population	0.413	0.449	0.441	0.439	0.464	0.447
Potential accessibility to population	0.409	0.435	0.426	0.418	0.454	0.439

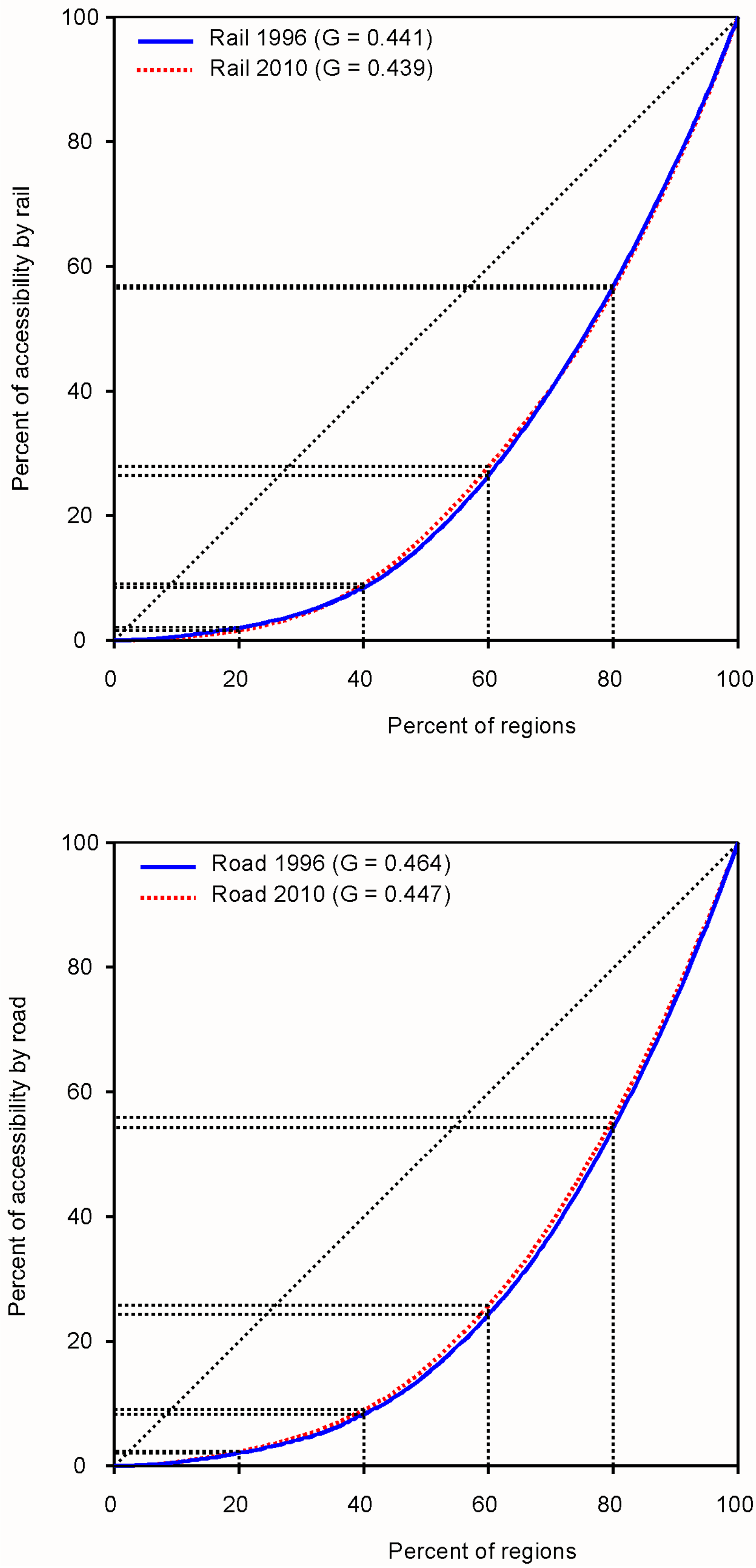


Figure 38. Lorenz curves of daily accessibility in 1996 and 2010, by rail top) and by road (bottom).

6. Accessibility Indicators and Regional Economic Development

The purpose of this section is to gain first insights into the relationship between accessibility and regional socioeconomic development in Europe. Regional GDP per capita is selected as indicator representing economic output of regions (see Deliverable D4, Bökemann et al., 1997). Therefore this first and tentative assessment of the relationship between accessibility and regional economic development correlates selected accessibility indicators with GDP per capita for 1981 and 1991.

It needs to be emphasised that the bivariate analysis performed here is only a preparatory exercise for the multivariate analysis to be undertaken later in SASI.

Not surprisingly, the empirical analysis results in rather low correlations between accessibility and GDP per capita reflecting the well-known fact that location is only one factor of regional economic development. However, by temporarily eliminating characteristic groups of outlier regions and nonlinear transformation of accessibility significant increases in r^2 can be obtained.

This is demonstrated for one accessibility indicator in Figure
39. The top diagram shows the relationship between daily accessibility and GDP per capita in 1991 for all 201 SASI regions. Because no accessibility indicators were available for 1991, accessibility indicators of 1996 were used. The correlation with $r^2 = 0.14$ is extremely low. Two characteristic groups of outlier regions can be identified: Sweden and Finland have rather low accessibility but above-average economic performance, which can only be explained by non-transport factors. The new German Länder have average accessibility but their economic performance is poor due to their problems of transition from a planned to a market economy. By removing these specific cases from the analysis, the correlation coefficient is more than doubled to $r^2 = 0.32$ (centre) The resulting correlation diagram suggests a non-linear relationship. By transforming the accessibility indices by $A_i = A_i^{\alpha}$, the correlation increases to $r^2 = 0.40$ (bottom).

Except for travel cost accessibility this procedure results in significant increases in correlation between accessibility and GDP per capita. Therefore all results reported in this section are based on the temporary exclusion of Sweden and Finland and the new German Länder and non-linear transformation of accessibility.

Average travel time and GDP per capita

Figure 40 presents the correlation between average rail travel time to cities with a population of more than 250,000 and GDP per capita for 1981 (top) and 1991 (bottom). Again accessibility of 1996 is used. A clear negative relationship is visible expressed by high correlation coefficients with $r^2 = 0.60$ for 1981 and $r^2 = 0.57$ for 1991. Regions in Portugal and Greece have the longest travel times and are the poorest regions within the European Union. However, some regions in Scotland show above-average economic performance, though they have long travel times. As expected, most prosperous agglomerations such as Hamburg, Frankfurt, München, Brussels and Paris are located in the European core and so belong to the regions with shortest travel times. However, there are also regions with relatively short travel times and yet poor economic performance such as Brabant Wallon in Belgium and Burgenland in Austria.

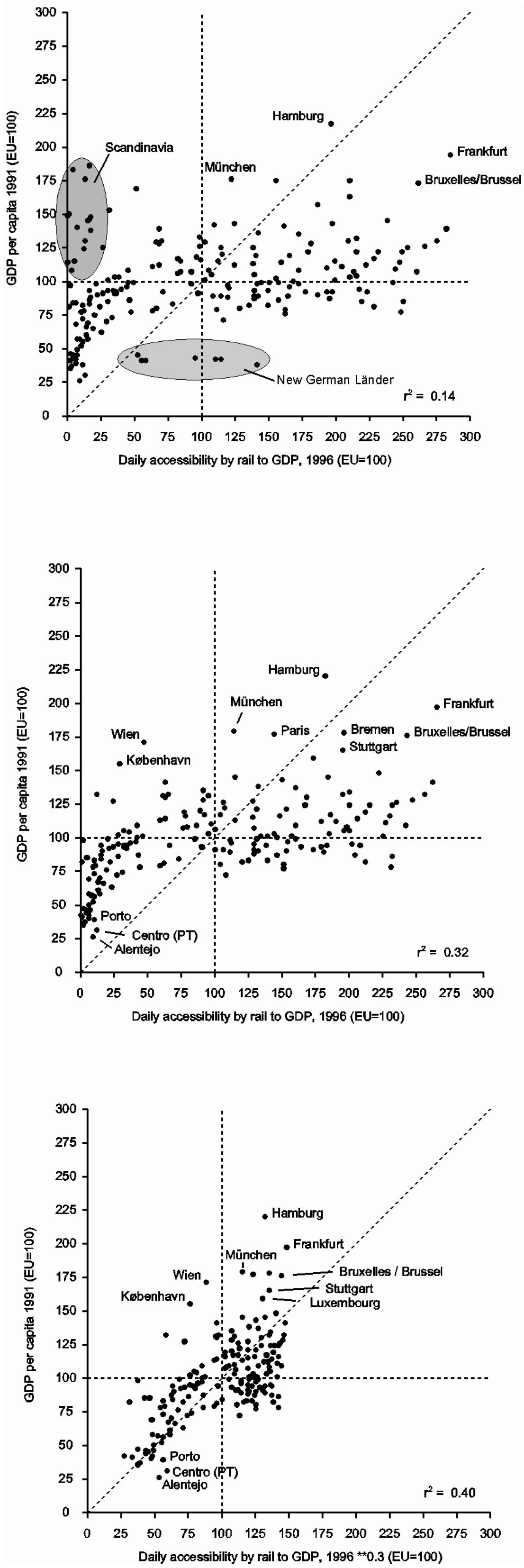


Figure 39. Correlation between daily accessibility and GDP per capita in 1991: basic correlation (top), exclusion of outlier regions (centre) and non-linear transformation of accessibility (bottom).

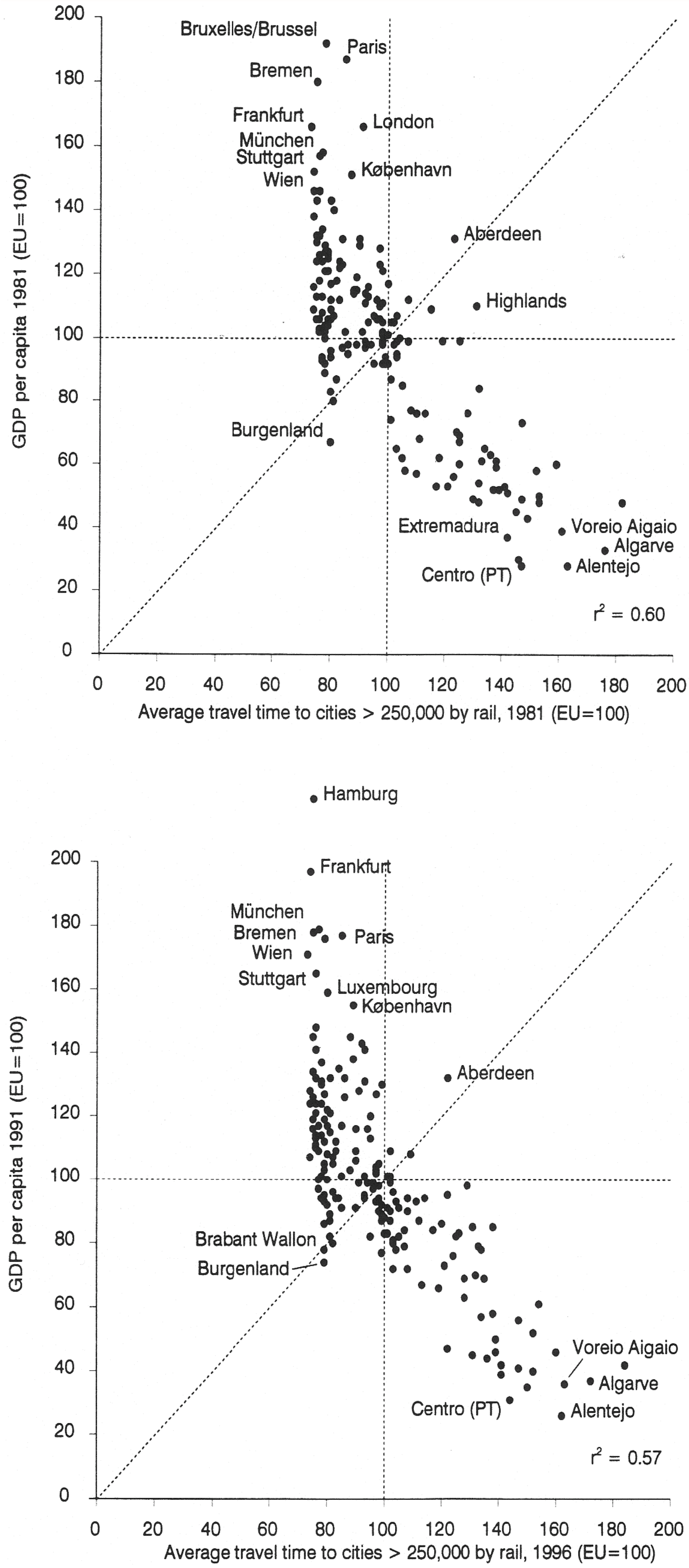


Figure 40. Average rail travel time v. GDP per capita, 1981 (top) and 1991 (bottom).

Daily accessibility and GDP per capita

The correlation between daily accessibility and GDP per capita in 1981 (r^2 = 0.43) and 1991 (r^2 = 0.33) is less than the one of travel cost. Figure 41 shows the two correlation diagrams. The poorest regions are again the least accessible regions in Greece and Portugal, the most prosperous regions are again the highly accessible major agglomerations in Belgium, France and Germany. However, some regions perform economically better than their accessibility would suggest: some of the large agglomerations and some Mediterranean islands. Some regions, however, perform economically worse than their accessibility would suggest, for instance old industrial regions in Belgium and the United Kingdom.

Potential accessibility and GDP per capita

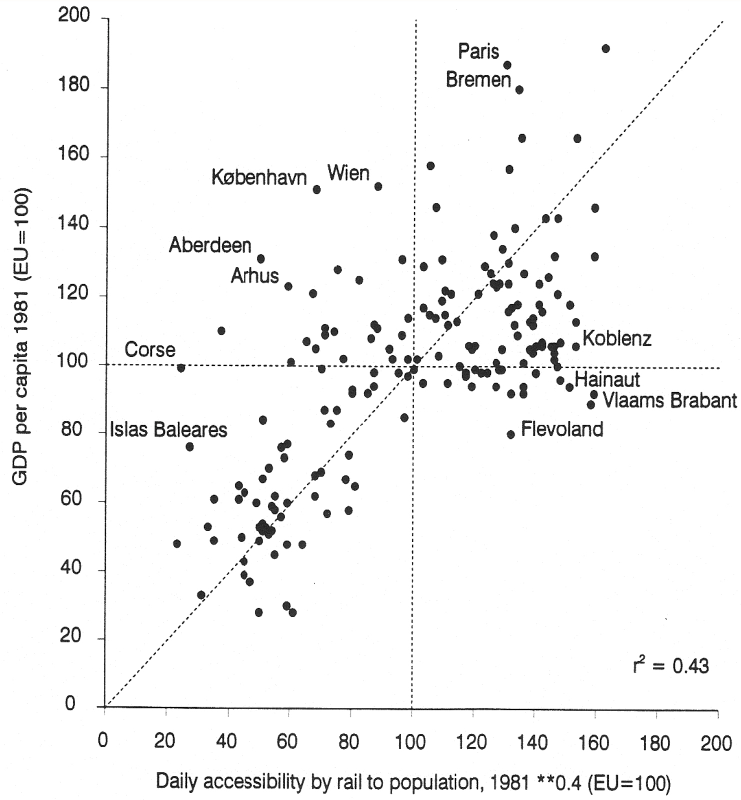
Because daily accessibility and potential accessibility are highly correlated, the correlation of potential accessibility with GDP per capita produces similar correlation diagrams in Figure 42. However, the correlations are slightly higher with r^2 = 0.47 for 1981 and r^2 = 0.35 for 1991.

Change in accessibility and GDP per capita

The relationship between accessibility and GDP per capita might be influenced by temporal dynamics. This means that not *levels* of accessibility and GDP per capita should be compared but *changes* in accessibility and *changes* in GDP per capita. However, this leads to very low correlations of $r^2 < 0.1$. However, correlating *changes* in accessibility with *levels* of GDP per capita improves the correlation. Figure 43 presents two correlation diagrams showing the effect of infrastructure on GDP per capita. The top diagram shows absolute change in potential accessibility between the no-network alternative and rail in 1981 v. GDP per capita in 1981, the lower diagram absolute change in accessibility by rail between 1981 and 1996 v. GDP per capita in 1991. In both diagrams change in accessibility is standardised by the average change in accessibility. The network effect in the top diagram and the effect of the development of the network between 1981 and 1996 are very similar, i.e. regions with high accessibility benefit most. The correlation with GDP per capita increases to r^2 = 0.57 in 1981 and r^2 = 0.48 in 1991. However, this effect may well be caused by the fact that regions with high GDP per capita have more travel demand and are more capable to finance infrastructure investments and so attract more infrastructure than poorer regions.

Overview of correlation coefficients

Table 7 summarises all correlations between accessibility and GDP per capita. Average travel time has the highest correlation followed by potential accessibility and daily accessibility. For all indicators the correlation with GDP per capita is higher in 1981 than in 1991. Even accessibility in 1996 correlates better with GDP per capita in 1981 than with GDP per capita in 1991. This might be explained by the fact that rail infrastructure development between 1991 and 1996, e.g. the French TGV or the German ICE, primarily occurred in rich regions. If not levels of accessibility but changes in accessibility are correlated with GDP per capita, correlations tend to increase.



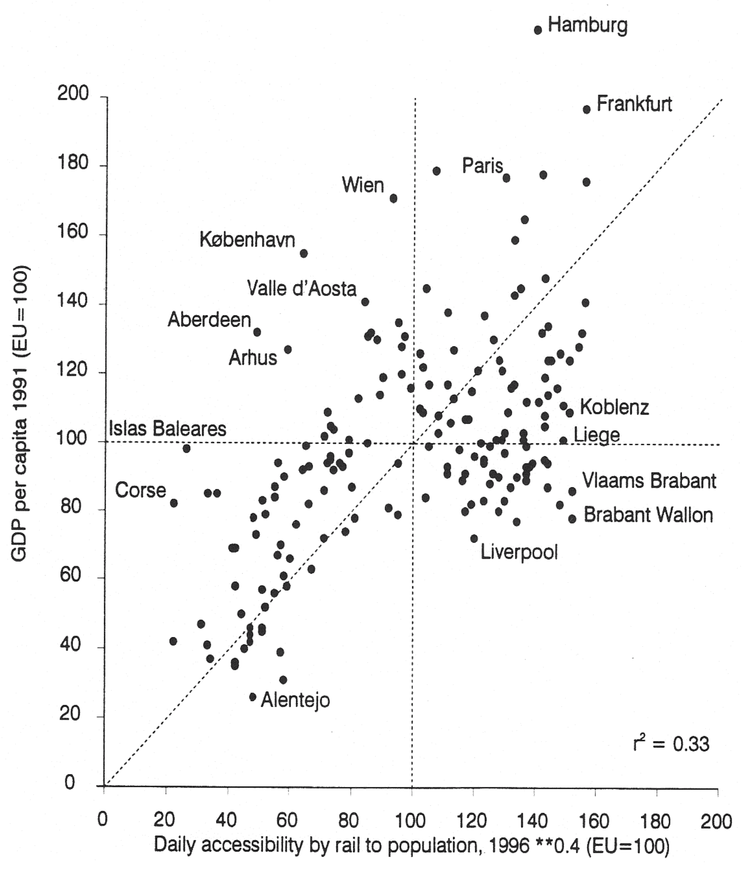
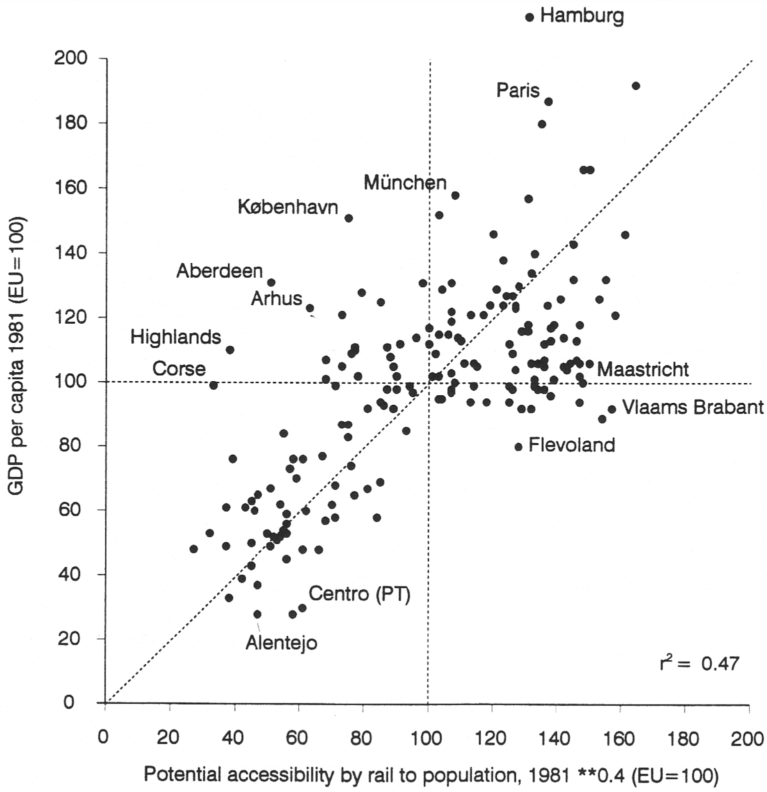


Figure 41. Daily accessibility by rail to population v. GDP per capita, 1981 (top) and 1991 (bottom).



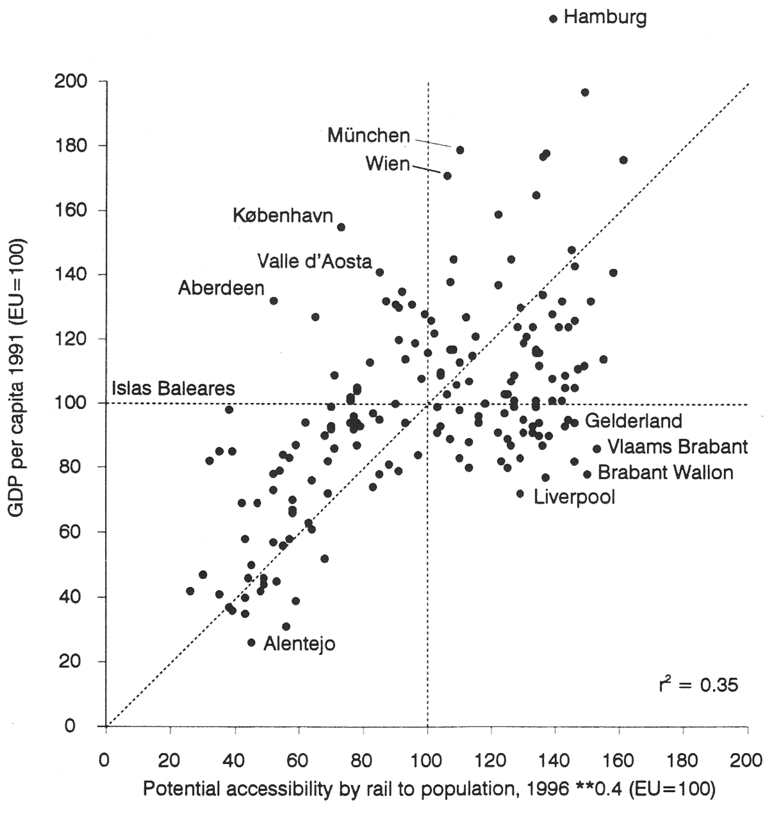


Figure 42. Potential accessibility by rail to population v. GDP per capita, 1981 (top) and 1991 (bottom).

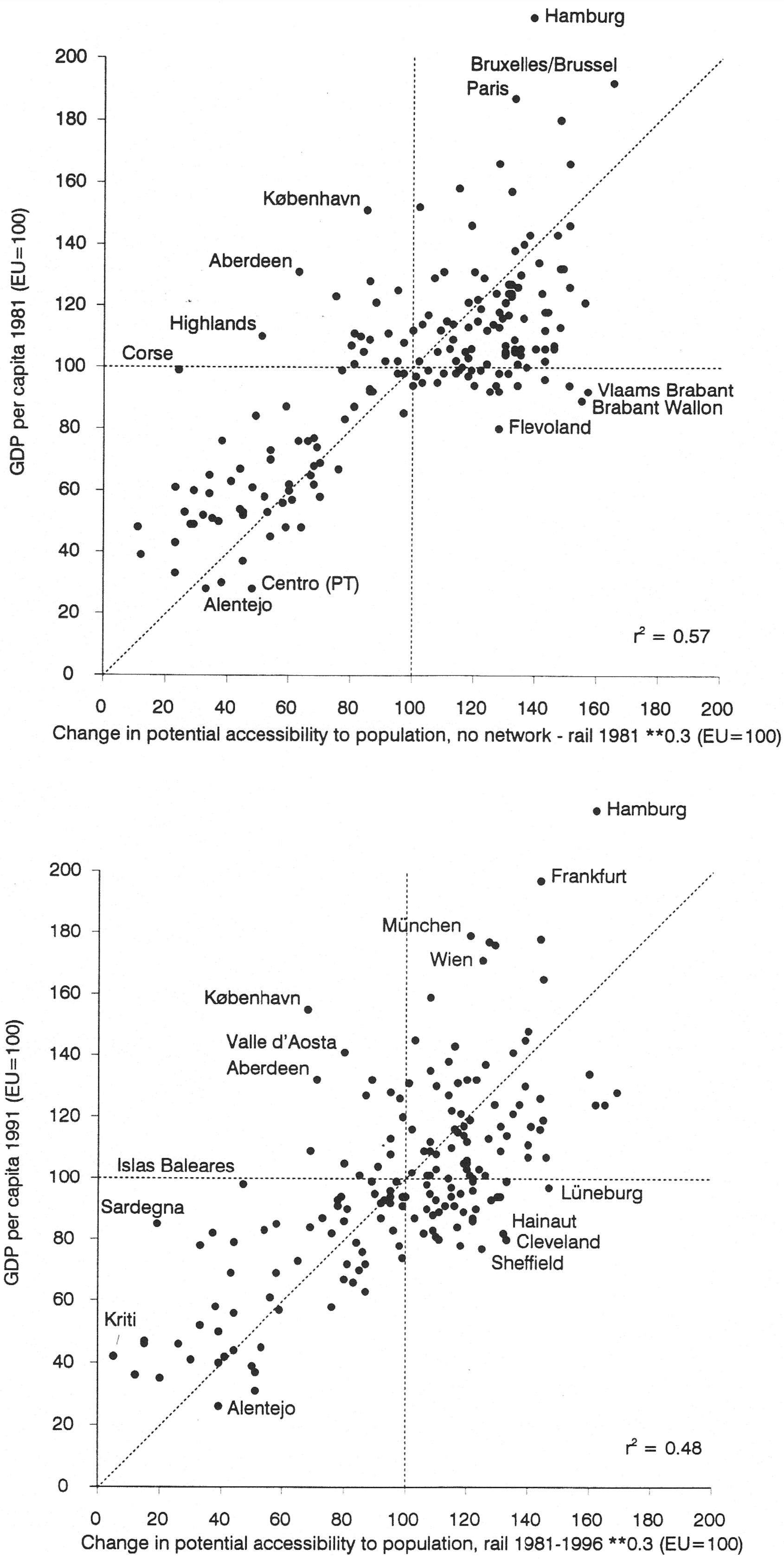


Figure 43. Accessibility potential by rail to population v. GDP per capita: change from no high-level network to 1981 (top) and growth from 1981 to 1996 (bottom).

Table 7. Overview of correlation coefficients

		GDP per capita, 1981	GDP per capita, 1991
Average travel time to cities > 250,000	Road 1996	0.51	0.48
	Rail 1981	0.60	0.57
	Rail 1996	0.58	0.57
Average travel time to cities > 1,000,000	Road 1996	0.41	0.44
	Rail 1981	0.52	0.54
	Rail 1996	0.52	0.54
Weighted average travel time to cities > 250,000	Road 1996	0.49	0.47
	Rail 1981	0.59	0.56
	Rail 1996	0.57	0.57
Weighted average travel time to cities > 1,000,000	Road 1996	0.46	0.45
	Rail 1981	0.56	0.54
	Rail 1996	0.55	0.55
Daily accessibility to population **0.4	No network	0.30	0.21
	Road 1996	0.36	0.25
	Rail 1981	0.43	0.29
	Rail 1996	0.47	0.33
Change in daily accessibility to population **0.3	1981 - no network	0.52	
	1996 - 1981		0.40
Daily accessibility to GDP **0.4	No network	0.37	0.32
	Road 1996	0.40	0.32
	Rail 1996	0.50	0.39
Potential accessibility to population **0.4	No network	0.34	0.23
	Road 1996	0.39	0.27
	Rail 1981	0.47	0.32
	Rail 1996	0.50	0.35
Change in potential accessibility to population **0.3	1981 - no network	0.57	
	1996 - 1981		0.48
Potential accessibility to GDP **0.4	No network	0.43	0.36
	Road 1996	0.45	0.35
	Rail 1996	0.55	0.43

Spatial distribution of residuals

The correlation of regional accessibility indicators with regional GDP per capita has confirmed that accessibility is only one of several, transport and non-transport, factors determining regional economic performance. It will be the task of later phases in SASI to identify these other factors and to assess their individual contribution and joint interaction.

However, it is possible already now to analyse the spatial pattern of the residuals of the correlation between accessibility and economic performance, i.e. to show which regions in Europe conform to the hypothesis that more accessible regions are economically more successful and which do not.

This can be done by classifying regions by their position in the correlation diagram, i.e. with respect to their residual or distance from the diagonal. Figure 44 shows as one example potential accessibility by rail correlated with GDP per capita in 1991 (again potential accessibility of 1996 had to be used). The data are the same as in Figure 42 (bottom) except that no nonlinear transformation of accessibility was performed in order to expose rather than minimise the residuals.

At the bottom of Figure 44 a miniature correlation diagram is shown in which the area along the diagonal and the triangles above and below the diagonal are shaded in different colours. In addition the diagram is divided into quadrants by two lines indicating the European average of accessibility and GDP per capita, respectively. The regions in the map above the diagram are shaded in the same colours as the areas in the correlation diagram, in which the dots associated with them are located. According to this classification and colour scheme the following types of region can be distinguished:

- The regions in the green buffer zone along the diagonal conform to the hypothesis that the higher the accessibility the higher the economic performance, i.e. their residuals are small. In the dark green area there are regions with above-average accessibility and GDP per capita such as Luxembourg, the southern ring of regions around Paris, East Anglia, Hamburg and Bremen and some regions in Bavaria. The regions in the light green area include most of Portugal, Wales, and some regions in northern England, southern Italy and Greece as well as border regions in Germany and Austria.

- The regions in the blue triangle below the diagonal are economically less successful than their accessibility would suggest. This group includes regions with high and very high accessibility in the centre of Europe with above-average economic performance such as London and Paris, the Randstad and most of western Germany and Berlin, but also regions with economic problems, among them many old industrial regions in England, northern France, Belgium, the Netherlands and Germany. For these regions accessibility seems to be so abundant that further improvements of it have only marginal benefits for them. The real bottlenecks for their development seem to be non-transport such as over-agglomeration diseconomies in the case of large agglomerations or an outdated economic structure in the case of old industrial cities. A special group are Mecklemburg-Vorpommern and Brandenburg, the most depressed of the new German Länder, which are still in the transition from planned to market economy and not yet in a position to take advantage of their favourable geographic location.

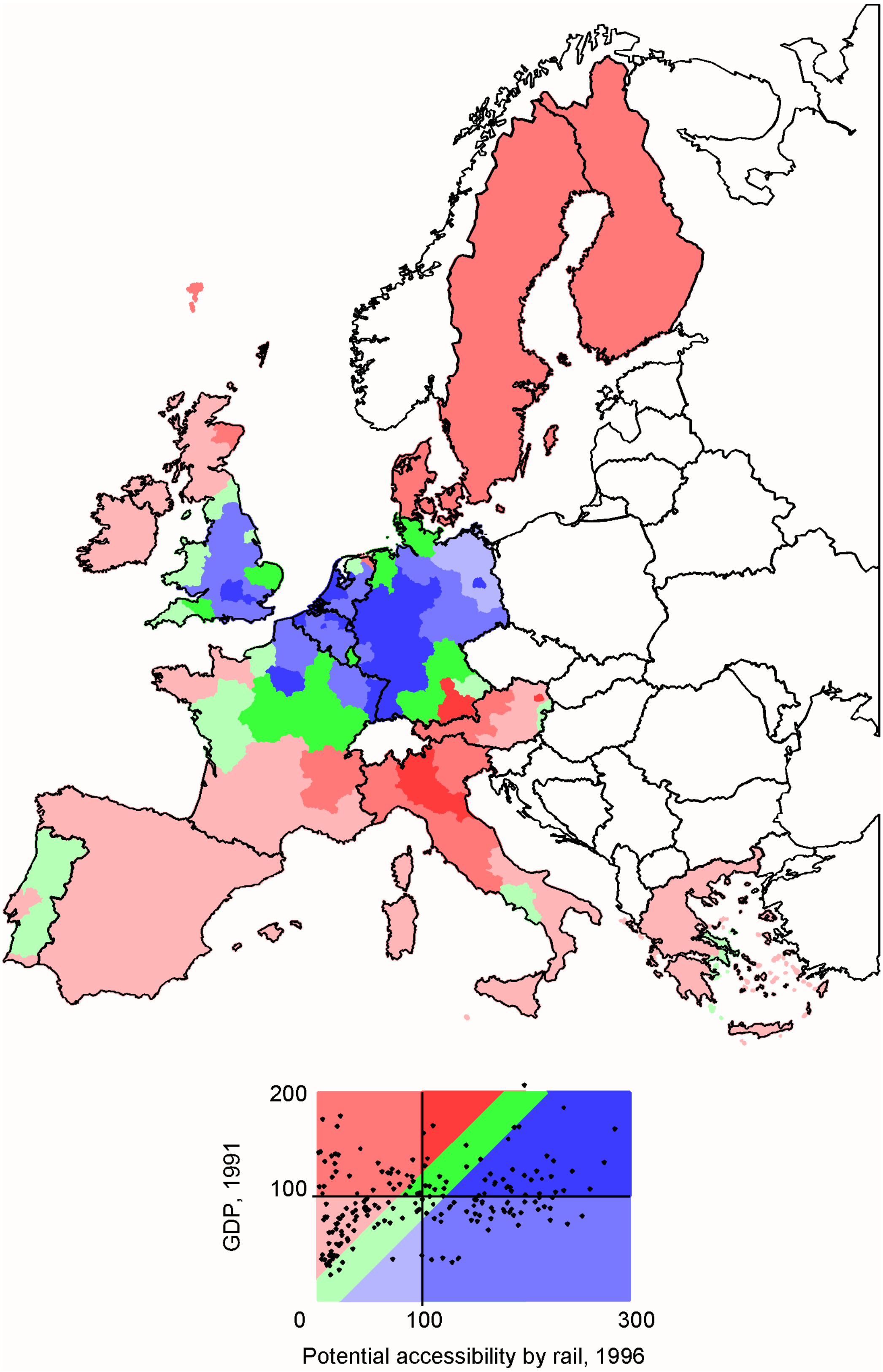


Figure 44. Spatial distribution of residuals of potential accessibility to population by rail v. GDP per capita in 1991.

- The regions in the red triangle above the diagonal are regions that economically perform better than their accessibility would suggest. Of these only some regions in northern Italy and Bavaria have above-average accessibility. Some regions, among them all Scandinavian regions, have above-average economic performance despite below-average accessibility. The largest number of regions, however, are peripheral regions in Portugal, Spain, southern France and southern Italy, Greece, Ireland, Scotland and Austria with below-average economic performance. It is possible that the relative economic success of these regions can be traced to external transfers such as support from the Structural Funds.

The above conjectures about the residuals, i.e. about the reasons why accessibility in some regions is positively associated with economic development but not in others, will have to remain tentative. It will be one of the main tasks of later phases of SASI to relate accessibility to other transport and non-transport factors determining region economic development and resume the analysis in a more comprehensive, multi-variate fashion.

7. Conclusions

This report defined, discussed and tested accessibility indicators to be used in the SASI model of regional socioeconomic development. Based on a preliminary outline of the model to be developed, the role of accessibility as the essential link between the transport infrastructure and regional socioeconomic development was identified. In its theoretical part the report proposed a typology of basic accessibility indicators with their various refinements and summarised accessibility indicators used in other studies. The theoretical part closed with a discussion of accessibility and cohesion. In its empirical part the report presented how the previously discussed accessibility indicators are implemented for 228 pan-European regions using high-resolution raster GIS methods. The accessibility indicators calculated were correlated with each other and with indicators of regional socioeconomic development.

Main results

Accessibility is the main product of a transport system. It determines the locational advantage of a region relative to all regions and so is a major factor for the social and economic development of a region. At the same time accessibility has a value by itself as an element of quality of life. Accessibility indicators therefore are a central subgroup of the socio-economic indicators discussed in Deliverable D4 of SASI (Bökemann et al., 1997).

Simple accessibility indicators consider only intraregional transport infrastructure and fail to recognise the network character of transport infrastructure linking parts of the region with each other and the region with other regions. More complex indicators distinguish between the network itself and the activities that can be reached by it. Accessibility then is a construct of two functions, one representing the activities or opportunities to be reached and one the effort, time, distance or cost needed to reach them. Depending on the way these two functions are defined, three basic types of accessibility indicator can be distinguished: *travel cost accessibility, daily accessibility* and *potential accessibility*. There is a wide range of applications of these three basic indicators differing in details of implementation.

However, most accessibility studies so far have concentrated on the accessibility of cities, i.e. network nodes which are assumed to represent the whole metropolitan area or region, and so have ignored that accessibility is continuous in space. To overcome this problem, spatially disaggregate accessibility indicators using raster GIS methods based on synthetic raster data generated by microsimulation were calculated for the three basic indicator types for two networks (road and rail) plus a third 'no-network' alternative and two or three years, 1981, 1996 and 2010 and aggregated for 201 regions in the European Union.

These indicators were then compared with each other and over time. The results are summarised as follows:

- Of the three types of accessibility indicator, daily accessibility and potential accessibility are highly correlated, whereas travel cost accessibility seems to measure a different aspect of accessibility.

- For the same indicator, the difference between road and rail accessibility is small but increases with the completion of the European high-speed rail network.
- Travel cost accessibility is the indicator least sensitive to transport infrastructure impreve-ments.

- The differences between unweighted and weighted average travel time accessibility are negligible.

- It does not matter much whether a population of 250,000 or 1,000,000 is taken as minimum destination size for travel cost accessibility.

- For all three indicators, accessibility to population and accessibility to GDP are highly correlated.

- The change in rail accessibility between 1981 and 1996 has in general been much less than the likely change between 1996 and 2010.

- The motorway projects planned until 2010 are likely to have little impact on the rank order of regions with respect to accessibility, however, then planned high-speed rail network is likely to advantage particular regions with the effect that they move up in the accessibility rank order.

- For both road and rail, accessibility tends to become more polarised between central and peripheral regions between 1996 and 2010, even though some statistical measures of cohesion such as standard deviation and GINI coefficient show a slight convergence in accessibility.

The last result confirms earlier studies with less detailed networks (Spiekermann and Wegener, 1996) that in particular the European high-speed rail system under development, even though it contains new lines connecting peripheral regions to the European core, will stabilise if not increase the accessibility advantage of the core regions. They also suggest that the statistical indicators conventionally used for measuring interregional disparities, standard deviation and GINI coefficient, may not sufficient to evaluate spatial polarisation processes of the kind examined here.

Selected accessibility indicators were finally correlated with regional GDP per capita as one indicator of regional socioeconomic development. As expected, bivariate correlation between accessibility and GDP per capita was found to be low, even though signifiant increases in correlation can be obtained by eliminating outlier regions and non-linear transformation of accessibility. These results confirmed the well-known fact that accessibility, i.e. transport cost, is no longer the most important factor determining location choice of firms but rather one of many transport and non-transport, quantitative and qualitative location factors.

Nevertheless, the correlation analysis also showed that accessibility is unequivocally positively associated with GDP per capita, i.e. that location still matters. However, one should be aware that correlation measures do not provide causal explanations but merely state that two phenomena with a certain probability tend to occur together. This means that even where accessibility is positively correlated with economic development, it cannot be assumed that accessibility is the cause and economic activity the effect. It seems more appropriate to see accessibility as an enabling condition necessary to facilitate economic development but which, if present, does not guarantee that development will occur.

Conclusions for further work

The results of the analytical work presented in this report are preliminary and should be used with caution.

The main reason for this reservation is that - by intention - the analysis in this phase of the work has been concentrated on accessibility and has ignored the interaction of accessibility with other, non-transport location factors. Only by taking these other factors into account will it be possible to 'explain' the existing 'paradoxical' combinations of high accessibility and industrial decline (as for instance in eastern Germany) or of remoteness and high economic prosperity (as for instance in Scandinavia).

The main task of further work in SASI will therefore be to bring the discussions on transport and non-transport location factors to a synthesis.

In substantive terms this implies that the non-transport factors tentatively earmarked for inclusion into the model (see Linneker, 1997 and Sections 2.4 and 6 of this report) such as regional infrastructure, regional settlement structure and regional labour supply as well as exogenous net transfers such as support from national sources or the Structural Funds of the European Union will be thoroughly examined with respect to their impacts on regional development.

Which of the accessibility indicators assessed in this report will eventually be selected for inclusion in the model cannot be determined at this time. On the one hand the selection of accessibility indicators will depend on their statistical interaction with the other transport and non-transport factors of the regional production function. On the other hand the accessibiliy indicators selected need to be sensitive to the whole range of transport investments and transport infrastructure improvements to be studied with the SASI model.

In methodological terms essentially two methodological instruments will be employed. One tool will be multivariate statistical analysis such as multiple linear and nonlinear regression by which the joint contribution of non-transport and transport variables to the statistical explanation of regional GDP in the regional production function will be examined. The other tool is experimental work with the dynamic SASI simulation itself by which lagged feedback relations that cannot be detected by cross-sectional analysis will be explored.

8. References

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9. Annex

The Annex contains a list of the regions used in the SASI model as discussed in Section 2.4.2 (Table A1) and tabulations of the correlation coefficients (r^2) discussed in Section 5.2 (Tables A2-A5).

Table A1. SASI regions

Country	No	Region	NUTS 1995 or equivalent code	Internal/ external	Centroid
Österreich	1	Burgenland	AT11	Internal	Eisenstadt
	2	Niederösterreich	AT12	Internal	St.Pölten
	3	Wien	AT13	Internal	Wien
	4	Kärnten	AT21	Internal	Klagenfurt
	5	Steiermark	AT22	Internal	Graz
	6	Oberösterreich	AT31	Internal	Linz
	7	Salzburg	AT32	Internal	Salzburg
	8	Tirol	AT33	Internal	Innsbruck
	9	Vorarlberg	AT34	Internal	Dornbirn
Belgique/	10	Bruxelles/Brussel	BE1	Internal	Bruxelles/Brussel
België	11	Antwerpen	BE21	Internal	Antwerpen
	12	Limburg (BE)	BE22	Internal	Hasselt
	13	Oost-Vlaanderen	BE23	Internal	Gent
	14	Vlaams Brabant	BE24	Internal	Leuven
	15	West-Vlaanderen	BE25	Internal	Brugge
	16	Brabant Wallon	BE31	Internal	Wavre
	17	Hainaut	BE32	Internal	Charleroi
	18	Liege	BE33	Internal	Liege
	19	Luxembourg (BE)	BE34	Internal	Arlon
	20	Namur	BE35	Internal	Namur
Deutschland	21	Stuttgart	DE11	Internal	Stuttgart
	22	Karlsruhe	DE12	Internal	Mannheim
	23	Freiburg	DE13	Internal	Freiburg im Breisgau
	24	Tübingen	DE14	Internal	Tübingen
	25	Oberbayern	DE21	Internal	München
	26	Niederbayern	DE22	Internal	Landshut
	27	Oberpfalz	DE23	Internal	Regensburg
	28	Oberfranken	DE24	Internal	Bamberg
	29	Mittelfranken	DE25	Internal	Nürnberg
	30	Unterfranken	DE26	Internal	Würzburg
	31	Schwaben	DE27	Internal	Augsburg
	32	Berlin	DE3	Internal	Berlin
	33	Brandenburg	DE4	Internal	Potsdam
	34	Bremen	DE5	Internal	Bremen
	35	Hamburg	DE6	Internal	Hamburg
	36	Darmstadt	DE71	Internal	Frankfurt am Main
	37	Giessen	DE72	Internal	Giessen
	38	Kassel	DE73	Internal	Kassel
	39	Mecklenburg-Vorpommern	DE8	Internal	Rostock
	40	Braunschweig	DE91	Internal	Braunschweig
	41	Hannover	DE92	Internal	Hannover
	42	Lüneburg	DE93	Internal	Lüneburg
	43	Weser-Ems	DE94	Internal	Oldenburg
	44	Düsseldorf	DEA1	Internal	Düsseldorf
	45	Köln	DEA2	Internal	Köln
	46	Münster	DEA3	Internal	Münster
	47	Detmold	DEA4	Internal	Bielefeld
	48	Arnsberg	DEA5	Internal	Dortmund
	49	Koblenz	DEB1	Internal	Koblenz
	50	Trier	DEB2	Internal	Trier
	51	Rheinhessen-Pfalz	DEB3	Internal	Mainz
	52	Saarland	DEC	Internal	Saarbrücken

Table A1. SASI regions (continued)

Country	No	Region	NUTS 1995 or equivalent code	Internal/ external	Centroid
Deutschland	53	Sachsen	DED	Internal	Leipzig
(continued)	54	Dessau	DEE1	Internal	Dessau
	55	Halle	DEE2	Internal	Halle
	56	Magdeburg	DEE3	Internal	Magdeburg
	57	Schleswig-Holstein	DEF	Internal	Kiel
	58	Thüringen	DEG	Internal	Erfurt
Danmark	59	Hovedstadtsregionen and Øst for Storebælt	DK11 (DK001-7)	Internal	København
	60	Vest for Storebælt	DK12 (DK008-F)	Internal	Arhus
España	61	Galicia	ES11	Internal	Santiago
	62	Principado de Asturias	ES12	Internal	Oviedo
	63	Cantabria	ES13	Internal	Santander
	64	Pais Vasco	ES21	Internal	Bilbao
	65	Comunidad Foral de Navarra	ES22	Internal	Pamplona
	66	La Rioja	ES23	Internal	Logrono
	67	Aragón	ES24	Internal	Zaragoza
	68	Comunidad de Madrid	ES3	Internal	Madrid
	69	Castilla y Leon	ES41	Internal	Valladolid
	70	Castilla-la Mancha	ES42	Internal	Toledo
	71	Extremadura	ES43	Internal	Mérida
	72	Cataluña	ES51	Internal	Barcelona
	73	Comunidad Valenciana	ES52	Internal	Valencia
	74	Islas Baleares	ES53	Internal	Palma de Mallorca
	75	Andalucia	ES61	Internal	Sevilla
	76	Región de Murcia	ES62	Internal	Murcia
Suomi/	77	Uusimaa	FI11	Internal	Helsinki
Finland	78	Etelä-Suomi	FI12	Internal	Tampere
	79	Itä-Suomi	FI13	Internal	Kuopio
	80	Väli-Suomi	FI14	Internal	Jyväskylä
	81	Pohjois-Suomi	FI15	Internal	Oulu
	82	Ahvenanmaa/Åland	FI2	Internal	Maarianhamina
France	83	Île de France	FR1	Internal	Paris
	84	Champagne-Ardenne	FR21	Internal	Reims
	85	Picardie	FR22	Internal	Amiens
	86	Haute-Normandie	FR23	Internal	Le Havre
	87	Centre	FR24	Internal	Orleans
	88	Basse-Normandie	FR25	Internal	Caen
	89	Bourgogne	FR26	Internal	Dijon
	90	Nord-Pas-de-Calais	FR3	Internal	Lille
	91	Lorraine	FR41	Internal	Metz
	92	Alsace	FR42	Internal	Strasbourg
	93	Franche-Comté	FR43	Internal	Besancon
	94	Pays de la Loire	FR51	Internal	Nantes
	95	Bretagne	FR52	Internal	Brest
	96	Poitou-Charentes	FR53	Internal	Poitiers
	97	Aquitaine	FR61	Internal	Bordeaux
	98	Midi-Pyrénées	FR62	Internal	Toulouse
	99	Limousin	FR63	Internal	Limoges
	100	Rhône-Alpes	FR71	Internal	Lyon
	101	Auvergne	FR72	Internal	Clermont-Ferrand
	102	Languedoc-Roussillon	FR81	Internal	Montpellier
	103	Provence-Alpes-Côte d`Azur	FR82	Internal	Marseille
	104	Corse	FR83	Internal	Ajaccio

Table A1. SASI regions (continued)

Country	No	Region	NUTS 1995 or equivalent code	Internal/ external	Centroid
Ellada	105	Anatoliki Makedonia, Thraki	GR11	Internal	Kavala
	106	Kentriki Makedonia	GR12	Internal	Thessaloniki
	107	Dytiki Makedonia	GR13	Internal	Kozani
	108	Thessalia	GR14	Internal	Larissa
	109	Ipeiros	GR21	Internal	Ioannina
	110	Ionia Nisia	GR22	Internal	Kerkyra
	111	Dytiki Ellada	GR23	Internal	Patrai
	112	Sterea Ellada	GR24	Internal	Lamia
	113	Peloponnisos	GR25	Internal	Tripolis
	114	Attiki	GR3	Internal	Athinai
	115	Voreio Aigaio	GR41	Internal	Mytilini
	116	Notio Aigaio	GR42	Internal	Ermoupolis
	117	Kriti	GR43	Internal	Irakleion
Ireland	118	Dublin, Mid-East	IE11 (IE002-3)	Internal	Dublin
	119	Border, Midland-West	IE12 (IE001, IE004, IE008)	Internal	Galway
	120	Mid-West, South-East, South-West	IE13 (IE005-7)	Internal	Cork
Italia	121	Piemonte	IT11	Internal	Torino
	122	Valle d'Aosta	IT12	Internal	Aosta
	123	Liguria	IT13	Internal	Genova
	124	Lombardia	IT2	Internal	Milano
	125	Trentino-Alto Adige	IT31	Internal	Bolzano
	126	Veneto	IT32	Internal	Venezia
	127	Friuli-Venezia Giulia	IT33	Internal	Trieste
	128	Emilia-Romagna	IT4	Internal	Bologna
	129	Toscana	IT51	Internal	Firenze
	130	Umbria	IT52	Internal	Perugia
	131	Marche	IT53	Internal	Ancona
	132	Lazio	IT6	Internal	Roma
	133	Abruzzo	IT71	Internal	Pescara
	134	Molise	IT72	Internal	Campobasso
	135	Campania	IT8	Internal	Napoli
	136	Puglia	IT91	Internal	Bari
	137	Basilicata	IT92	Internal	Potenza
	138	Calabria	IT93	Internal	Reggio
	139	Sicilia	ITA	Internal	Palermo
	140	Sardegna	ITB	Internal	Cagliari
Luxembourg	141	Luxembourg	LU	Internal	Luxembourg
Nederland	142	Groningen	NL11	Internal	Groningen
	143	Friesland	NL12	Internal	Leeuwarden
	144	Drenthe	NL13	Internal	Emmen
	145	Overijssel	NL21	Internal	Enschede
	146	Gelderland	NL22	Internal	Apeldoorn
	147	Flevoland	NL23	Internal	Lelystad
	148	Utrecht	NL31	Internal	Utrecht
	149	Noord-Holland	NL32	Internal	Amsterdam
	150	Zuid-Holland	NL33	Internal	Rotterdam
	151	Zeeland	NL34	Internal	Middelburg
	152	Noord-Brabant	NL41	Internal	Eindhoven
	153	Limburg (NL)	NL42	Internal	Maastricht

Table A1. SASI regions (continued)

Country	No	Region	NUTS 1995 or equivalent code	Internal/ external	Centroid
Portugal	154	Norte	PT11	Internal	Porto
	155	Centro (PT)	PT12	Internal	Coimbra
	156	Lisboa e Vale do Tejo	PT13	Internal	Lisboa
	157	Alentejo	PT14	Internal	Evora
	158	Algarve	PT15	Internal	Faro
Sverige	159	Stockholm	SE01	Internal	Stockholm
	160	Östra Mellansverige	SE02	Internal	Uppsala
	161	Småland med Öarna	SE03	Internal	Jönköping
	162	Sydsverige	SE04	Internal	Malmö
	163	Västsverige	SE05	Internal	Göteborg
	164	Norra Mellansverige	SE06	Internal	Gävle
	165	Mellersta Norrland	SE07	Internal	Sundsvall
	166	Övre Norrland	SE08	Internal	Umea
United Kingdom	167	Cleveland, Durham	UK11	Internal	Middlesbrough
	168	Cumbria	UK12	Internal	Carlisle
	169	Northumberland, Tyne and Wear	UK13	Internal	Newcastle upon Tyne
	170	Humberside	UK21	Internal	Kingston upon Hull
	171	North Yorkshire	UK22	Internal	Harrogate
	172	South Yorkshire	UK23	Internal	Sheffield
	173	West Yorkshire	UK24	Internal	Leeds
	174	Derbyshire, Nottinghamshire	UK31	Internal	Nottingham
	175	Leicestershire, Northamptonshire	UK32	Internal	Leicester
	176	Lincolnshire	UK33	Internal	Lincoln
	177	East Anglia	UK4	Internal	Cambridge
	178	Bedfordshire, Hertfordshire	UK51	Internal	Luton
	179	Berkshire, Buckinghamshire, Oxfordshire	UK52	Internal	Reading
	180	Surrey, East-West Sussex	UK53	Internal	Brigthon
	181	Essex	UK54	Internal	Southend-On-Sea
	182	Greater London	UK55	Internal	London
	183	Hampshire, Isle of Wight	UK56	Internal	Southampton
	184	Kent	UK57	Internal	Maidstone
	185	Avon, Gloucestershire, Wiltshire	UK61	Internal	Bristol
	186	Cornwall, Devon	UK62	Internal	Plymouth
	187	Dorset, Somerset	UK63	Internal	Bournemouth
	188	Hereford & Worcester, Warwickshire	UK71	Internal	Warwick
	189	Shropshire, Staffordshire	UK72	Internal	Newcastle-u.-Lyme
	190	West Midlands (County)	UK73	Internal	Birmingham
	191	Cheshire	UK81	Internal	Warrington
	192	Greater Manchester	UK82	Internal	Manchester
	193	Lancashire	UK83	Internal	Blackpool
	194	Merseyside	UK84	Internal	Liverpool
	195	Clwyd, Dyfed, Gwynedd, Powys	UK91	Internal	Wrexham Maelor
	196	Gwent, Mid-South-West Glamorgan	UK92	Internal	Cardiff
	197	Borders, Central, Fife, Lothian, Tayside	UKA1	Internal	Edinburgh
	198	Dumfries & Galloway, Strathclyde	UKA2	Internal	Glasgow
	199	Highlands, Islands	UKA3	Internal	Inverness
	200	Grampian	UKA4	Internal	Aberdeen
	201	Northern Ireland	UKB	Internal	Belfast

Table A1. SASI regions (continued)

Country	No	Region	NUTS 1995 or equivalent code	Internal/ external	Centroid
Shqipëria	202	Shqipëria	AL	External	Tiranë
Bosna i Hercegovina	203	Bosna i Hercegovina	BA	External	Sarajevo
B□lgarija	204	B□lgarija	BG	External	Sofija
Belarus	205	Belarus	BY	External	Minsk
Schweiz	206	Schweiz (West)	CH1	External	Bern
	207	Schweiz (East)	CH2	External	Zürich
□esko	208	□esko	CZ	External	Praha
Eesti	209	Eesti	EE	External	Tallinn
Hrvatska	210	Hrvatska	HR	External	Zagreb
Magyarország	211	Magyarország	HU	External	Budapest
Island	212	Island	IS	External	Reykjavik
Lietuva	213	Lietuva	LT	External	Vilnius
Latvija	214	Latvija	LV	External	Riga
Moldova	215	Moldova	MD	External	Chisinau
Republica Makedonija	216	Makedonija	MK	External	Skopje
Norge	217	Norge	NO	External	Oslo
Polska	218	Polska (East)	PL1	External	Warszawa
	219	Polska (North-West)	PL2	External	Poznan
	220	Polska (South-West)	PL3	External	Wroclaw
România	221	România	RO	External	Bucuresti
Rossija	222	Rossija (Moskva)	RU1	External	Moskva
	223	St. Peterburg	RU2	External	St. Peterburg
Slovenija	224	Slovenija	SI	External	Ljubljana
Slovensko	225	Slovensko	SK	External	Bratislava
Türkiye	226	Türkiye	TR	External	Istanbul
Ukraina	227	Ukraina	UA	External	Kyiv
Jugoslavija	228	Jugoslavija	YU	External	Beograd
West Africa and the Americas	229	America	AM	External	Model node
East Africa, Asia, Australasia	230	Asia	AS	External	Model node
Egypt and the Middle East	231	Middle East	ME	External	Cairo
Morocco, Algeria, Tunisia, Libya	232	North Africa	NA	External	Alger

Note:

The system of regions consists of 232 regions. There are 201 'internal' regions. Of these there are 196 NUTS-2 regions for all EU countries except Danmark and Ireland. NUTS-0/1/2 regions DK (Danmark) and IE (Ireland) were further subdivided into two and three groups of NUTS-3 regions, respectively, because of modelling requirements. NUTS-2 region ES63 (Ceuta e Mellila) and NUTS-1 regions ES7 (Canarias), FR9 (Départements d'outre mer), PT2 (Açores) and PT3 (Madeira), which are not part of the European continent, are not included in the system of regions. There are 27 'external' regions for other European countries outside the EU. Of theses, 20 countries are handled as whole countries. Three countries are further subdivided: Poland into three regions, Switzerland into two regions, and Russia has a separate region for St. Peterburg. There are four external regions for the rest of the world indicating the direction from where commodity flows enter or leave Europe.

Table A2. Correlation (r^2) between average travel time and other accessibility indicators

		Average travel time to cities > 250,000					Average travel time to cities > 1,000,000				
		Road 1996	Road 2010	Rail 1981	Rail 1996	Rail 2010	Road 1996	Road 2010	Rail 1981	Rail 1996	Rail 2010
Average travel time to cities > 250,000	Road 1996	1.00	0.99	0.93	0.93	0.87	0.96	0.93	0.92	0.93	0.91
	Road 2010	0.99	1.00	0.90	0.90	0.85	0.95	0.95	0.91	0.91	0.90
	Rail 1981	0.93	0.90	1.00	1.00	0.92	0.84	0.81	0.95	0.95	0.92
	Rail 1996	0.93	0.90	1.00	1.00	0.94	0.84	0.80	0.94	0.95	0.93
	Rail 2010	0.87	0.85	0.92	0.94	1.00	0.76	0.73	0.83	0.85	0.97
Average travel time to cities > 1,000,000	Road 1996	0.96	0.95	0.84	0.84	0.76	1.00	0.98	0.92	0.93	0.86
	Road 2010	0.93	0.95	0.81	0.80	0.73	0.98	1.00	0.90	0.90	0.84
	Rail 1981	0.92	0.91	0.95	0.94	0.83	0.92	0.90	1.00	1.00	0.90
	Rail 1996	0.93	0.91	0.95	0.95	0.85	0.93	0.90	1.00	1.00	0.92
	Rail 2010	0.91	0.90	0.92	0.93	0.97	0.86	0.84	0.90	0.92	1.00
Weighted average travel time to cities > 250,000	Road 1996	1.00	0.99	0.92	0.92	0.85	0.97	0.95	0.93	0.94	0.90
	Road 2010	0.97	0.99	0.88	0.88	0.81	0.96	0.97	0.91	0.91	0.88
	Rail 1981	0.93	0.91	1.00	0.99	0.90	0.86	0.83	0.97	0.97	0.92
	Rail 1996	0.93	0.91	0.99	1.00	0.92	0.86	0.83	0.96	0.97	0.93
	Rail 2010	0.89	0.87	0.93	0.94	1.00	0.79	0.77	0.86	0.87	0.98
Weighted average travel time to cities > 1,000,000	Road 1996	0.98	0.98	0.89	0.88	0.80	0.99	0.98	0.94	0.94	0.88
	Road 2010	0.93	0.97	0.82	0.82	0.74	0.96	0.99	0.89	0.90	0.83
	Rail 1981	0.92	0.91	0.97	0.96	0.85	0.89	0.87	0.99	0.99	0.90
	Rail 1996	0.92	0.91	0.97	0.97	0.87	0.89	0.87	0.98	0.99	0.92
	Rail 2010	0.90	0.90	0.93	0.94	0.98	0.83	0.82	0.89	0.90	0.99
Daily accessi-bility to population	No network	0.39	0.37	0.39	0.39	0.37	0.30	0.28	0.33	0.32	0.33
	Road 1996	0.48	0.46	0.47	0.46	0.43	0.38	0.36	0.40	0.39	0.39
	Road 2010	0.48	0.47	0.48	0.47	0.44	0.39	0.37	0.41	0.40	0.40
	Rail 1981	0.47	0.46	0.49	0.48	0.45	0.37	0.35	0.41	0.41	0.40
	Rail 1996	0.52	0.51	0.54	0.54	0.49	0.42	0.40	0.47	0.46	0.45
	Rail 2010	0.61	0.61	0.62	0.62	0.58	0.53	0.52	0.56	0.57	0.57
Daily accessi-bility to GDP	No network	0.41	0.39	0.42	0.41	0.39	0.33	0.31	0.36	0.35	0.36
	Road 1996	0.48	0.47	0.48	0.47	0.44	0.40	0.38	0.41	0.41	0.40
	Rail 1996	0.53	0.52	0.55	0.55	0.50	0.44	0.42	0.48	0.48	0.47
Potential accessi-bility to population	No network	0.37	0.35	0.38	0.38	0.36	0.29	0.27	0.32	0.31	0.32
	Road 1996	0.47	0.45	0.47	0.46	0.43	0.37	0.35	0.39	0.39	0.39
	Road 2010	0.48	0.47	0.48	0.47	0.44	0.38	0.36	0.40	0.40	0.40
	Rail 1981	0.47	0.45	0.49	0.48	0.45	0.37	0.35	0.41	0.41	0.41
	Rail 1996	0.51	0.50	0.54	0.53	0.49	0.41	0.39	0.46	0.46	0.45
	Rail 2010	0.61	0.60	0.62	0.62	0.59	0.53	0.51	0.56	0.56	0.57
Potential accessi-bility to GDP	No network	0.39	0.38	0.41	0.40	0.39	0.32	0.29	0.35	0.35	0.35
	Road 1996	0.48	0.47	0.48	0.47	0.44	0.39	0.37	0.41	0.41	0.41
	Rail 1996	0.53	0.52	0.55	0.55	0.51	0.44	0.42	0.48	0.48	0.48

Table A3. Correlation (r^2) between weighted average travel time and other accessibility indicators

		Weighted average travel time to cities > 250,000					Weighted average travel time to cities > 1,000,000				
		Road 1996	Road 2010	Rail 1981	Rail 1996	Rail 2010	Road 1996	Road 2010	Rail 1981	Rail 1996	Rail 2010
Average travel time to cities > 250,000	Road 1996	1.00	0.97	0.93	0.93	0.89	0.98	0.93	0.92	0.92	0.90
	Road 2010	0.99	0.99	0.91	0.91	0.87	0.98	0.97	0.91	0.91	0.90
	Rail 1981	0.92	0.88	1.00	0.99	0.93	0.89	0.82	0.97	0.97	0.93
	Rail 1996	0.92	0.88	0.99	1.00	0.94	0.88	0.82	0.96	0.97	0.94
	Rail 2010	0.85	0.81	0.90	0.92	1.00	0.80	0.74	0.85	0.87	0.98
Average travel time to cities > 1,000,000	Road 1996	0.97	0.96	0.86	0.86	0.79	0.99	0.96	0.89	0.89	0.83
	Road 2010	0.95	0.97	0.83	0.83	0.77	0.98	0.99	0.87	0.87	0.82
	Rail 1981	0.93	0.91	0.97	0.96	0.86	0.94	0.89	0.99	0.98	0.89
	Rail 1996	0.94	0.91	0.97	0.97	0.87	0.94	0.90	0.99	0.99	0.90
	Rail 2010	0.90	0.88	0.92	0.93	0.98	0.88	0.83	0.90	0.92	0.99
Weighted average travel time to cities > 250,000	Road 1996	1.00	0.98	0.93	0.93	0.87	0.99	0.96	0.93	0.93	0.89
	Road 2010	0.98	1.00	0.89	0.90	0.84	0.99	0.99	0.91	0.91	0.87
	Rail 1981	0.93	0.89	1.00	1.00	0.92	0.91	0.85	0.99	0.99	0.93
	Rail 1996	0.93	0.90	1.00	1.00	0.93	0.90	0.85	0.98	0.99	0.94
	Rail 2010	0.87	0.84	0.92	0.93	1.00	0.83	0.77	0.88	0.89	0.99
Weighted average travel time to cities > 1,000,000	Road 1996	0.99	0.99	0.91	0.90	0.83	1.00	0.98	0.92	0.92	0.87
	Road 2010	0.96	0.99	0.85	0.85	0.77	0.98	1.00	0.88	0.89	0.82
	Rail 1981	0.93	0.91	0.99	0.98	0.88	0.92	0.88	1.00	1.00	0.91
	Rail 1996	0.93	0.91	0.99	0.99	0.89	0.92	0.89	1.00	1.00	0.92
	Rail 2010	0.89	0.87	0.93	0.94	0.99	0.87	0.82	0.91	0.92	1.00
Daily accessi-bility to population	No network	0.37	0.35	0.38	0.37	0.36	0.34	0.31	0.35	0.34	0.35
	Road 1996	0.46	0.44	0.46	0.45	0.42	0.43	0.39	0.43	0.42	0.41
	Road 2010	0.47	0.45	0.47	0.46	0.43	0.43	0.40	0.44	0.43	0.42
	Rail 1981	0.46	0.43	0.48	0.47	0.44	0.42	0.39	0.44	0.44	0.42
	Rail 1996	0.50	0.48	0.53	0.52	0.49	0.47	0.44	0.50	0.49	0.48
	Rail 2010	0.60	0.59	0.61	0.61	0.59	0.58	0.55	0.59	0.59	0.58
Daily accessi-bility to GDP	No network	0.39	0.37	0.40	0.40	0.39	0.37	0.33	0.38	0.37	0.37
	Road 1996	0.47	0.45	0.47	0.46	0.43	0.44	0.41	0.44	0.43	0.42
	Rail 1996	0.52	0.50	0.54	0.54	0.50	0.49	0.46	0.51	0.51	0.49
Potential accessi-bility to population	No network	0.36	0.33	0.37	0.36	0.36	0.33	0.30	0.34	0.33	0.34
	Road 1996	0.45	0.43	0.45	0.45	0.42	0.42	0.39	0.42	0.42	0.41
	Road 2010	0.46	0.44	0.46	0.45	0.43	0.43	0.40	0.43	0.42	0.42
	Rail 1981	0.45	0.43	0.47	0.47	0.44	0.42	0.39	0.44	0.44	0.43
	Rail 1996	0.50	0.48	0.52	0.52	0.49	0.46	0.43	0.49	0.49	0.48
	Rail 2010	0.60	0.58	0.61	0.61	0.60	0.57	0.54	0.59	0.59	0.59
Potential accessi-bility to GDP	No network	0.38	0.36	0.40	0.39	0.38	0.35	0.32	0.37	0.37	0.37
	Road 1996	0.47	0.45	0.47	0.46	0.44	0.44	0.41	0.44	0.43	0.43
	Rail 1996	0.52	0.50	0.54	0.54	0.51	0.48	0.45	0.51	0.51	0.50

Table A4. Correlation (r^2) between daily accessibility and other accessibility indicators

		Daily accessibility (population)						Daily accessibility (GDP)		
		No network	Road 1996	Road 2010	Rail 1981	Rail 1996	Rail 2010	No network	Road 1996	Rail 1996
Average travel time to cities > 250,000	Road 1996	0.39	0.48	0.48	0.47	0.52	0.61	0.41	0.48	0.53
	Road 2010	0.37	0.46	0.47	0.46	0.51	0.61	0.39	0.47	0.52
	Rail 1981	0.39	0.47	0.48	0.49	0.54	0.62	0.42	0.48	0.55
	Rail 1996	0.39	0.46	0.47	0.48	0.54	0.62	0.41	0.47	0.55
	Rail 2010	0.37	0.43	0.44	0.45	0.49	0.58	0.39	0.44	0.50
Average travel time to cities > 1,000,000	Road 1996	0.30	0.38	0.39	0.37	0.42	0.53	0.33	0.40	0.44
	Road 2010	0.28	0.36	0.37	0.35	0.40	0.52	0.31	0.38	0.42
	Rail 1981	0.33	0.40	0.41	0.41	0.47	0.56	0.36	0.41	0.48
	Rail 1996	0.32	0.39	0.40	0.41	0.46	0.57	0.35	0.41	0.48
	Rail 2010	0.33	0.39	0.40	0.40	0.45	0.57	0.36	0.40	0.47
Weighted average travel time to cities > 250,000	Road 1996	0.37	0.46	0.47	0.46	0.50	0.60	0.39	0.47	0.52
	Road 2010	0.35	0.44	0.45	0.43	0.48	0.59	0.37	0.45	0.50
	Rail 1981	0.38	0.46	0.47	0.48	0.53	0.61	0.40	0.47	0.54
	Rail 1996	0.37	0.45	0.46	0.47	0.52	0.61	0.40	0.46	0.54
	Rail 2010	0.36	0.42	0.43	0.44	0.49	0.59	0.39	0.43	0.50
Weighted average travel time to cities > 1,000,000	Road 1996	0.34	0.43	0.43	0.42	0.47	0.58	0.37	0.44	0.49
	Road 2010	0.31	0.39	0.40	0.39	0.44	0.55	0.33	0.41	0.46
	Rail 1981	0.35	0.43	0.44	0.44	0.50	0.59	0.38	0.44	0.51
	Rail 1996	0.34	0.42	0.43	0.44	0.49	0.59	0.37	0.43	0.51
	Rail 2010	0.35	0.41	0.42	0.42	0.48	0.58	0.37	0.42	0.49
Daily accessi-bility to population	No network	1.00	0.85	0.85	0.87	0.81	0.66	0.95	0.81	0.77
	Road 1996	0.85	1.00	1.00	0.94	0.91	0.82	0.83	0.98	0.90
	Road 2010	0.85	1.00	1.00	0.94	0.92	0.82	0.82	0.97	0.90
	Rail 1981	0.87	0.94	0.94	1.00	0.97	0.87	0.84	0.92	0.95
	Rail 1996	0.81	0.91	0.92	0.97	1.00	0.91	0.79	0.89	0.98
	Rail 2010	0.66	0.82	0.82	0.87	0.91	1.00	0.69	0.83	0.93
Daily accessi-bility to GDP	No network	0.95	0.83	0.82	0.84	0.79	0.69	1.00	0.84	0.80
	Road 1996	0.81	0.98	0.97	0.92	0.89	0.83	0.84	1.00	0.92
	Rail 1996	0.77	0.90	0.90	0.95	0.98	0.93	0.80	0.92	1.00
Potential accessi-bility to population	No network	0.94	0.80	0.81	0.85	0.79	0.66	0.89	0.76	0.74
	Road 1996	0.90	0.96	0.96	0.94	0.89	0.81	0.88	0.93	0.87
	Road 2010	0.91	0.96	0.96	0.93	0.89	0.80	0.88	0.92	0.87
	Rail 1981	0.88	0.90	0.90	0.97	0.94	0.85	0.85	0.87	0.91
	Rail 1996	0.85	0.89	0.89	0.96	0.97	0.89	0.82	0.86	0.93
	Rail 2010	0.75	0.83	0.83	0.90	0.92	0.97	0.75	0.83	0.92
Potential accessi-bility to GDP	No network	0.90	0.79	0.79	0.83	0.78	0.70	0.93	0.79	0.78
	Road 1996	0.87	0.95	0.94	0.92	0.88	0.83	0.90	0.96	0.89
	Rail 1996	0.82	0.88	0.87	0.95	0.95	0.92	0.85	0.88	0.96

Table A5. Correlation (r^2) between potential accessibility and other accessibility indicators

		Potential accessibility (population)						Potential accessibility (GDP)		
		No network	Road 1996	Road 2010	Rail 1981	Rail 1996	Rail 2010	No network	Road 1996	Rail 1996
Average travel time to cities > 250,000	Road 1996	0.37	0.47	0.48	0.47	0.51	0.61	0.39	0.48	0.53
	Road 2010	0.35	0.45	0.47	0.45	0.50	0.60	0.38	0.47	0.52
	Rail 1981	0.38	0.47	0.48	0.49	0.54	0.62	0.41	0.48	0.55
	Rail 1996	0.38	0.46	0.47	0.48	0.53	0.62	0.40	0.47	0.55
	Rail 2010	0.36	0.43	0.44	0.45	0.49	0.59	0.39	0.44	0.51
Average travel time to cities > 1,000,000	Road 1996	0.29	0.37	0.38	0.37	0.41	0.53	0.32	0.39	0.44
	Road 2010	0.27	0.35	0.36	0.35	0.39	0.51	0.29	0.37	0.42
	Rail 1981	0.32	0.39	0.40	0.41	0.46	0.56	0.35	0.41	0.48
	Rail 1996	0.31	0.39	0.40	0.41	0.46	0.56	0.35	0.41	0.48
	Rail 2010	0.32	0.39	0.40	0.41	0.45	0.57	0.35	0.41	0.48
Weighted average travel time to cities > 250,000	Road 1996	0.36	0.45	0.46	0.45	0.50	0.60	0.38	0.47	0.52
	Road 2010	0.33	0.43	0.44	0.43	0.48	0.58	0.36	0.45	0.50
	Rail 1981	0.37	0.45	0.46	0.47	0.52	0.61	0.40	0.47	0.54
	Rail 1996	0.36	0.45	0.45	0.47	0.52	0.61	0.39	0.46	0.54
	Rail 2010	0.36	0.42	0.43	0.44	0.49	0.60	0.38	0.44	0.51
Weighted average travel time to cities > 1,000,000	Road 1996	0.33	0.42	0.43	0.42	0.46	0.57	0.35	0.44	0.48
	Road 2010	0.30	0.39	0.40	0.39	0.43	0.54	0.32	0.41	0.45
	Rail 1981	0.34	0.42	0.43	0.44	0.49	0.59	0.37	0.44	0.51
	Rail 1996	0.33	0.42	0.42	0.44	0.49	0.59	0.37	0.43	0.51
	Rail 2010	0.34	0.41	0.42	0.43	0.48	0.59	0.37	0.43	0.50
Daily accessi-bility to population	No network	0.94	0.90	0.91	0.88	0.85	0.75	0.90	0.87	0.82
	Road 1996	0.80	0.96	0.96	0.90	0.89	0.83	0.79	0.95	0.88
	Road 2010	0.81	0.96	0.96	0.90	0.89	0.83	0.79	0.94	0.87
	Rail 1981	0.85	0.94	0.93	0.97	0.96	0.90	0.83	0.92	0.95
	Rail 1996	0.79	0.89	0.89	0.94	0.97	0.92	0.78	0.88	0.95
	Rail 2010	0.66	0.81	0.80	0.85	0.89	0.97	0.70	0.83	0.92
Daily accessi-bility to GDP	No network	0.89	0.88	0.88	0.85	0.82	0.75	0.93	0.90	0.85
	Road 1996	0.76	0.93	0.92	0.87	0.86	0.83	0.79	0.96	0.88
	Rail 1996	0.74	0.87	0.87	0.91	0.93	0.92	0.78	0.89	0.96
Potential accessi-bility to population	No network	1.00	0.90	0.90	0.91	0.88	0.76	0.95	0.86	0.83
	Road 1996	0.90	1.00	1.00	0.94	0.92	0.86	0.88	0.98	0.90
	Road 2010	0.90	1.00	1.00	0.94	0.92	0.86	0.88	0.98	0.90
	Rail 1981	0.91	0.94	0.94	1.00	0.99	0.92	0.89	0.92	0.96
	Rail 1996	0.88	0.92	0.92	0.99	1.00	0.94	0.86	0.90	0.98
	Rail 2010	0.76	0.86	0.86	0.92	0.94	1.00	0.78	0.87	0.95
Potential accessi-bility to GDP	No network	0.95	0.88	0.88	0.89	0.86	0.78	1.00	0.90	0.88
	Road 1996	0.86	0.98	0.98	0.92	0.90	0.87	0.90	1.00	0.92
	Rail 1996	0.83	0.90	0.90	0.96	0.98	0.95	0.88	0.92	1.00