

**SOCIO-ECONOMIC AND SPATIAL IMPACTS  
OF TRANS-EUROPEAN TRANSPORT NETWORKS:  
THE SASI PROJECT**

Paper presented at the 8th World Conference on Transport Research  
Antwerpen, 12-17 July 1998

Revised, 24 July 1998

Klaus Spiekermann and Michael Wegener  
Institute of Spatial Planning  
University of Dortmund  
D-44221 Dortmund  
Fax: +49 231 755 4788

## 1 INTRODUCTION

The trans-European transport networks (TETN) 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 between 400 and 500 billion ECU until the year 2010. However, critics argue that the TETN programme primarily serves the objective of economic competitiveness of Europe and not the equally important objective of reducing economic disparities between the regions in Europe. In the face of this goal conflict, the consistent prediction and the rational and transparent evaluation of likely socio-economic impacts of major transport infrastructure investments and transport system improvements become of primary political importance both for the European Union and its member states.

The paper presents an overview on the project "Socio-Economic and Spatial Impacts of Transport Infrastructure Investments and Transport System Improvements" (SASI) conducted for DG VII (Transport) of the European Commission as part of the 4th Framework Programme for Research and Technological Development by the Institute of Urban and Regional Research of the University of Vienna, the Department of Town and Regional Planning of the University of Sheffield and the Institute of Spatial Planning of the University of Dortmund. The project is one of three parallel and co-ordinated projects directed at the development and adoption of a comprehensive and transferable methodology for the assessment of socio-economic impacts of major transport infrastructure investments and transport system improvements. It aims at designing an interactive, transparent modelling system for forecasting 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 and uncertainty/probability of impacts; at developing flexible input and output interfaces for linking the modelling system both to its own data base and to data bases and evaluation methods developed in other projects; and at 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.

To achieve these objectives, a dynamic simulation model forecasting the development of accessibility, GDP, employment, population and labour force in 201 regions of the European Union until the year 2016 subject to assumptions about the future economic performance of the European economy as a whole, about immigration and outmigration across Europe's borders, about transfer payments by the European Union via the Structural Funds and about policy decisions with respect to the trans-European transport networks is developed. Output of the model are indicators describing the socio-economic development of regions such as regional accessibility, GDP per capita and unemployment as well as cohesion indicators describing the distribution of these indicators across regions.

The paper starts with a statement of the problem and a review of previous studies on the spatial impact of transport infrastructure. It then explains the theoretical foundation and internal structure of the simulation model developed as well as its input and output and the calibration techniques applied. Finally it presents exploratory results from calibrating and applying the model and closes with an outlook on future work in the project.

## 2 PROBLEM

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 Communities, 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 between 400 and 500 billion ECU until the year 2010, nearly a quarter of which are needed for fourteen priority projects proposed at the 1995 EU summit in Essen.

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."

### 3 THE SASI MODEL

The model 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, and it 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 above, 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. 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.

Based on the above considerations, the SASI model has 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.

### 3.1 Submodels

In this section the seven submodels of the SASI model and the interrelationships between them are briefly described. Figure 1 visualises the interactions between the seven submodels.

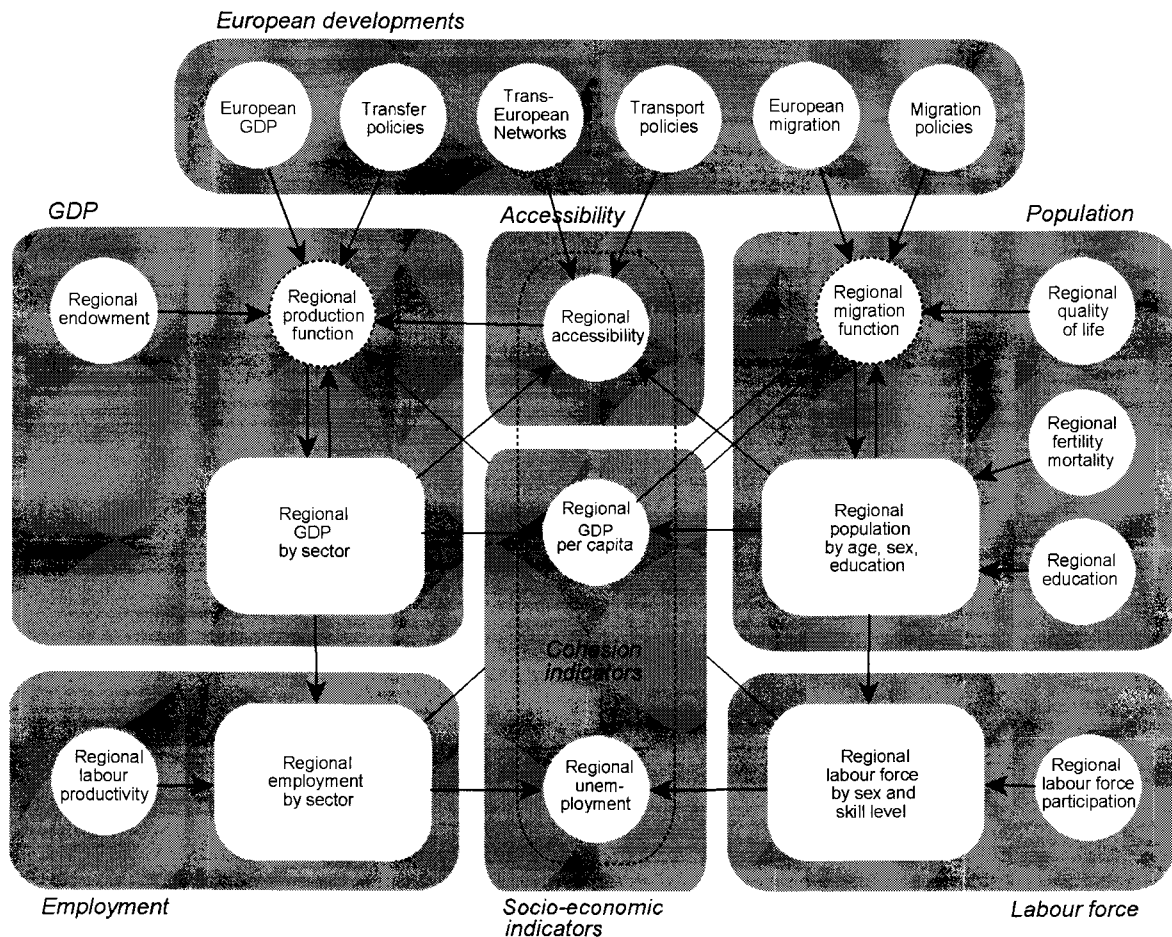


Figure 1. The SASI model.

#### *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 of economic development and population are consistent with external developments not modelled. Given the expected rapid population growth and lack of economic opportunity in many origin countries, total European immigration will be largely a function of immigration policies by national governments of the countries of the European Union. Another relevant European policy field are transfer payments by the European Union via the Structural Funds or the Common Agricultural Policy or by national governments to assist specific regions, which, because of their concentration on peripheral regions, are responsible for a sizeable part of their economic growth. The last group of assumptions are those about

policy decisions on the trans-European networks. As these are of focal interest in SASI, they are modelled with considerable detail. A network scenario is a time-sequenced investment programme for addition, upgrading or closure of links of the road, rail or air networks. Besides a 'baseline' scenario several TETN scenarios will be specified.

#### *Regional Accessibility*

This submodel calculates regional accessibility indicators expressing the 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, rail and air networks.

#### *Regional GDP*

This is the core submodel of the SASI model. It calculates a forecast of gross domestic product (GDP) per capita by industrial sector (agriculture, manufacturing, services) generated in each region as a function of endowment indicators and accessibility. Endowment indicators are indicators measuring the suitability or capacity 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 infrastructure as well as 'soft' location factors such as indicators describing the spatial organisation of the region, i.e. its settlement structure and internal transport system, or institutions of higher education, cultural facilities, good housing and a pleasant climate and environment. Accessibility indicators are derived from the *Regional Accessibility* submodel. In addition to endowment and accessibility indicators, monetary transfers to regions by the European Union such as assistance by the Structural Funds or the Common Agricultural Policy or national governments are considered, as these account for a sizeable portion of the economic development of peripheral regions. The results of the regional GDP per capita forecasts are adjusted such that the total of all regional forecasts multiplied by regional population 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 exogenous forecasts of regional labour productivity by industrial sector (GDP per worker) modified by effects of changes in regional accessibility.

#### *Regional Population*

Regional population changes due to natural change and migration. Births and deaths are modelled by a cohort-survival model subject to exogenous forecasts of regional fertility and mortality rates. Interregional migration within the European Union is modelled in a simplified migration model as annual net migration as a function of regional unemployment and other indicators expressing the attractiveness of the region as a place of employment and a place to live, whereas immigration to and outmigration from the European Union are modelled separately. The migration forecasts are adjusted to comply with total European immigration and outmigration forecast by the *European Developments* submodel and the limits on immigration set by individual countries. In addition educational attainment, i.e. the proportion of residents with higher education, is forecast as a function of national education policy.

### *Regional Labour Force*

Regional labour force is derived from regional population and exogenous forecasts of regional labour force participation rates modified by effects of regional unemployment.

### *Socio-economic Indicators*

Total GDP and employment are related to population and labour force by calculating total regional GDP per capita and regional unemployment. Accessibility, besides being a factor determining regional production, is also considered a policy-relevant output of the model. In addition, equity or cohesion indicators describing the distribution of accessibility, GDP per capita and unemployment across regions are calculated.

## **3.2 Space and Time**

The SASI model forecasts socio-economic development in the 201 regions at the NUTS-2 level defined for SASI for the fifteen EU countries. These are the 'internal' regions of the model. The 27 regions defined for the rest of Europe are the 'external' regions which are used 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 Communities, 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. The SASI system of regions and the strategic networks used in SASI are also used in the concurrent DGVII projects STREAMS, EUNET and STEM.

The temporal dimension of the model is established by dividing time into discrete time intervals or periods of one year duration. By modelling relatively short time periods both short- and long-term lagged impacts can be taken into account. The base year of the simulations is 1981 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 is 2016.

## **3.3 Model Data**

Two major groups of data can be distinguished: data required for running the model and data needed for the calibration and validation of the model:

### *Simulation Data*

Simulation data are the data required to perform a typical simulation run. They can be grouped into base year data and time series data. Base year data describe the state of the re-

gions and the strategic rail and road networks in the base year 1981. Base year data are either regional or network data. Time series data describe exogenous developments or policies defined to control or constrain the simulation. They are either collected or estimated from actual events for the time between the base year and the present, or are assumptions or policies for the future. Time series data must be defined for each simulation period, but in practice may be entered only for specific (not necessarily equidistant) years, with the simulation model interpolating between them.

#### Base year data

##### Regional data (201 EU regions)

- Regional GDP per capita by industrial sector in 1981
- Regional labour productivity (GDP per worker) by industrial sector in 1981
- Regional population by five-year age group and sex in 1981
- Regional educational attainment in 1981
- Regional labour force participation rate by sex in 1981

##### Network data (pan-Europe)

- Node and link data of strategic road network in 1981
- Node and link data of strategic rail network in 1981
- Node and link data of air network in 1981

#### Time-series data

##### European data (EU)

- Total European GDP by industrial sector, 1981-2016
- Total European immigration and outmigration, 1981-2016

##### National data (15 EU countries)

- National GDP per worker by industrial sector, 1981-2016
- National fertility rates by five-year age group and sex, 1981-2016
- National mortality rates by five-year age group and sex, 1981-2016
- National immigration limits, 1981-2016
- National educational attainment, 1981-2016
- National labour force participation by sex, 1981-2016

##### National data (23 non-EU countries)

- National population, 1981-2016
- National GDP, 1981-2016

##### Regional data (201 EU regions)

- Regional endowment factors, 1981-2016
- Regional transfers, 1981-2016

##### Network data (pan-Europe)

- Changes of node and link data of strategic road network, 1981-2016
- Changes of node and link data of strategic rail network, 1981-2016
- Changes of node and link data of air network, 1981-2016

#### *Calibration/Validation Data*

The regional production function in the GDP submodel is the only model function *calibrated* using statistical estimation techniques. All other model functions are *validated* by comparing the output of the model with observed values for the period between the base year and the present. The following data for calibration/validation are required:



### Calibration data

#### Regional data (201 EU regions)

- Regional GDP per capita by industrial sector in 1981, 1986, 1991
- Regional endowment factors in 1981, 1986, 1991
- Regional labour force in 1981, 1986, 1991
- Regional transfers in 1981, 1986, 1991
- Regional net migration in 1981, 1986, 1991
- Regional unemployment rates in 1981, 1986, 1991

#### Network data (pan-Europe)

- Node and link data of strategic road network in 1981, 1986, 1991
- Node and link data of strategic rail network in 1981, 1986, 1991
- Node and link data of air network in 1981, 1986, 1991

### Validation data

#### Regional data (201 EU regions)

- Regional population (by age and sex) in 1981, 1986, 1991, 1996
- Regional GDP (by industrial sector) in 1981, 1986, 1991, 1996
- Regional labour force (by sex) in 1981, 1986, 1991, 1996
- Regional employment (by industrial sector) in 1981, 1986, 1991, 1996
- Regional unemployment rate in 1981, 1986, 1991, 1996

### *Data Sources*

The Eurostat data base REGIO has been identified as the primary data input to the project as a whole, as it is the main official source of regional data that is provided on a regular basis and in a harmonised framework (Masser et al., 1997).

Data problems identified were large differences in the size of regions, changes in region boundaries and the creation of new regions all resulting in outliers and gaps in the data set. Data coverage was found to be very poor for the new member states Austria, Finland and Sweden and the new German Länder.

Missing data, in particular for the base year 1981, are estimated or derived from other data sources such as national statistical offices. Although REGIO covers a considerable amount of the data required, calculation of regional endowment factors requires other data sources, as does the information needed for the *European Developments* submodel.

Network data used for SASI are the ‘strategic’ road, rail and air networks described in Section 3.2. For past years they contain information on the historical development of transport infrastructure, whereas for future years they represent the transport network investments and transport system improvements to be investigated. Travel cost is presently represented by travel time only; in future applications also generalised travel cost consisting of a combination of travel time, travel cost and mode-specific inconvenience will be used.

### 3.4 Model Output

Output of the model are indicators measuring socio-economic and spatial impacts of the simulated policies. Three groups of output indicators were defined:

- Gross domestic product (GDP) was chosen to represent the economic performance of a region. GDP per capita allows to draw conclusions on regional income levels. Despite its well-known theoretical and methodological drawbacks this indicator continues to be the most commonly used indicator of regional economic efficiency.
- The unemployment rate is used to indicate the social condition of a region. This indicator, too, presents measurement problems because there exist large differences in the definition of unemployment in European countries. Nevertheless unemployment remains the most widely used social indicator and is easily related to policy goals.
- In addition macro indicators expressing the distribution of GDP and unemployment across regions are used as indicators of cohesion between the regions of the European Union. Cohesion indicators inform about the degree of spatial concentration or dispersion of GDP or unemployment and if applied to modelled policies show whether the implementation of a policy would contribute to the political goal of reducing socio-economic disparities or not.

Using these indicators it can be shown that cohesion and integration policies of the European Union have not always been successful. In fact there is no evidence that regional income differences in Europe have been reduced during the 1980s. In terms of regional unemployment, the gap between successful and declining regions even seems to have widened (Bökemann et al., 1997).

## 4 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 accessibility. 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 (Masser et al., 1992). Several trends combine to reinforce the tendency to reduce 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:

- 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*.

#### **4.1 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. Böckmann, 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:

$$A_i = \sum_j g(W_j) f(c_{ij})$$

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  $g(W_j)$  and  $f(c_{ij})$  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 more easily 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  $f(c_{ij})$ , where  $W_{\min}$  and  $c_{\max}$  are constants and  $\alpha$  and  $\beta$  parameters:

Table 1. Typology of accessibility indices

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

## 4.2 Disaggregate accessibility indicators

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.

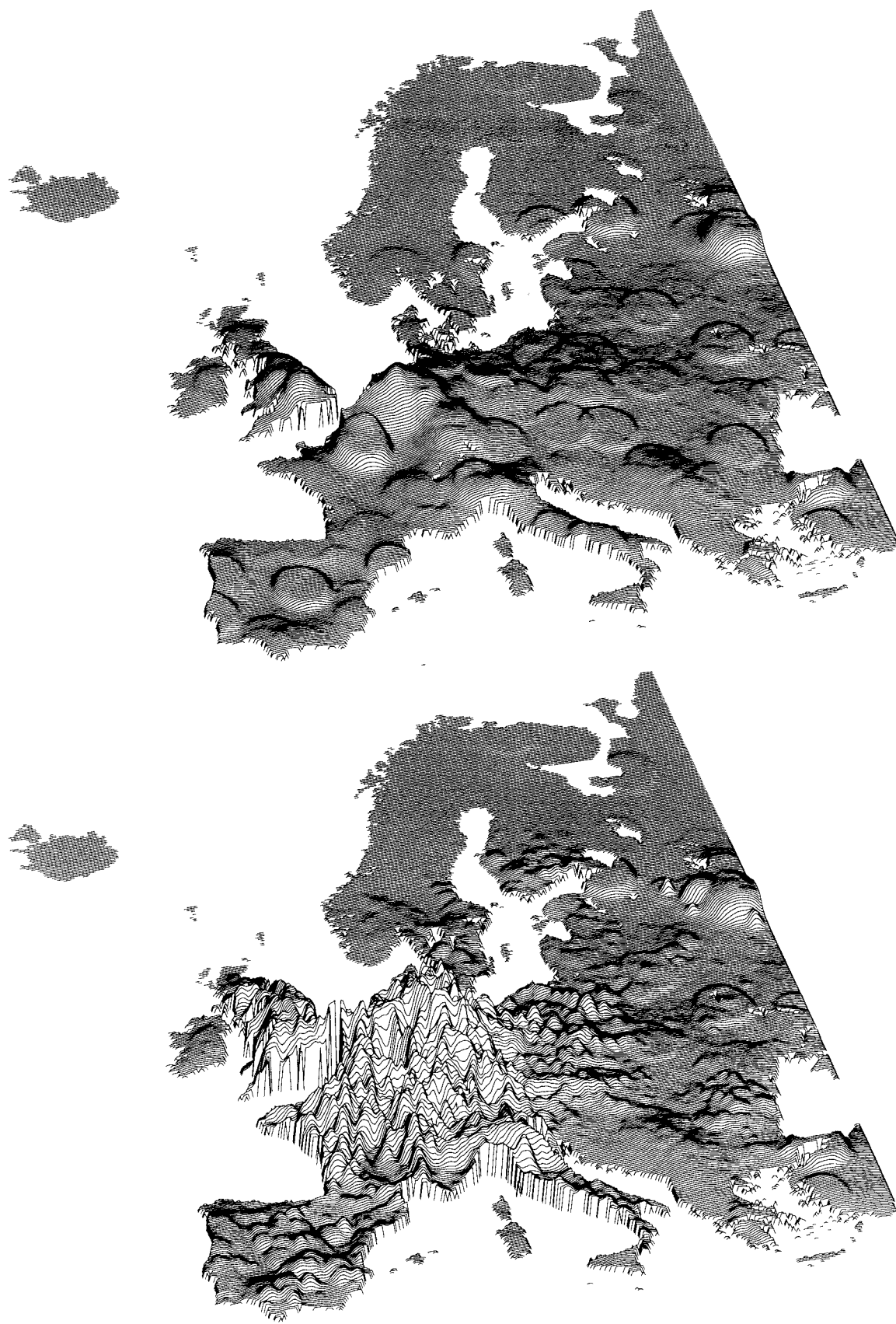
To overcome this problem, Spiekermann and Wegener developed spatially disaggregate accessibility indicators using raster-based GIS technology (Spiekermann and Wegener, 1994; 1996, Vickerman et al., 1997). By this method the raster structure is applied to represent a quasi-continuous activity surface 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 to 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. The method is described in Schürmann et al. (1997).

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.

Figure 2 (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 given maximum travel time of five hours destinations within a radius of 150 km are included. 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 2 (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 2. Daily accessibility to population without high-level network (top) and by rail in 1996 (bottom).*



## 5 Accessibility Indicators and Regional Economic Development

As a preparatory exercise for the calibration of the multivariate regional production function to be used in the SASI model, a tentative assessment of the relationship between accessibility and regional economic development was performed by correlating selected accessibility indicators with GDP per capita for 1981 and 1991.

Not surprisingly, the analysis results in a rather low correlation 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 the coefficient of determination  $r^2$  can be obtained. Table 2 summarises coefficients of determination  $r^2$  between the accessibility indicators of Table 1 and GDP per capita.

*Table 2. Coefficient of determination ( $r^2$ ) of accessibility indicators and GDP per capita*

		GDP per capita, 1981	GDP per capita, 1991
Average travel cost to cities > 250,000	Road 1996	0.51	0.48
	Rail 1981	0.60	0.57
	Rail 1996	0.58	0.57
Average travel cost 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 cost 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 cost 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 1996-1981	0.52	0.40
Daily accessibility to GDP **0.4	No network	0.37	0.32
	Road 1996	0.40	0.32
	Rail 1996	0.50	0.32
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 1996-1981	0.57	0.48
Potential accessibility to GDP **0.4	No network	0.43	0.36
	Road 1996	0.45	0.35
	Rail 1981	0.55	0.43



Average travel cost 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.

## **6 Conclusions**

The model of socio-economic and spatial impacts of large-scale European transport infrastructure investments presented in this paper has a number of advantages compared with other approaches to modelling the impacts of transport infrastructure investments and transport system improvements:

- The model predicts not only regional production but also regional population and so is capable of modelling regional unemployment, which is of major importance for policy making of the European Union.
- The model stands out by its comprehensive geographical coverage including all regions of the fifteen member states of the European Union at NUTS-2 level and as external regions the rest of Europe with the European part of Russia.
- In methodological terms the model steers a middle course between the complexity of a multi-regional input-output framework and aggregate econometric modelling approaches by modelling transport infrastructure investments and transport system improvements on regional production by regional production functions in which transport infrastructure is represented by spatially disaggregate accessibility indicators.
- The model is particularly flexible in incorporating 'soft' non-transport factors of regional economic development beyond the economic factors traditionally included in regional production functions.
- The dynamic character of the model enables it to appropriately deal with the range of different dynamics associated with interactions processes determining regional socio-economic development.
- The cohesion indicators calculated by the model make it particularly relevant for studying the impacts of transport infrastructure investments and transport system improvements on the convergence (or divergence) of socio-economic development in the regions over time.
- The model has relatively moderate data requirements and does not require highly disaggregate classifications of industries or population or an input-output table nor road, rail and air networks coded with excessive detail.

The ongoing work phase in the SASI project concentrates on making the model operational and completing the calibration of the model equations. Programming work for implementing a prototype of the model as outlined in this paper is underway. The completion of the air network will soon make it possible to calculate accessibility by air and multimodal (fastest-mode and logsum) accessibility. Data collection and estimation of missing data are nearing completion. The statistical analyses to test different hypotheses about factors to be included in the regional production and migration functions are in progress.

The calibrated and validated model will be used to forecast the impacts of future additions or modifications to the base TETN with respect to the indicators discussed in Section 3.4.

As a reference or 'baseline' scenario the implementation of all new or upgraded TETN links on which decisions already have been taken will be used. Other TETN scenarios will be developed by adding to the baseline scenario different subsets of the remaining TETN links laid down in Decision No. 1692/96/CE of the European Parliament and the Council (European Communities, 1996) and the east European road and rail corridors identified by the Second Pan-European Transport Conference in Crete in 1994 such as

- baseline network + all planned TETN road projects
- baseline network + all planned TETN rail projects
- baseline network + all planned TETN road and rail projects

Further scenarios may be developed as modifications of the above scenarios by assuming different time schedules or priorities for the completion of selected road or rail projects both within the European Union or in the east European corridors. If accessibility indicators based on generalised cost are applied, it is also possible to investigate impacts of road pricing policies.

## ACKNOWLEDGMENTS

The authors are grateful to Dieter Bökemann, Hans Kramar and Roland Hackl of the Institute of Urban and Regional Research of the Technical University of Vienna and Ian Masser, Max Craglia and Adelheid Holl of the Department of Town and Regional Planning of the University of Sheffield and their colleagues Carsten Schürmann and Meinhard Lemke for their permission to present the results of the joint work in the SASI project.

## REFERENCES

- Biehl, D., ed (1986) *The Contribution of Infrastructure to Regional Development*. Final Report of the Infrastructure Studies Group to the Commission of the European Communities. Office for Official Publications of the European Communities, Luxembourg.
- Biehl, D. (1991) 'The role of infrastructure in regional development'. In *Infrastructure and Regional Development*, ed R.W. Vickerman, pp. 9-35. European Research in Regional Science 1. Pion, London.

Blum, U. (1982) Effects of transportation investments on regional growth: a theoretical and empirical investigation. *Papers of the Regional Science Association* **49**, 169-184.

Bökemann, D. (1982) *Theorie der Raumplanung*. Oldenbourg, München/Wien.

Bökemann, D., Hackl, R. and Kramar, H. (1997) *Socio-Economic Indicators Model and Report*. SASI Deliverable D4. Report to the European Commission. Institut für Stadt- und Regionalforschung, Technische Universität Wien.

Bröcker, J. and Peschel, K. (1988) Trade. In *Regional Impact of Community Policies in Europe*, eds W. Molle and T. Cappelin, Avebury., Aldershot.

European Commission (1997) *Cohesion and the Development Challenge Facing the Lagging Regions*. Fourth Cohesion Report. Regional Development Studies. Office for Official Publications of the European Communities, Luxembourg.

European Communities (1996): Decision No. 1692/96/CE of the European Parliament and of the Council of 23 July 1996 on the Community guidelines for the development of the trans-European transport networks. *Official Journal of the European Communities* **39**, L 228, 9 September 1996, 1-104.

Keeble, D., Owens, P.L. and Thompson, C. (1982) Regional accessibility and economic potential in the European Community. *Regional Studies* **16**, 419-432.

Keeble, D., Offord, J. and Walker, S. (1988) *Peripheral Regions in a Community of Twelve Member States*. Office for Official Publications of the European Communities, Luxembourg.

Linneker, B. (1997): Transport Infrastructure and Regional Economic Development in Europe: A Review of Theoretical and Methodological Approaches. TRP 133. Department of Town and Regional Planning, University of Sheffield.

Lutter, H., Pütz, T. and Spangenberg, M. (1993) *Lage und Erreichbarkeit der Regionen in der EG und der Einfluß der Fernverkehrssysteme*. Forschungen zur Raumentwicklung Band 23. Bundesforschungsanstalt für Landeskunde und Raumordnung, Bonn.

Masser, I., Craglia, M. and Holl, A. (1997): *Data Requirements and Structures*. SASI Deliverable D7. Department of Town and Regional Planning, University of Sheffield.

Masser, I., Svidén, O. and Wegener, M. (1992) *The Geography of Europe's Futures*. Belhaven Press, London.

Newman, P. and Vickerman, R. (1993) Infrastructure indicators and regional development: redefining economic potential. Paper presented at the British Section of the Regional Science Association Conference, Nottingham, 1-3 September.

Schürmann, C., Spiekermann, K. and Wegener, M. (1997) *Accessibility Indicators: Model and Report*. SASI Deliverable D5. Institut für Raumplanung, Universität Dortmund.

Spiekermann, K. and Wegener, M. (1994) Trans-European networks and unequal accessibility in Europe. Paper presented at the NECTAR Working Group 3 Workshop 'Infrastructure and Peripheral Regions in Europe' at Molde College, Molde, Norway, 30 September and 1 October 1994.

Spiekermann, K. and Wegener, M. (1996) Trans-European networks and unequal accessibility in Europe. *European Journal of Regional Development (EUREG)* **4/96**, 35-42.

Stewart, J.Q. (1947) Empirical mathematical rules concerning the distribution and equilibrium of population. *Geographical Review* **37**, 461-485.

Vickerman, R.W. (1991a): Introduction. In *Infrastructure and Regional Development*, ed R.W. Vickerman, pp. 1-8, European Research in Regional Science 1. Pion, London.

Vickerman, R.W. (1991b) Other regions' infrastructure in a region's development. In *Infrastructure and Regional Development*, ed R.W. Vickerman, pp. 61-74, European Research in Regional Science 1. Pion, London.

Vickerman, R., Spiekermann, K. and Wegener, M. (1997) Accessibility and economic development in Europe. Submitted to *Regional Studies*.