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Urban Agglomerations in European Infrastructure Networks

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URBAN AGGLOMERATIONS IN EUROPEAN INFRASTRUCTURE NETWORKS

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[1] This study is based on Bruinsma and Rietveld (1992) to which we refer for a more detailed account of data collection procedures and outcomes.
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Abstract

Infrastructure networks are often assumed to be important determinants of the economic potential of urban agglomerations. This paper addresses the position of 42 major European cities in three infrastructure networks: road, rail and air.

Ranking of cities in terms of a gravity based accessibility index are produced. Also the effects of planned or possible future developments in these networks are studied.

The effects of changes in the air and road network on average accessibility are expected to be rather small; in the rail network the introduction of high speed links will have considerable impacts on average accessibility. Existing inequalities in accessibility are expected to remain rather constant in the air system. In the rail system, the further introduction of high speed links will increase existing inequalities by reinforcing the position of the cities in the Northwestern part of Europe. In the road system on the other hand it will be the peripheral countries which will benefit most.

Further we note that an analysis of non-physical border related barriers on accessibility reveals that attention should not be restricted to improving physical infrastructure networks.

Keywords: cities, infrastructure, Europe, rail, road, air, borders, accessibility.

1 Introduction

The ongoing process of European integration causes an increasing competition between major urban agglomerations in Western Europe. The target of integration is the removal of all barriers to international trade, which includes among others the harmonisation of fiscal policies. An implication is that several of the policy instruments which national governments could use in the past to promote development of their major urban agglomerations are no longer applicable. The development of urban infrastructure is seen as one of the last opportunities of the national government to support their cities in the international competition. It is no surprise therefore to see that in a number of recent studies, urban infrastructure plays a role as a determinant of competiveness of urban regions (Biehl, 1986, NEI, 1987, DATAR, 1989, Cheshire, 1990, Bruinsma & Rietveld, 1991, Healey & Baker, 1991). In most of these studies, attention is focused on the intra-metropolitan infrastructure. This includes the supply of transport infrastructure such as highways and (light) rail in metropolitan areas. In some studies also a broader range of infrastructure types is taken into account, so that also education, culture and environmental amenities are included.

In addition to intra-metropolitan infrastructure, also inter-metropolitan infrastructure will be important for the urban areas concerned. The free market forces the cities to be outward oriented. Good connections in the international infrastructure networks will be a critical success factor in the distribution of economic activity in Europe. This raises the issue of the appropriateness of European infrastructure networks. The road and railway network have been planned in the past with a clear national orientation. This is no surprise since the domestic component was dominant in trade and communication flows. During the last decades one observes a tendency that international flows grow faster than domestic flows, however. This implies an increase in demand for international infrastructure. The supply response can be observed for example in the development of the Channel Tunnel, a connection between Sweden and Denmark, and of tunnels through the Alps. Another example is the design of an international network of high speed rail connections. In air transport physical constraints do not play an important role in international communication. Nevertheless it can be observed that also here certain non-physical barriers to international communication exist.

This article describes the relative position of urban agglomerations in three European infrastructure networks: road, rail and air. The effects of planned or possible future major improvements in the infrastructure networks on these accessibility patterns are studied. In addition, for the road network an analysis is given of the effects of national borders - which are seen as barriers in international interaction patterns - and the decline of these border effects through major political changes.

2 *Methodology*

The accessibility of each agglomeration is measured by the following simple gravity type formulation in which travel time is the main indicator:

$$A_i = \Sigma_j 1/T_{ij}^c$$

where:

A_i = accessibility of agglomeration i

T_{ij} = travel time from i to agglomeration j

The gravity parameter c is assumed to equal 1 (cf. Keeble et al., 1982). The total travel time T is measured in minutes and consists of three elements:

$$T = V + RT + I$$

where:

V = penalty because one cannot depart at the desired moment (rail, ferries and air)

RT = real travel time while moving

I = check in and check out time (ferries and air)

The penalty V is estimated as follows:

$$V = \frac{1}{4} E/F$$

where E is the effective travel period during which one can depart - for instance between 06.00 hours and 18.00 hours - and F is the frequency of the connection. For example, if one would go at an arbitrary moment to the airport, average waiting time would be half of the average time in between two departures (which equals ½ E/F). We suppose most travellers know their departure time, but we still give a penalty because travellers cannot leave at the moment they most desire. Therefore, we reduce the penalty of ½ (as would occur in the case of an arbitrary arrival on the airport) to ¼ to express this inconvenience.

If interaction is supposed to depend on the size of the agglomerations with which an agglomeration interacts, then weighting can take place by use of the population size of those agglomerations. This leads to the next formula, where P_j is the population of agglomeration j:

$$A_i = \Sigma_j P_j/T_{ij}^c$$

The weighting by population size makes it necessary to include the internal interaction in agglomeration i. The value of the share of the internal interaction in the total accessibility score of agglomeration i depends on two factors. The share is higher the larger the population size of agglomeration i and the share is lower the larger the number of connections with the agglomerations j located nearby.

To measure the interaction pattern for air, rail and road networks we selected the 42 agglomerations in Europe excluding the former U.S.S.R. with a population size of over 1 million. Data on travel time and frequencies between those agglomerations are obtained of ABC World Airways Guide (air), Thomas Cook European Timetable (rail, ferries) and the Michelin Roadatlas of Europe. The data of the road network are converted from distance into travel time. For highways we used an average speed of 90 kilometres per hour, for roads of a lower quality this figure is 60. Within the urban agglomerations we used an average speed of 30 kilometres per hour.

3 Air traffic

To measure the accessibility of the 42 European agglomerations we start with studying direct air connections. The index which is not weighted for population size reflects only the spatial dimension of the location in the network, whereas the weighted index in which the internal interaction is included reflects a combination of the mass of the agglomeration itself and its external contacts.

Table 1 Accessibility of European cities by air traffic

	1	2	3	4	5
London	100	99	99	99	98
Paris	96	100	100	100	100
Frankfurt	90	75	77	76	77
Zurich	87	73	76	75	69
Brussels	83	70	74	72	66
Amsterdam	83	70	73	72	66
Milan	75	69	72	70	65
Munich	69	65	70	67	62
Copenhagen	68	64	70	66	60
Rome	64	66	73	68	63
Berlin	64	69	75	72	66
Düsseldorf	63	60	69	62	58
Vienna	62	61	70	64	58
Madrid	57	67	73	67	63
Hamburg	56	60	71	61	57
Barcelona	55	60	67	62	57
Budapest	47	55	63	59	53
Prague	47	48	59	53	47
Warsaw	46	52	58	56	50
Manchester	44	51	63	52	49
Istanbul	43	65	70	67	62
Dublin	43	50	66	51	47
Athens	41	57	64	59	54
Birmingham	41	48	62	50	47
Stockholm	41	50	60	51	47
Belgrade	39	47	55	51	46
Lyon	39	48	65	50	46
Bucharest	36	48	56	52	47
Cologne	36	42	60	43	41
Lisbon	35	49	59	50	47
Sofia	35	43	51	47	43
Zagreb	30	36	51	39	37
Marseille	24	39	61	41	38
Turin	22	35	60	36	35
Newcastle	21	32	55	33	32
Naples	20	33	54	34	33
Leeds	13	31	56	31	30
Genoa	13	28	54	29	29
Rotterdam	11	32	66	32	32
Liverpool	6	21	54	21	20
Essen	0	18	60	17	16
Lodz	0	17	49	16	16

1 = unweighted 2 = weighted 3 = indirect connections 4 = even growth 5 = mainport

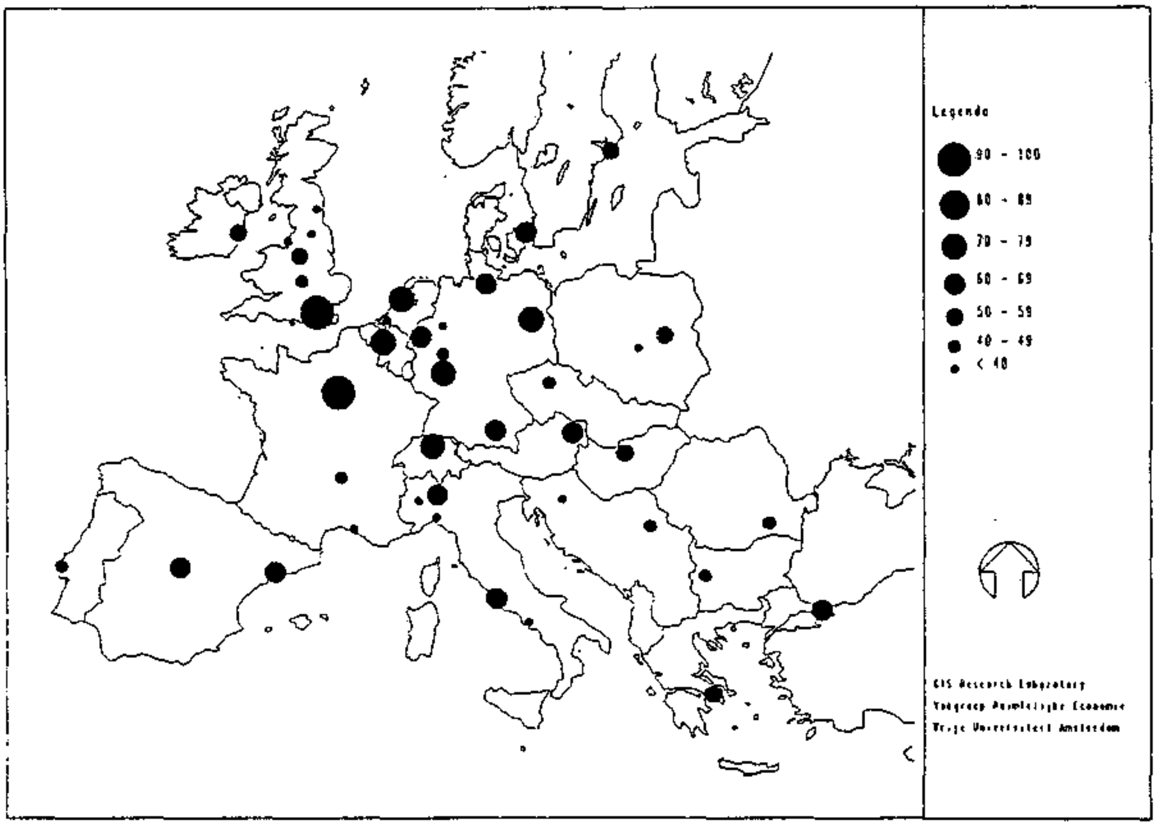

Figure 1 Accessibility of European cities by air traffic, weighted by population size

According to the unweighed index, London and Paris have the best accessibility in air traffic. Their position is not very dominant, however; the difference with other European cities such as Frankfurt and Zurich being rather small (see Table 1, column 1). However, when the weighted index is used, their position is much more dominant (see Table 1, column 2 and Figure 1). This rising dominance is completely explained by the share of the internal interaction. For London and Paris the share of the internal interaction is (both in a relative and an absolute sense) rather large compared with its smaller competitors like Frankfurt, Zurich, Brussels and Milan. The scores of Essen and Lodz, which have no airport, completely depends on their internal interaction. As a consequence the spread of the index is relatively large (100-17) compared with the other modes of transport, in which all agglomerations are linked.

A problem with airports is that their home markets often exceed the urban agglomeration. For instance, Schiphol does not only serve Amsterdam but also Rotterdam and the same could be said for the relation between Frankfurt and the Ruhr-area. For this reason we have included the indirect connections in the gravity model. As can be seen in Table 1, column 3 the scores of agglomerations with no or small airports rise sharply. In the ranked scores Rotterdam and Essen rise respectively 18 and 14 places. Important to note is that the third position of Frankfurt becomes less clear. In the situation with only direct flights only 7 competitors are within the 10 per cent points distance of Frankfurt. When the indirect flights are included the number of competitors has risen to 13. We conclude that in this context the mainport position of Frankfurt is not very evident.

We have formulated two scenarios for future developments. The first scenario is based on an even growth assumption: the frequencies of all flights are doubled. In the second scenario it is assumed that the total volume of flights is again doubled, but that the growth is uniquely concentrated on the mainports London, Paris and Frankfurt; the frequencies of all flights to and from these airports are multiplied by four, the frequencies of the other flights remain unchanged. These scenarios describe the two extremes between which the future of the airline system may be expected to be: growth without structural change, and the development of a limited number of large mainports.

In the even growth scenario especially the East-European agglomerations improve their scores (Table 1, column 4). Those cities have relatively large numbers of connections but low frequencies on those connections. A doubling of the frequencies leads to a relatively sharp fall in the penalty V what means a substantial shortening of the total travel time T. As a consequence the accessibility of these cities rises.

In the mainport scenario the mainports do not become as dominant as one might expect (Table 1, column 5). The explanation is the reverse of the former one. The connections of the mainports are already flown with high frequencies, so that the penalty V does not change much (this is the consequence of putting the frequency F in the denominator of the formula of the penalty). The relative scores of the nearest competitors of the mainports tend to decrease with about four points, which means a strengthening of the mainport positions. Interesting is the fact that the individual index of small airports is relatively stable. An explanation is that those airports have relatively many connections with mainports.

4 Rail traffic

In the situation where no weighting by population size has taken place the Central German cities score best followed by the Mid-England cities, the Benelux cities and Paris (Table 2, column 1). The Mid-England cities are not centrally located in the European railway system. They score high because here a

Table 2 Accessibility of European cities by rail traffic

	unweighted	weighted	HSL		unweighted	weighted	HSL
Düsseldorf	100	90	83	Vienna	37	51	54
Cologne	92	85	84	Berlin	35	62	55
Essen	86	81	74	Marseille	35	51	56
Manchester	66	77	68	Rome	34	57	52
Leeds	63	77	69	Budapest	31	51	43
Rotterdam	63	67	68	Prague	30	45	38
Brussels	63	71	82	Copenhagen	28	44	42
Amsterdam	62	66	67	Zagreb	27	42	35
Paris	61	100	100	Naples	26	42	44
Liverpool	59	71	63	Warsaw	26	44	37
Frankfurt	58	64	71	Belgrade	24	42	35
Birmingham	57	76	69	Lodz	24	39	32
London	54	96	90	Barcelona	23	46	49
Milan	50	57	62	Dublin	22	39	33
Hamburg	48	61	56	Madrid	20	53	50
Turin	47	52	54	Stockholm	18	40	34
Munich	45	54	54	Sofia	17	35	29
Lyon	45	63	68	Bucharest	16	42	34
Zurich	44	54	59	Lisbon	13	42	36
Genoa	43	49	47	Istanbul	12	58	47
Newcastle	43	55	50	Athens	11	46	37

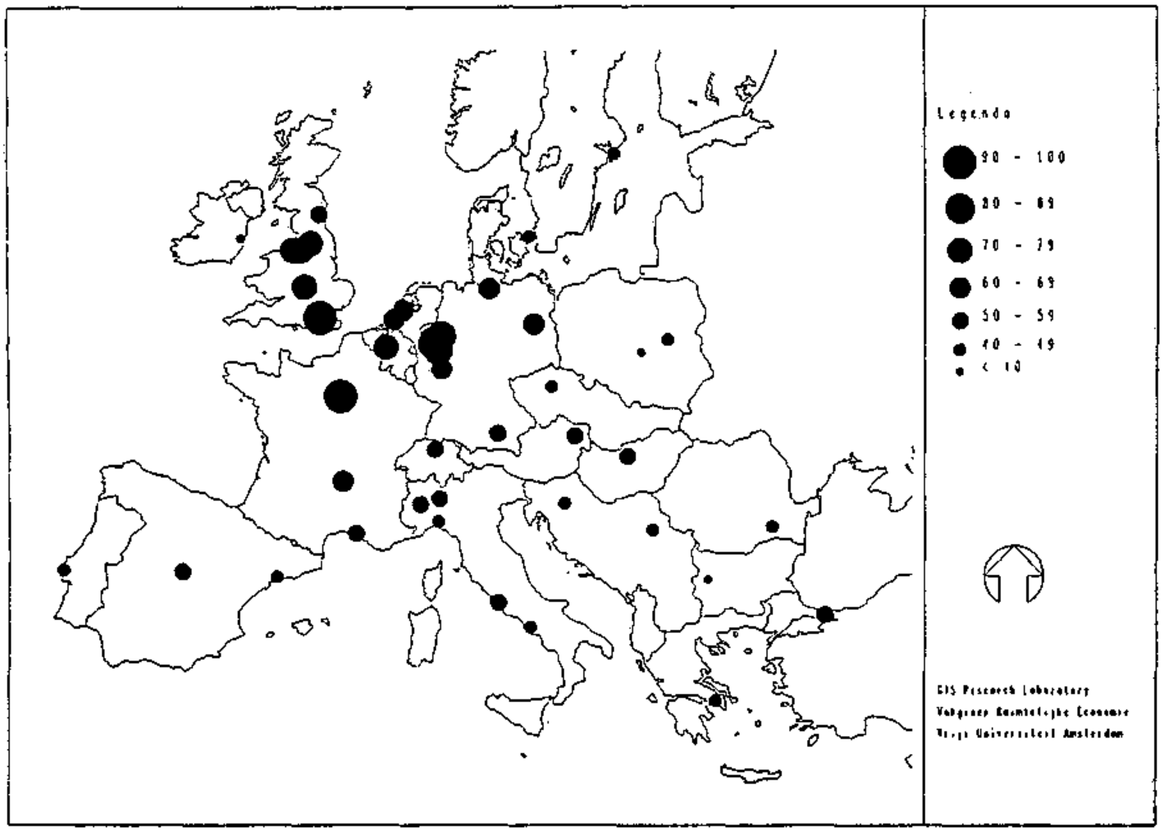

Figure 2 Accessibility of European cities by rail traffic, weighted by population size

relatively large number of cities are located near to each other. In the gravity model interaction over short distance is relatively high.
When weighting for population size takes place, Paris and London become dominant again by their large internal interaction (Table 2, column 2 and Figure 2). The scores of other large agglomerations also improves considerably.

For rail traffic only one future scenario is formulated. The high speed links (HSL) as proposed by the European Commission (CEC, 1990) are integrated in the model. The measures already taken in the various countries make the C.E.C. proposal plausible, altough. One must of course always take into account that at the level of individual links differences will emerge between proposal and realization. The high speed rail network is planned in Northwestern Europe, the area which at the moment is already best accessible by rail traffic. Before explaining the results we have to indicate how travel times are computed in the HSL case. We have not changed the frequencies of the existing connections. We only reduced the travel time on the parts of the network where high speed services are planned.

Interesting is that it is Brussels and not Paris which gains most by the introduction of high speed links (Table 2, column 3). Brussels gains most both in a relative and an absolute sense. The central location of Brussels in between the large population concentrations of London, Paris and the Ruhr-area explains this favourable development.

The development of the high speed rail network is of course most favourable for the cities located on this network, especially Northwestern Europe. Interesting is the relatively large impact of the high speed rail network on the urban axis Northern Italy - Barcelona. For those cities not only their links with Northwestern Europe improves, but also their mutual links, which are at the moment rather bad.

5 Road traffic

The results of the road network are to a great extent similar to the results of the rail network. Again in the unweighed situation the cities in the Ruhr-area score best and in the situation weighted for population size, Paris and London become dominant (Table 3, column 1 and 2 and Figure 3).

We have formulated two future scenario's. In the first scenario all connections considered achieve highway quality (Table 3, column 3); in the second scenario in addition to the improvement of the road network itself, the ferries are replaced by bridges and tunnels (Table 3, column 4). Both scenarios are plausible. The first one entails the upgrading of the road quality in the Northern, Eastern and Southern part of Europe; this is what one may expect when economic conditions improve in these areas. Agreement on most of the bridges and tunnels mentioned in the second scenario has already been reached between the

governments concerned.
The improvement of the road network leads to better scores for the East and South European cities and Stockholm. At the moment most of the roads in these regions are of a low quality. The relatively strong rise in the scores of the East European cities compared with the South European cities and Stockholm can be explained by the shorter distance of the East European cities to the centrally located agglomerations. In the gravity model a gain of 10 minutes travel time on a trip of one hour has a greater effect on accessibility than the same gain in travel time on a two hour trip.

If, in addition to the improvement of the road network itself, ferries are replaced by bridges and tunnels (the Channel-tunnel, links between Sweden - Denmark and Denmark - Germany) the impact on the accessibility index seems to be marginal. However, the individual index of for instance the English cities shows a

Table 3 Accessibility of European cities by road traffic

	1	2	3	4		1	2	3	4
Düsseldorf	100	78	79	78	London	72	94	94	95
Essen	98	77	78	77	Vienna	71	60	62	61
Cologne	97	75	75	74	Prague	71	58	61	60
Brussels	87	70	70	70	Marseille	69	56	57	56
Rotterdam	85	69	69	69	Zagreb	67	54	57	55
Leeds	85	74	74	74	Budapest	66	61	64	62
Amsterdam	85	67	67	67	Rome	64	63	64	62
Frankfurt	84	70	70	69	Copenhagen	60	52	52	56
Manchester	84	71	71	71	Lodz	60	49	55	54
Liverpool	81	68	68	68	Belgrade	60	52	55	54
Milan	80	65	65	64	Barcelona	59	54	54	54
Turin	78	61	61	60	Naples	59	49	50	49
Munich	78	63	64	63	Warsaw	58	51	57	56
Zurich	78	63	63	62	Sofia	55	45	49	48
Birmingham	77	70	70	71	Dublin	52	43	43	43
Genoa	77	59	60	59	Madrid	51	58	60	59
Paris	76	100	100	100	Bucharest	51	50	54	53
Lyon	75	62	62	62	Stockholm	50	45	46	47
Newcastle	75	60	60	61	Istanbul	47	67	70	68
Hamburg	74	66	66	66	Lisbon	46	48	50	49
Berlin	72	74	75	74	Athens	44	52	55	54

1 = unweighted 2 = weighted 3 = road improvement 4 = road improvement/bridges/tunnels

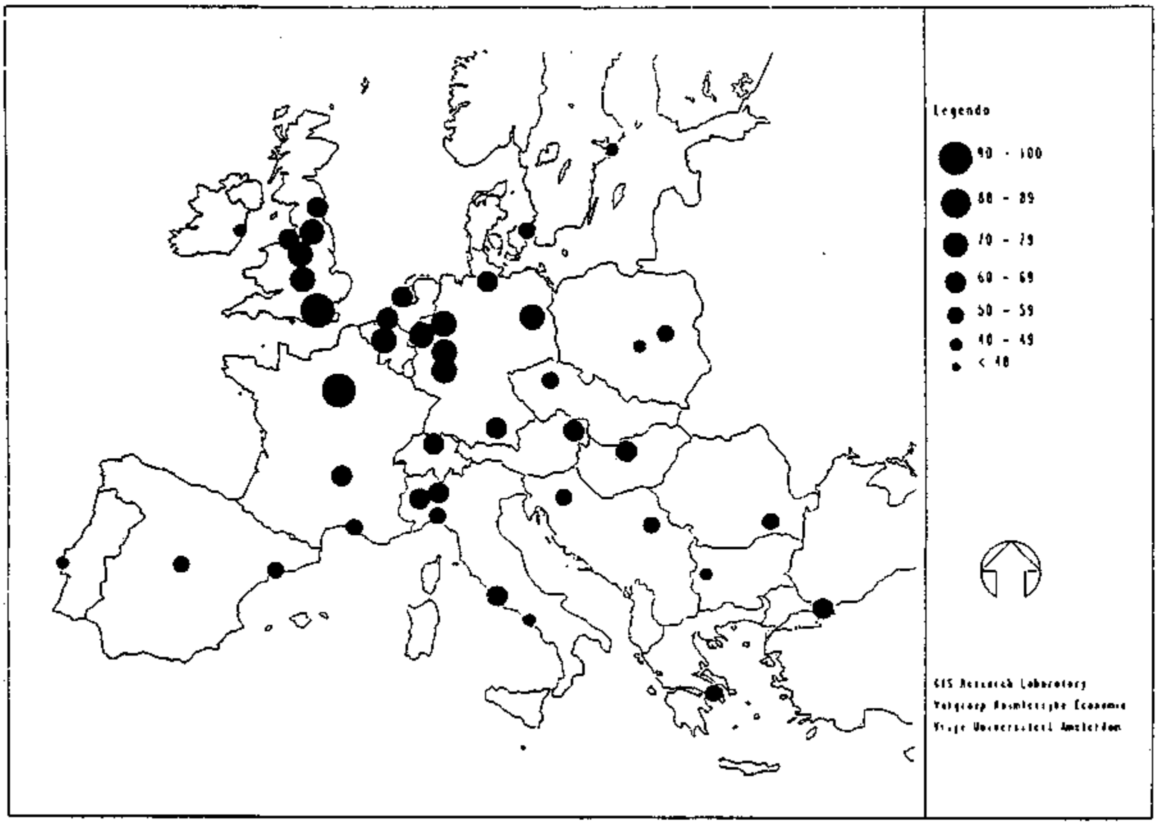

Figure 3 Accessibility for road traffic, weighted by population size

relatively sharp rise. This rise in the individual score does not appear in the final index because also Paris (the reference city) profits from the improvement of the road network as well as from the Channel-tunnel.

6 National borders as barriers in the road network

It is generally recognized that national borders function as barriers in international interaction patterns. Research has proved that the crossing of national borders is more then just the physical crossing of an administrative barrier, which could lead to extra travel time for instance as a consequence of customs formalities. A national border often can be understood as a non-physical barrier with an economic, political, cultural or language dimension (see Nijkamp et al., 1990).
In most of the research on the effects of borders on international interaction

patterns it is tried to trace the difference in interaction patterns of two cities located in the same country compared with two cities located in different countries. The results show a reduction in interaction of in between 70 or 80 per cent in the case a border has to be crossed within Northwest Europe (see Bröcker, 1984 and Nuesser, 1985). The interaction is even more disrupted when borders between other countries are crossed (see Rietveld en Jansen, 1990).

Another approach would be to analyze the density of infrastructure networks (both road and rail) in border regions, national border zones (contains all regions of a country bordering on another country) and on the border line itself and to compare these figures with the national average. One might expect that network densities in border areas are in general lower than their national average. We have tested this for a number of Western and central European regions (for the E.C NUTS-II regions have been used (EUROSTAT, 1990)). It appears that our expectation is not confirmed: the density of the highway network in 44 % of the border regions and 49 % of the national border zones is above the national average. Only 26 % of the national border zones score below the national average. In 25 % of the cases an equal score is found. This high score can be explained by the fact that some countries (Luxembourg, Switzerland and Austria) could not be divided in border zones.

The explanation of these unexpected results is that at the level of spatial aggregation used, many border regions have large centres within their area. For example, NorthRhein Westfalia which includes the Ruhr-area is a border region in Germany. Therefore we have checked to which extent population density can explain the observed results. Regression results show that infrastructure density is closely related to population density. Corrected for population density, border regions still have slightly higher infrastructure densities however. Thus at this level of spatial aggregation no clear sign can be found of a disadvantageous position of border regions in terms of infrastructure densities.

Completely different results are obtained when one focuses on infrastructure densities on the border line itself. The density on the border line is in nearly all cases below the regional average (on average only 29 % of the regional average). Exceptions have to be made for areas in which on an extremely short border line a highway is located, for instance the region Pais Vasco in Spain.

Similar results are found if the density on border lines is compared with the density in national border zones. Although still clearly below the national average, the density on the border line is relatively high on the mutual Benelux borders, on the borders between the Benelux and Germany and on the borders between the Benelux and France.

We conclude that, although the border regions are relatively well equipped with highway infrastructure the density on the border line itself remains far below the national average. Thus it appears that the orientation of the well equipped border regions is focused on the national instead of the international economy.

Our conclusion is that national borders exert a barrier effect on international communication. In the case of the road transport this barrier effect is due to both non-physical factors such as language differentials, and physical factors such as the low density of roads on border lines. In the case of air traffic the physical network infrastructure is not biased against border crossing flights. However, here too barrier affects will occur since the frequencies of flights between cities tend to be lower when these cities are located in different countries compared with only one country. With rail both elements play a role: network densities on borders are relatively low, and also the frequencies of international trains are relatively low.

It is interesting to investigate the impact of barrier effects on the accessibility measures. We will focus on road transport here. Barrier effects are taken into account by reduction factors. The reduction factors for the different combinations of countries are given in Table 4. The domestic interaction flows are not reduced.

The results are striking compared with the situation without barriers (Table 5, column 1 and 2, Figure 3 and 4). London takes over the first position from Paris.

Table 4 Border related reduction factors for road transport

	E.C.-country	E.F.T.A.-country	East European country
E.C.-country	.250	.167	.125
E.F.T.A.-country	.167	.167	.125
East European country	.125	.125	.167

Table 5 Impact of borders as barriers in the road network on the accessibility of European cities

	1	2	3	4	5	6		1	2	3	4	5	6
Paris	100	97	1	-	-	-	Budapest	61	48	-1	1	-	4
London	94	100	-	-	-	-	Turin	61	49	1	1	-	-
Düsseldorf	78	69	1	-	1	-	Newcastle	60	61	-	-	-	-
Essen	77	68	1	-	-	1	Vienna	60	43	-	-	5	-
Cologne	75	64	1	-	1	-	Genoa	59	50	1	-	-	-
Berlin	74	71	1	-	-	-	Madrid	58	59	-	-	-	-
Leeds	74	77	-	-	-	-	Prague	58	38	-	1	-	-
Manchester	71	73	1	-	-	-	Marseille	56	47	2	-	-	-
Brussels	70	41	4	-	1	-	Barcelona	54	48	1	-	-	-
Birmingham	70	70	1	-	-	-	Zagreb	54	39	-1	1	-	-
Frankfurt	70	59	2	-	-	-	Copenhagen	52	42	1	-	1	-
Rotterdam	69	49	3	-	-	-	Athens	52	55	-	-	-	-
Liverpool	68	69	1	-	-	-	Belgrade	52	41	-	1	-1	-
Istanbul	67	73	-2	-	2	-	Warsaw	51	44	-	-	-	-
Amsterdam	67	47	3	-	-	-	Bucharest	50	45	-1	1	-	-
Hamburg	66	60	1	-	-	-	Naples	49	46	1	-	-	-
Milan	65	54	2	-	-	-	Lodz	49	39	-	1	-	-1
Rome	63	62	-	-	-	-	Lisbon	48	48	1	-	-	-
Munich	63	62	1	1	-	-	Sofia	45	35	-	-	-	-
Zurich	63	40	-1	-	7	-	Stockholm	45	41	-	-	3	-
Lyon	62	51	1	-	1	-	Dublin	43	36	1	-	-	-

1 = without border effect
2 = with border effect
3 = change due scenario 1
4 = difference between scenario 2 to 1
5 = difference between 3 - 2
6 = difference between 4 - 3

The explanation is rather simple. Reduction factors are only used for international connections. In our sample six English and seven German agglomerations are included. They are all ranked within the first twenty. Only large agglomerations like Paris, Istanbul, Rome, Madrid and Athens are ranked in between them. The share of the internal interaction in their total score can be as high as 96 % as is the case for Istanbul.

Major losers are the agglomerations in smaller countries which are rather centrally located, like Brussels, Amsterdam, Rotterdam, Zurich and Prague: their

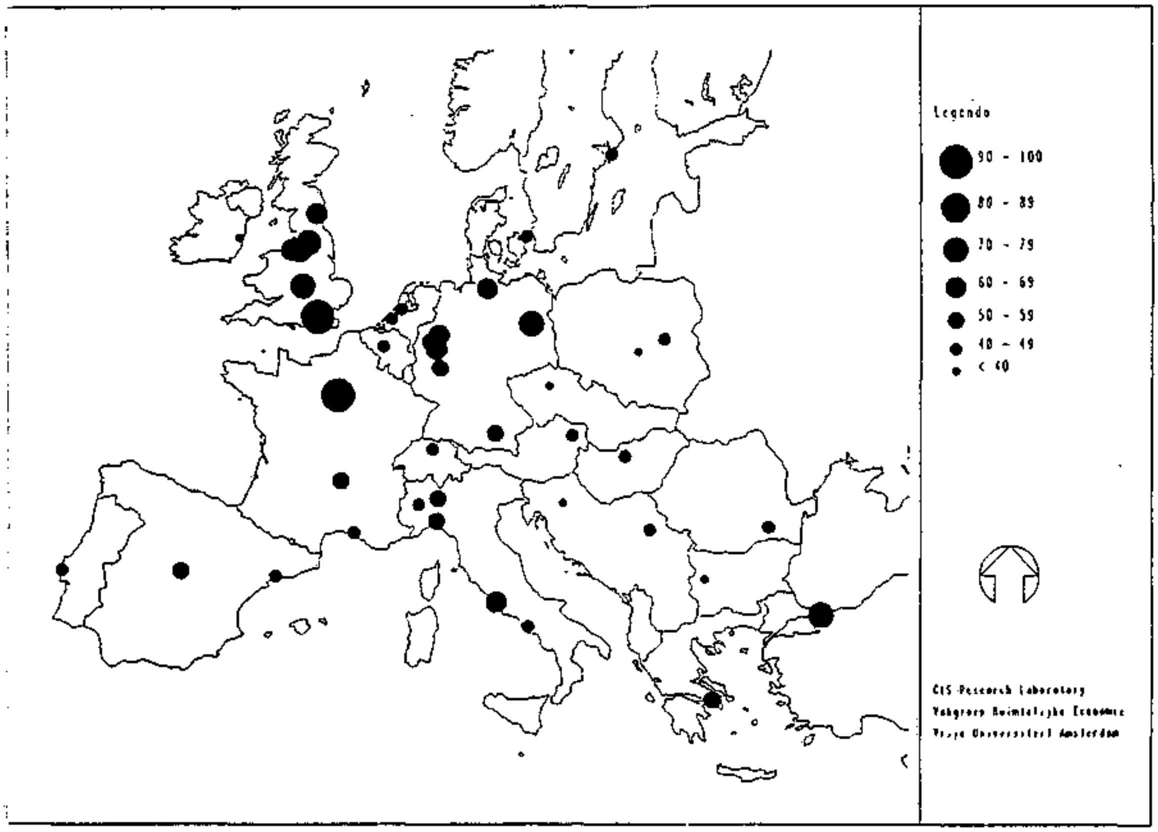

Figure 4 Impact of borders as barriers in the road network on the accessibility index of European cities

score largely depends on connections with foreign agglomerations.

We have formulated four scenarios of future political developments which could decrease the barrier effects of national borders. In the first scenario we assumed that in Europe after 1992 the cross-national interaction would be less disturbed as at present. So the reduction factor declines from .250 to .333. In the second scenario, above this development within the E.C., we expect that the political transition in Eastern Europe leads to an easier access of those countries. So all relations with East European countries receive a reduction factor of .167. In the third scenario we analyze the changes when the E.F.T.A.-countries are welcomed in the E.C. and in the last scenario also Hungary becomes an E.C. member.

One might expect some major changes in the accessibility index, but as shown in

Table 5, columns 3-6 the changes are moderate. The smaller agglomerations in relatively small countries gain most from Europe 1992. In the second scenario, the rise in accessibility of Eastern European countries is marginal, Warsaw and Sofia do not even gain one per cent point. The acceptance of the E.F.T.A.-countries in the E.C. leads to the first rise of real importance. However, notice that here the possibility to cross the border is doubled. When Hungary is accepted as a member of the E.C. a similar rise would occur for Budapest.

The conclusion is that there has to be a relatively large decline in the barrier related reduction factor before a substantial rise in the accessibility score of an agglomeration occurs. It would be rather short sighted to be only concerned about the extension of physical infrastructure networks, however. The non-physical - organisational and political - barriers seem to be as important for an improvement of accessibility.

7 Integration of the transport modes: the shortest travel time

In the preceding sections we have studied the accessibility for the individual infrastructure networks. An important reason to proceed in this way is that the changes in accessibility as a consequence of certain major improvements in the individual networks can be shown most clearly by this way. However, the real interaction pattern consists of a mix of those infrastructure modes. The choice of transport mode depends on the preferences of the individual travellers. Their preference will be strongly influenced by the travel time and price of the transport modes. On short trips the share of the car and train will be high because those modes are cheap and fast over short distances. However, on the longer trips the high price of air travelling will be compensated by the gain in travel time.

The prices of transport are not included in our study, so we only used the shortest travel time for the measurement of an integrated accessibility index. When the indirect flights are included the airplane is the fastest transport mode for 93 % of the connections (1604). The car and train are fastest for respectively

5 (92) and 2 (26) per cent of the connections. The 118 non-airplane connections consists for 36 % of connections for which no direct air connection is available (mainly domestic connections).

The results, weighted for population size, are given in Table 6 and Figure 5. Düsseldorf, an agglomeration with a small population (low share of the internal interaction) scores best. Düsseldorf has fast road and rail links with the other cities in the Ruhr-area which means a high interaction between those cities. Furthermore, Düsseldorf can use the airport of Frankfurt for missing air connections.

Table 6 Accessibility by use of the transport mode with the shortest travel time

Düsseldorf	100	Birmingham	76	Lyon	67	Prague	57
London	98	Rotterdam	74	Copenhagen	67	Lisbon	57
Paris	96	Milan	73	Istanbul	67	Genoa	56
Manchester	91	Berlin	73	Barcelona	64	Bucharest	54
Essen	89	Zurich	73	Dublin	63	Belgrade	53
Leeds	87	Rome	70	Turin	62	Naples	53
Cologne	87	Madrid	70	Athens	61	Zagreb	50
Liverpool	86	Hamburg	70	Budapest	61	Sofia	49
Amsterdam	81	Munich	68	Marseille	59	Lodz	49
Brussels	78	Vienna	68	Stockholm	58		
Frankfurt	77	Newcastle	67	Warsaw	57		

Although the air traffic deals with 93 per cent of the connections, the interaction pattern is quite different from the pattern of the air traffic (compare Table 1, column 3). This can be explained by analyzing the car and train connections. The car and train connections all concern connections over short distances, which results in high interaction flows in the gravity model. Another interesting result is the relatively small spread in the integrated index (100-49) compared with the spread in the index of road traffic (100-43) and rail traffic (100-35). This can be explained by the reduction of the large travel time differences which exists for car and train traffic between short and long connections by introducing the air traffic for the long distances. Thus the integrated index shows a greater equity in

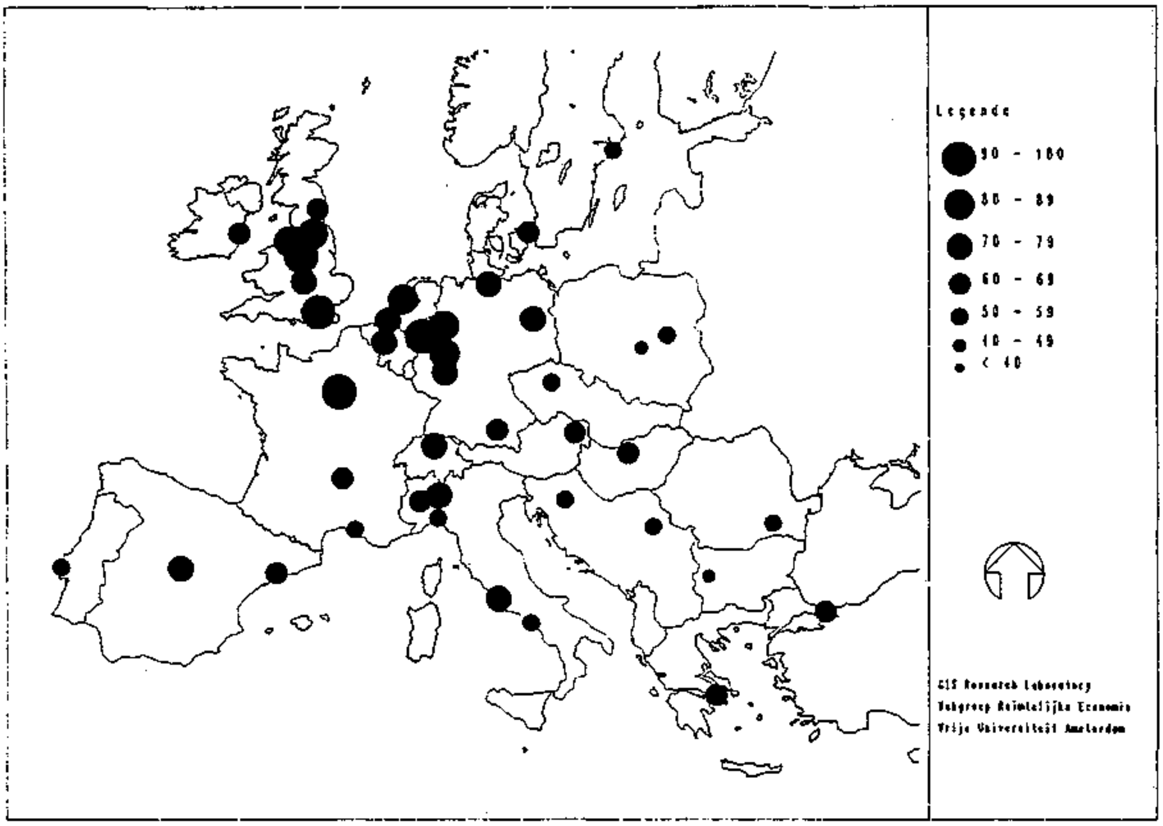

Figure 5 Accessibility of European cities by use of the transport mode with the shortest travel time

accessibility compared with the individual transport modes.

8 Equity in accessibility

A major issue which until now has been neglected is the equity in accessibility of the agglomerations in the infrastructure networks.

Which transport modes show the smallest differences in accessibility? Does this difference increase or decrease as a consequence of the improvements in the network? Which transport mode has the highest average accessibility? Does this average increase or decrease as a consequence of the improvements? What are the mutual relationships between these improvements?

8.1 Air traffic and shortest travel time

In Table 7 we present some key summary indicators on accessibility for air traffic, weighted by population size. The coefficient of variation is rather high which means that there are large differences in the accessibility of the agglomerations. This could be expected because for instance Essen and Lodz have no airport and as a consequence have very low scores. This explains also why the impact of the future scenarios on the coefficient of variation is rather small. The situation of Lodz and Essen does not change.

Table 7 Development average accessibility by air traffic and shortest travel time

	Actual	Doubled frequency	Mainport orientation	Indirect connections	Shortest time
Average score	264671	285942	274660	340625	379371
Standard deviation	94164	99410	97520	55933	74206
Coefficient of variation	.356	.348	.355	.164	.196
Average accessibility	100	108.0	103.8	128.7	143.3

The fact that the doubling of all frequencies results in larger effects than the mainport development is shown in the coefficient of variation and in the average accessibility. In both situations the development of the doubling of all frequencies is favourable.

Major changes are recognized when indirect flights are included. Compared with the situation without indirect flights the inequity in accessibility is halved and the average accessibility has risen by one third. It might be clear that in this situation the accessibility of agglomerations with no or bad air traffic connections rise sharply, while the accessibility of the best accessible agglomerations rises only marginally by adding the indirect flights.

If we compare the results of air traffic in which indirect flights are included with the results based on the fastest transport mode, some interesting changes occur. Although the average accessibility rises sharply, there is a slight decrease in the equity of accessibility.This can be explained as follows. The average accessibility rises because for the lacking inland connections or for unfavourable air connections one can choose for a trip by car or go by train. In all cases this concerns connections over short distance, which according to the gravity model, generate large interaction flows. The agglomerations for which those connections are included had already a relatively high accessibility in the reference case (cities in the Ruhr-area and Mid-England). Their accessibility tends to rise sharply while the accessibility of the low scoring agglomerations hardly rises. So the equity in accessibility decreases.

8.2 Rail traffic

As is the case for air traffic without indirect flights the equity in accessibility for rail traffic is rather low (Table 8). Especially the connections in East and South Europe are rather bad. The development of high speed links in Northwest Europe makes the situation only worse. The rise in inequity is evident.
Notable, however, is the sharp rise in the average accessibility as a consequence of the high speed links. Of the formulated future scenario's for all the transport modes the impact of the high speed links on the average accessibility is by far the largest. However, the measures needed are also far-reaching (both in network changes and in investment volumes).

Table 8 Development average accessibility by rail traffic

	Actual	High-speed links
Average score	211304	205695
Standard deviation	59321	79673
Coefficient of variation	.281	.318
Average accessibility	100	118.6

8.3 Road traffic

The inequity in accessibility for the road network is relatively small (Table 9). The inequity further decreases when all roads become of the highway quality. This is not surprising because this means road improvements in areas already peripherally located; South Europe, East Europe and Sweden. So the score of the lowest scoring agglomerations tends to rise. The construction of tunnels and bridges leads to a rising inequity. Paris, London - the highest scoring cities - and the English cities are favoured by the Channel-tunnel, whereas the score of the low scoring agglomerations does not substantially rise. The investment program foreseen has only a marginal impact on average accessibility in Europe. However, the rise in inequity cannot compensate for the decrease in inequity achieved with the construction of highways.

The impact of national borders as barriers in the international interaction patterns is rather drastic. Compared with the reference situation the inequity of accessibility rises with over 40 % and the average accessibility decreases with over 30 %. This shows once more the impact of non-physical barriers on the accessibility of urban agglomerations.

In Table 10 the results are shown when the barriers are reduced by political changes as formulated in section 6. A decrease of the barriers within the E.C. with one third (scenario 1) as a consequence of the common market only has a small impact on the average accessibility. The impact on the equity issue is negligible. The impact is rather meagre if one bears in mind that here the

Table 9 Development average accessibility by road traffic

	Actual	Highway	Bridge/tunnel	Barriers
Average score	212914	218698	222930	145251
Standard deviation	40843	38534	40150	39867
Coefficient of variation	.192	.176	.180	.274
Average accessibility	100	102.7	104.7	68.2

Table 10 Development average accessibility by road traffic, barriers included

	Barriers	Scen. 1	Scen. 2	Scen. 3	Scen. 4
Average score	145251	149356	150237	150227	152829
Standard deviation	39867	40911	40467	40052	39977
Coefficient of variation	.274	.274	.269	.263	.262
Average accessibility	100	102.8	103.4	104.8	105.2

barriers of 33 out of the 42 agglomerations are concerned. The same could be said for scenario 2 where the barriers for the eight East-European agglomerations also decreases with one third. The coefficient of variation decreases because here the relative score of the lowest scoring agglomerations rises.
Scenario 3 concerns only the four EFTA-agglomerations of which barriers decrease from .167 to .333 (what means a doubling of the possibility to cross a border). The equity in accessibility increases in a relatively sharp way as does the average accessibility. The same pattern occurs when Budapest undergoes a similar decrease of barrier effect (scenario 4).
Keeping in mind the coefficient of variation before introducing the barrier effects (Table 9) one may conclude that the existence of non-physical barriers has strong impacts on the accessibility of cities.

8.4 The transport modes compared

In Table 11 the average accessibility of each transport mode is given as a percentage of the average accessibility of the air traffic in which indirect connections are excluded. The sequence in which the transport modes are ranked may not cause any surprise. However, the difference in the values is notable. Once more the effect of borders as barriers in interaction patterns stands out.

Table 11 Average accessibility of the transport modes in 1991 (air traffic = 100)

Road traffic, barriers included	54.9
Rail traffic	79.8
Road traffic, barriers excluded	80.4
Air traffic, indirect flights excluded	100
Air traffic, indirect flight included	128.7
Shortest travel time	143.3

Although the value for road traffic (barriers excluded) is higher than the value for rail traffic, the difference is marginal. This can be explained by the fast and frequent train connections between city centres within countries by the national railway companies. Those connections are often faster then car connections. On those short distances a small difference in the total travel time leads to rather large differences in accessibility. It is because of this effect that the average accessibility of rail traffic becomes that close to the average accessibility of road traffic.

9 *Concluding remarks*

The above numerical results depend on various assumptions about parameters, conventions used in measuring travel times and on the ways the scenarios have been formulated. We believe that the main patterns emerging are fairly robust. Inequalities in accessibility are least pronounced in the road network. In the rail network inequalities are clearly higher. In the air system inequalities depend strongly on whether or not indirect flights are considered: with direct flights only, inequality is high, whereas when also indirect flights are taken into account inequality is low.

The scenario studies reveal that the impacts of changes in the road and air system on average accessibility will be rather small. In the rail system larger impacts on average accessibility may be expected.

Existing inequalities in accessibility are expected to remain rather constant in the air system. For roads the improvement of the system in Eastern and Southern Europe is expected to contribute to improvements of relative accessibility of the cities there, which leads to a decrease in inequalities. For rail the reverse is expected to occur: cities in Northwestern Europe will benefit most from the high speed links, which leads to an increase of existing inequalities.

In our study we also investigated non-physical aspects of borders. Their effects on accessibility of cities in smaller countries is considerable. Therefor, non-physical aspects of networks should receive due attention in future studies and policies on infrastructure networks in Europe.

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