Changes in road infrastructure and accessibility in Europe since 1960

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DOI:
10.2776/82108

European Commission

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Final report

Regional and Urban Policy

June 2013

E-mail: regio-publication@ec.europa.eu
Internet: http://ec.europa.eu/regional_policy/index_en.cfm

Cataloguing data can be found at the end of this publication.
Luxembourg: Publications Office of the European Union, 2013
ISBN : 978-92-79-31566-4
doi: 10.2776/82108

Printed in Belgium
PRINTED ON ELEMENTAL CHLORINE-FREE BLEACHED PAPER (ECF)

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Tender reference nr **2012.CE.16.BAT.040**

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
REGIONAL POLICY
Policy development
Economic and quantitative analysis

Final Report
Revision and additions

June 7, 2013

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Acknowledgements

We would like to thank DG Regio for granting us the research assignment and funds and Lewis Dijkstra of Eurostat for his valuable comments and suggestions along the way. Marco van Egmond , curator of maps and atlases at the University library of Utrecht, has been very helpful in finding the right maps. Mr. Jean-Pierre Boisseau of Hallwag Kümmerly+Frey AG in Bern has been most helpful by giving access to his company's historical archives.

We give a very special thanks to Luuk Stelder and Jimme Zoete who have done all map referencing and drawing in this project. Without their enduring efforts and expertise on mapping and GIS techniques this project would have never been realized.

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1. Introduction

Infrastructure investment in roads is one of the main instruments of regional policy because regional accessibility is generally considered to be an essential prerequisite for regional economic growth. As the Territorial Agenda of the European Union reads: "Mobility and accessibility are key prerequisites for economic development of all regions of the EU" so transport infrastructure improvement is a key policy instrument to promote regional economic development (ESPON, 2006). During the first 15 years of its existence the European Regional Development Fund devoted 80% of its funding to infrastructure projects (Vickerman, 1991) and over the period 2000-2006 about 35% of the Structural Funds and 50% of the Cohesion Fund has been spent on infrastructure projects (Crescenzi & Rodríguez-Pose, 2008)[1].

There is a large and growing literature on policy evaluation and the effectiveness of these types of programs covering a wide range of approaches[2]. Most, if not all of these studies, however, suffer from an important lack on information on the development of regional accessibility over time thanks to infrastructure improvement. In addition, infrastructure improvement in one region does not help that region very much in its relative spatial competition position if the same improvements are taking place in other neighboring or competing regions. As Lakshmanan and Chatterjee (2005) state, the economic outcomes of transport improvements are dependent on the context in which the improvements are made: the state of the pre-existing transportation network, the state of economic development and the nature of competition in and between the regions. Crescenzi and Rodriguez-Pose (2008) have proven that regions benefit from neighbouring regions which are well endowed, but that additional highways in a neighbouring region might lure firms away from their own region towards that neighbouring region. Groote et. al. (2009) distinguish between long term and short term effects of infrastructure investment in the 19th century in the Netherlands and find that both effects are related to competition with neighboring regions.

The development over time and the relative accessibility position of regions can be studied in detail when a database of travel time and travel distances could be constructed for the European road networks for different years. This document reports the construction of this database and analyses the development of relative accessibility over time since 1955. It is the result of a Eurostat-funded project which has been carried out in 2012-2013[3].

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[1] One of the most well-known EU projects is the Trans-European Transport Network TEN-T programme aimed at 30 priority projects to be completed in 2020. See http://ec.europa.eu/transport/infrastructure/networks_eu/networks_eu_en.htm

[2] See for an overview Ottaviano (2008) or McCann and Shefer (2004)

[3] EU project "Changes in road infrastructure and accessibility in Europe since 1960". European Commission; Directorate General Regional Policy, Policy development; Economic and quantitative analysis, Nr 2012.CE.16.BAT.040

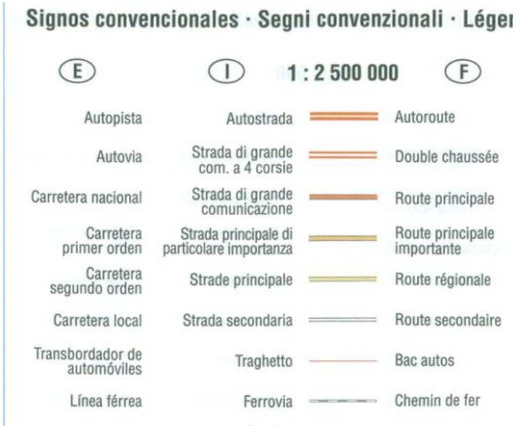
2. Data sources

Travel time route planners are nowadays freely available online (Google maps etc), but digital road networks for earlier years that are accessible for research are scarce. Companies like Teleatlas/Google or AND Solutions do not provide nor keep operational archives of online route planners for earlier years and the publication of digital route planners on CD archive has only been around for a limited number of years (around 1995-2000). This creates the somewhat strange situation that travel time between Amsterdam and Berlin is easily found today but cannot be retrieved anymore for 2009, 2008 or 2007. Therefore, in order to obtain consistent and comparable travel time matrices for earlier years digital road networks need to be reconstructed from printed road maps. For maximum comparability with today the best solution is to do the same for recently printed road maps instead of comparing earlier years from printed maps with digital route planner results for recent years. We have done this before for a historical road maps project for The Netherlands[4].

The geographical coverage of this project is the whole of Europe excluding Belarus, Ukraine, Russia and Turkey. In a first exploratory phase in 2011 various historical paper maps have been collected which are – as to be expected - not 100% consistent with each other. The key question is whether the maps are sufficiently detailed for a minimum road classification of 4 to 5 categories. There is a large international library of geographical maps available but only a small subsection of it has the desired classification information: the road maps designed for automobile drivers that are typically sold at gas stations. For overall consistency in drawing and classification, the ideal dataset would be a consistent set of European road maps, preferably as one large map, or as a small set of sub maps (like North/South) that can be scanned together into one image to be converted into a digitized road network. Road atlases in book form with many pages to be combined prove to be less desirable because of time costs in scanning/merging and because of – as we encountered frequently - different geographical projections per page. As a first option we collected a map set of Kümmerly & Frey at scale 1:2.500.000 for 1957, 1971, 1980, 1992, 2000 and 2010 with five road classifications. Except for 1957, all maps have the same classification in six categories as illustrated in Figure 1a. Figure 1b shows that the 1957 map has only four categories. To our best knowledge no comparable map has ever been published around the year 1960.

[4] A working paper is under publication. Technicalities and first results are available in this presentation. See http://www.regroningen.nl/stelder/doc/lse.zip

Figure 1a. Legend K&F 2010 ***Figure 1b. Legend K&F 1957***

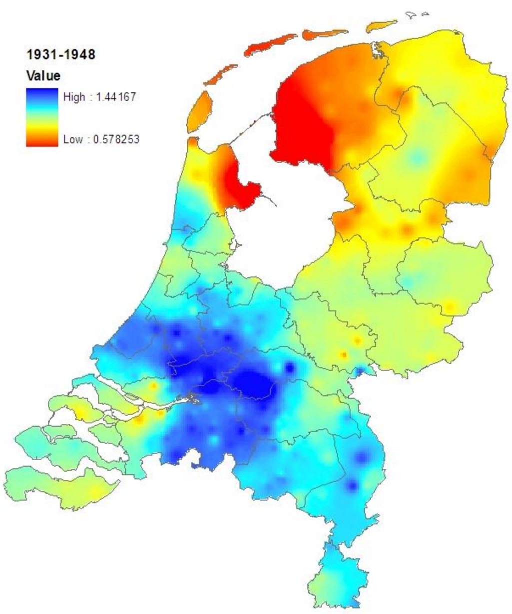


For today, as mentioned, travel time can be obtained directly from Google Maps or other route planning software but the comparability of that outcome with earlier years derived from the paper maps is of course difficult to evaluate. Therefore we also constructed a road network for 2012 from paper maps to guarantee methodological consistency for all years of the dataset. A second option came available in a later stage of the project in the form of an additional set of maps at a much higher detail of 1:800.000 for a slightly different set of years 1970, 1980, 1993, 2000 and 2012. This is “Het beste boek van de weg”, a Dutch road atlas publication of the ANWB that has kept an almost identical publication format over these years. Their road classification is the same as the one of K&F shown in fig 1a-b. It is this map set that has been used to construct the digital road networks for 1970 -2012. For the first year 1995 the K&F map mentioned in Figure 1b has been used.

Digital high resolution scans of the maps have been georeferenced (given their correct geographical mapping and projection in order to be consistent with other GIS sources) and redrawn into road networks including the road classification information. In order to estimate accessibility effects each classification is given a numerical indicator based on capacity, speed limits and/or average speed. For a given set of locations and/or regions then the shortest travel time path D_{ij} between two locations i and j over the networks can be calculated.

An accurate estimate of the *absolute* level of real historical travel time for each year is of course preferred but it should be stressed here that that is not necessary for an analysis of *changes* in accessibility. Absolute accessibility for each location i is given by the inverse of the sum of all travel times to all other locations $X_i = 1 / \sum_j D_{ij}$ and can then be scaled to relative accessibility $x_i = X_i / X^*$ with $X^* = \sum_{ij} D_{ij}$. Historical change of relative accessibility can then be mapped for all locations for each period as $x_i\ (t)/\ x_i\ (t\text{-}1)$. This method has the advantage that all kinds of maps with different scales and classifications can be compared with each other. As an example, figure 2 below shows such a map as a result of road development between 1931 and 1948 for The Netherlands based on two maps with substantially different formats. It clearly shows that the south west regions have gained in relative accessibility during this period at the cost of the North-East. These types of figures are constructed for the whole of Europe over all relevant time intervals between 1955 and today.

Figure 2. Change in relative road accessibility 1931- 1948 in the Netherlands



Source: Stelder (2011)

3. Maps used

Annex A shows an overview of the maps used and the resulting road networks for each of the seven selected years 1955, 1970, 1980, 1990, 2001, and 2012. We will briefly discuss each of them below.

1955

For the first year of the map dataset the K&F map of 1957 mentioned above has been used. It has been completed with parts of Northern Scotland and Scandinavia from an Esso road map of 1956 because the K&F map did not cover those areas (see Figure A1). The Esso map has a less detailed scale of 1: 4.000.000 but that is acceptable because of the low road density in that area, it has the three main road subdivisions and is of almost the same year of the K&F map. For map drawing, the priority has been set to the first three road categories and the main ferry connections. During the project this year has become labeled *1955* although strictly speaking is a combination of 1956 and 1957 data sources.

As the zoom-in to London shows (see Figure 3), the decision is taken to draw all larger cities (which are not drawn on the original map as a point but as an area) as a circle and connect all incoming roads somewhere inside to each other. This simplifies ring roads and inner city roads. For later travel time tables some travelling speed value for inner cities areas can be chosen (at wish for every city specifically as a variable).

Figure 3. Zoom-in London 1955

One problem with the 1955 map is that it does not cover the three Baltic States. In the network for 1955 this has been solved simply by copying the Baltic network of 1970 into the network of 1955. This implicitly assumes that there have been no road improvements in the Baltic network between 1955 and 1970. In the final harmonizing phase no efforts have been made to fully integrate the 1955 map with the later maps because the map sources are too different. The 1955 network therefore does not exactly match the network for later years while the networks of 1970 -2012 are almost exactly located “on top of each other”.

1970

The ANWB road atlas *Het Beste Boek van de Weg* of 1970, hereafter named ANWB1970, has been scanned by separate page and put together as an integrated geo-referenced background (see Figure A2). For the missing northern part of Scandinavia the coverage is taken from the larger K&F map for the whole of Europe.

1980-1993-2000-2012

For these years an exact match with the map of 1970 is intended because the ANWB publications follow the same format as 1970. The only difference with 1970 is that for the later years the coverage of Northern Scandinavia is also included (see figure A3 for 1980). The method followed is not to draw all roads every year again but only change those segments that have been changed/upgraded by giving them a new road category attribute. The exceptions to his rule are mainly new highways that have been constructed as a new track instead of an upgrade of already existing roads. This method leads to an optimal comparativeness of the road networks between different years. As an illustration to compare later maps with 1957 Figure 4 and 5 show the zoom-in to London for 1970 and 1980.

Figure 4. Roads London 1970

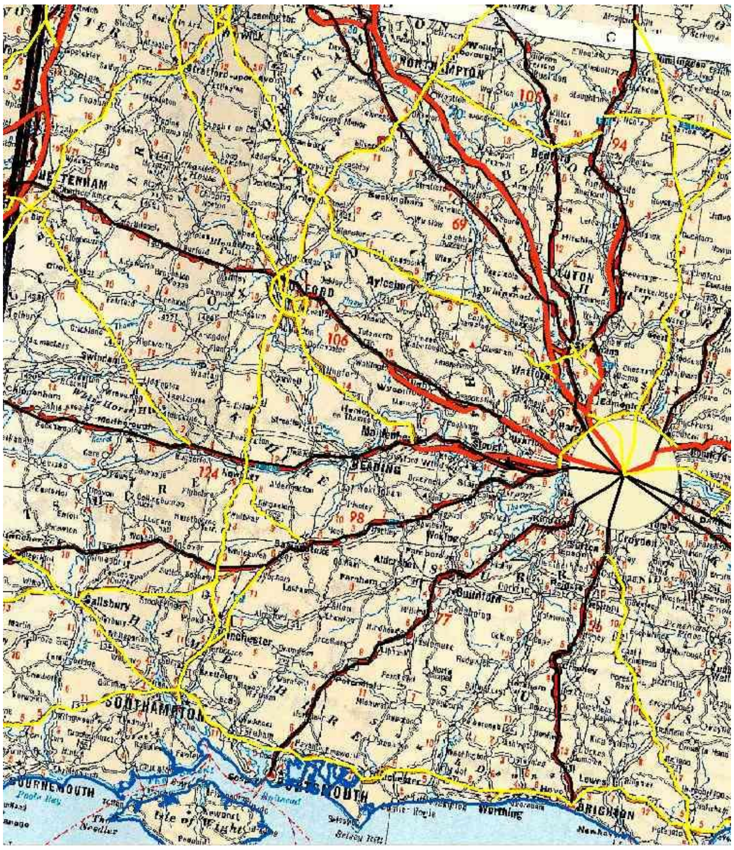
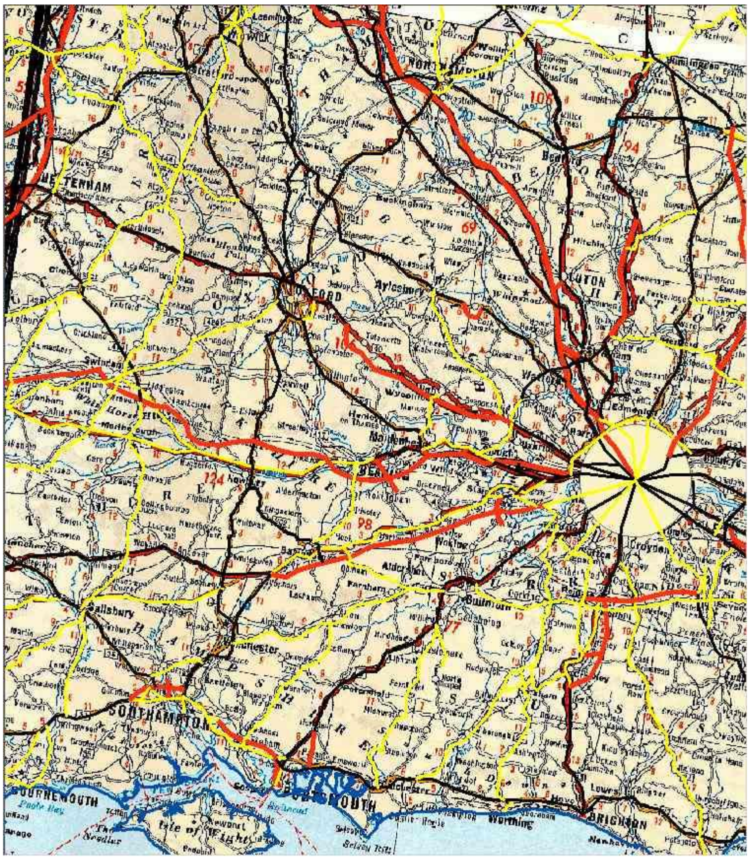


Figure 5. Roads London 1980 (background 1970)



4. Time coding

Given the resources of the project, of each map only the three most important roads could be drawn which implies three classes 1=highways, 2=main roads and 3=secondary roads. A frequently occurring problem, however, is that a class present in the map for year *t* disappears in *t+1*. This happens often with secondary roads that are "downgraded" to local roads in a later map. For consistency between the networks it is not logical to assume that these roads are no longer there in *t+1*, nor that their average speed has declined. For whatever reason the map maker in year *t+1* has valued this road not important enough for a class 3 classification while it still was a class 3 in *t*. The best interpretation of these cases is that the truth is somewhere in between. The fact that it was a class 3 in *t* indicates that this road is more important than other roads that are classified as local roads in both maps. Because we do not want to *reduce* the assumed speed for a segment over time, a simple alternative is chosen to assume a speed increase of 5% for all three classes for each decade, while keeping the speed of downgraded roads the same. Starting from the assumption of an average speed of 90,70 and 50 km/h for class 1,2 and 3 in 1970, this results in the code table given in Table 1.

Table 1. Road speed coding 1955 -2012

Digit 1: class

Digit 2-3: year

	class	Speed in km/h	
			Code for class 3 road in 1955
1955	155	85.5	
	255	66.5	
	355	47.5	355
1970	170	90	Same
	270	70	
	370	50	370
1980	180	94.5	Downgraded
	280	73.5	
	380	52.5	370
1990	190	99.2	Downgraded
	290	77.2	
	390	55.1	370
2001	101	104.2	returned
	201	81	
	301	57.9	301
2012	112	109.4	Upgraded
	212	85.1	212
	312	60.8	

As a hypothetical example, a class 3 road in 1955 and 1970, downgraded in 1980 and 1990, returning as a class 3 in 2001 and upgraded to class 2 in 2012 then gets 355, 370, 370, 370, 301 and 212 over time.

The relative overall speed increase of 5% is not based on empirical evidence but it enables the incorporation of downgraded roads without disturbing the general picture. In the theoretical case when two networks N_1 and N_2 would be exactly the same, one would only be 5% faster than the other for every route and nothing would change in relative accessibility: $x_i(1) = x_i(2)$ for every i.

In the analysis several time codes can be used for robustness checks, across categories as well as across time. Our pretentions in this project are not to give the final answer on correct absolute speed coding but to make the best guess possible given the time budget and the intended broader analytic framework. Much further historical research on exact time costs per road/year/country etc. is possible but in our view the main purpose of the project is to identify the main trends in accessibility developments. The architecture of the database is such that any code table can be easily replaced by another in the future. We refer to the technical description in Annex B for further details.

The treatment of ferry connections is done separately by exogenous entering travel time for each ferry taken from various sources. All ferry segments have been given an individual class code starting with 901 up to 948. An arbitrary choice has been made for the mean connections necessary to link Ireland, the UK, Corsica, Sardinia, Sicilia and Majorca to the continent, added with the most important connections for Scandinavia, the Baltic and across the Adriatic. All ferry links (around 45) are present in all networks and have a constant crossing time for all years. The only exceptions are ferries that are replaced by bridges, like the Great Belt Bridge. The Chunnel between Calais and Dover is entered for 2001 and 2012 as a ferry but with only limited consequences for the shortest paths between the UK and the continent.[5]

Figure 6. Ferries in the 2012 network

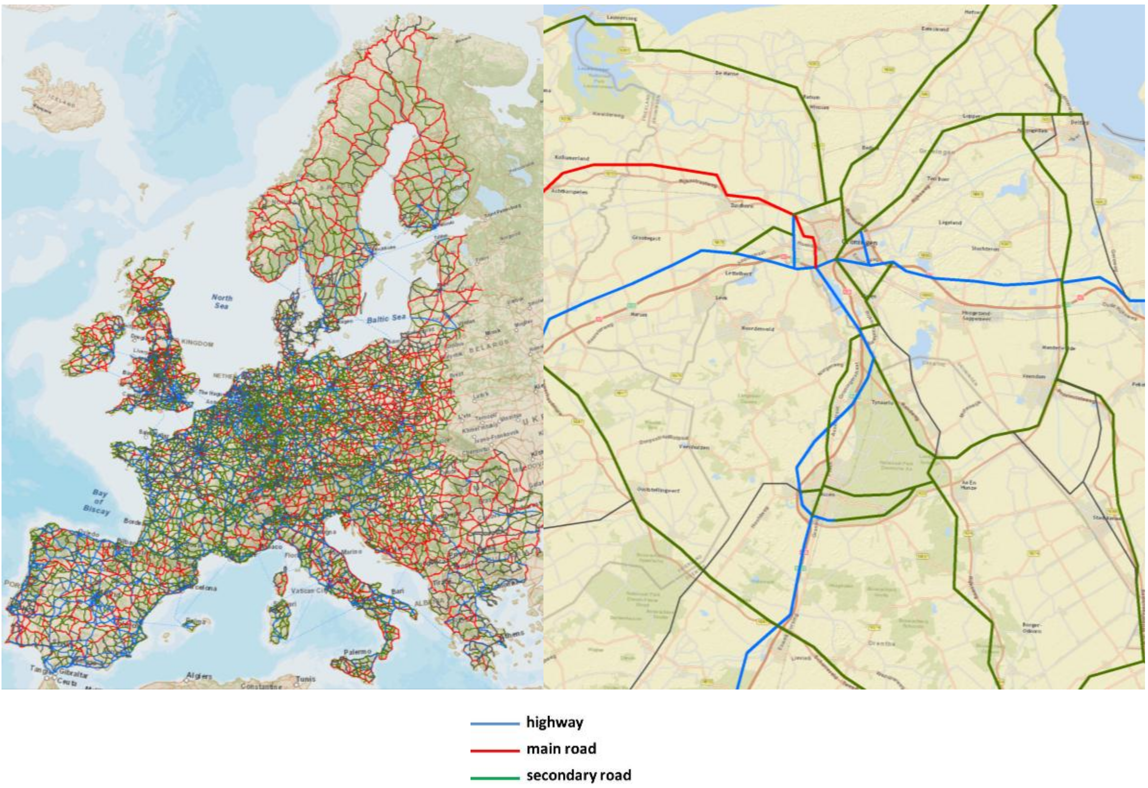
The geographical mapping of the network with other GIS sources is good on the whole but not perfect in close detail (see Figure 7). For correct road coding the most important issue was

[5] The tunnel between the UK and France lies very close to the ferry between Dover and Calais. Its travel time is strictly 35 minutes but around two hours when on/off loading of vehicles is included. The plain ferry time is 105 minutes so the two alternatives are competitive.

to fit the paper maps on each other as close as possible. Sometimes, consistency with correct geo-mapping and other GIS sources had to be compromised. This has been particularly an issue in the older maps for Eastern Europe which were less accurate in these areas. When the maps were too conflicting with each other to decide for either one of them on where the correct location of a road is. In those cases the location and exact shape of some road segment have been directly drawn over from World Street Map[6].

Figure 7. Comparison of the network 2012 with World Street Map

Whole map — Zoom to Groningen, Netherlands



It should be stressed, however, that this database is not intended for cartography but for spatial economic analysis. With some extra time and effort, all road segments can be reshaped and relocated to perfectly match today's high quality geographical maps. The outcome of the accessibility analysis, however, will remain the same.

Due to the simple time classification in Table 1 is not surprising that the shortest path estimates of the network differ from other sources. Table 2 shows the travel time in minutes between Brussels and some main European cities produced by the network 2012 and the Google Maps route planner (results June 2013). On average, the network produces lower

[6] World Street Map is part of an online ArcGis mapping library.

estimates, except for London and Dublin due to different ferry time estimates and Warsaw that benefits from recent highway upgrades which were not yet included in the 2012 map. For 12 out of the 18 destinations the difference is around 5% or lower and only for Paris and Amsterdam there a deviation of more than 10%. This probably due to a lower average highway speed in densely populated areas which is not accounted for in the network.

Obviously, more specific time coding in these areas can improve the performance of the most recent network relative to sophisticated route planners, but that is not the purpose of this project. What matters is the comparability of the historical networks between each other. In this respect Table 2 indicates that coding a lower average speed for the same roads in dense areas could be an option to investigate. The increasing importance of traffic congestion over time, however, may suggest that more of this speed adjustment should be applied in more recent years.

Table 2. Comparison between the network 2012 and Google Maps 2013

Road travel time from Brussels in minutes

	Lisbon	Madrid	Paris	London	Amsterdam	Berlin	Stockholm	Vienna	Rome
Network 2012	1080	824	161	268	109	398	883	582	767
Google Maps 2013	1098	854	184	254	134	415	924	595	824
% difference	-1.6	-3.5	-12.5	5.5	-18.7	-4.1	-4.4	-2.2	-6.9

	Budapest	Bucharest	Athens	Warsaw	Oslo	Helsinki	Tallinn	Prague	Dublin
Network 2012	706	1188	1486	717	887	1532	1263	470	709
Google Maps 2013	720	1311	1560	673	893	1620	1388	483	679
% difference	-1.9	-9.4	-4.7	6.5	-0.7	-5.4	-9.0	-2.7	4.4

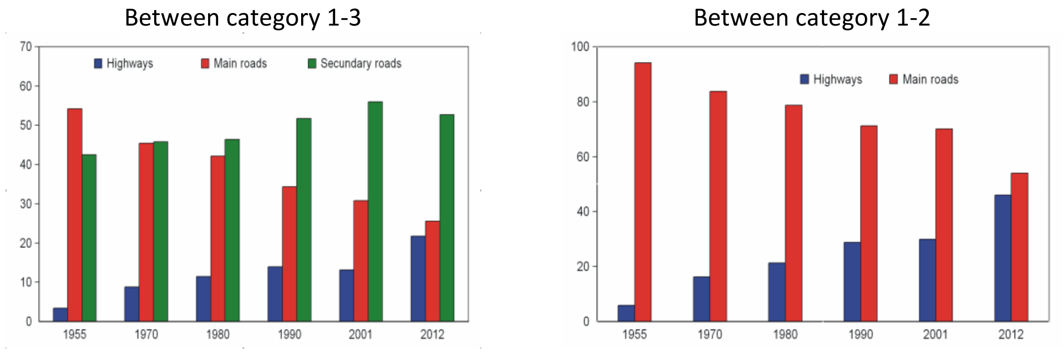
5. Network analysis and accessibility results

A consistent comparison of the six networks over time encounters several problems to be solved. A first straightforward exercise could be to calculate the average speed as an indicator of network improvement. Given the speed classification from Table 1, an unchanged network N_{t+1} will show an average speed that is 5% higher than N_t which is an exogenous assumption. Any structural improvement due to an upgrade of network segments to a higher category is then measured by the additional average speed increase above this 5%. As discussed above, however, the networks are not identical in their coverage and detail. Table 3 shows that the total length of the networks increases each year, in particular for the secondary roads. For the harmonized dataset the share of secondary roads in the total network length goes up from 43% in 1955 to 53% in 2012 (see left panel of Figure 8). Contrary to highways, which are frequently build as new tracks, the adding of a secondary road in N_{t+1} is most likely an upgrade of an existing (tertiary) road in N_t or the result of a better/different map for N_{t+1}. As the bottom of the table illustrates, adding secondary road segments from earlier years cumulates to 25% of all secondary roads in the 2012 network while only 8% for main roads and 0.2% for highways.

Table3 Network development and distribution of road categories 1955 - 2012

	1955	1970	1980	1990	2001	2012
Total length (mln km)	146.7	211.7	274.0	302.3	376.9	421.8
% increase		44.2	29.5	10.3	24.7	11.9
of which (% of km)			original maps			
Highways	3.4	8.8	12.1	15.0	14.6	25.6
Main roads	54.2	45.4	43.7	35.9	33.0	27.8
Secondary roads	42.5	45.8	44.2	49.2	52.4	46.6
			harmonized with previous years (left panel figure 8)			
Highways	3.4	8.8	11.5	13.9	13.2	21.7
Main roads	54.2	45.4	42.2	34.3	30.8	25.5
Secondary roads	42.5	45.8	46.4	51.7	56.0	52.7
			% km included from previous years			
Highways	0.0	0.0	0.0	0.3	1.2	0.2
Main roads	0.0	0.0	1.8	3.5	4.2	8.0
Secondary roads	0.0	0.0	9.8	12.2	16.2	25.3

Figure 8 Distribution of the networks by category 1955 - 2012
% of km



The right panel of figure 8 shows the distribution between highways and main roads for the harmonized dataset when secondary roads are not considered. The share of highways relative to main roads is less than 6% in 1955 and rises to 48% in 2012. It is from this development that the main travel time reduction should be expected.

Instead of looking at indicators of the networks itself an alternative is to calculate travel time tables for each network using a fixed set of locations. This has been carried out in two ways. First, a set of 811 urban areas with a population over 5000 inhabitants for 2006 was used that was provided by Eurostat[7]. From all travel time tables T_{ij} *(t)*, constructed by finding the shortest path for all 811 x 811 routes, total travel time *S(t)* for each network results from *S(t)*= $\sum_{ij} T_{ij}$ *(t)*. Table 4 gives the development *S(t)/S(t-1)* from 1955 onwards for this particular set of locations. When the exogenously assumed speed increase of 5% is deducted from the total travel time reduction a structural network effect of around 4% is found per decade until 1980, 2% per decade between 1980 and 2001 and a more rapid reduction of more than 4% in the most recent decade. In total these results indicate a structural network improvement of 15% since 1955 and 12% since 1970.

Table 4 Average travel time reduction of the networks 1955 - 2012

	1955-1970	1970-1980	1980-1990	1990-2001	2001-2012
Measured on EU urban areas (811 locations)					
Total	-8.8	-8.7	-7.3	-7.1	-9.4
Structural (-5%)	-3.8	-3.7	-2.3	-2.1	-4.4
Measured on the reference grid 1970 (2918 locations)					
Total	-7.6	-8.6	-6.7	-7.5	-8.6
Structural (-5%)	-2.6	-3.6	-1.7	-2.5	-3.6

[7] This dataset is included in the database.

These results are different when other sets of locations are used because they depend on the spatial distribution of the locations. The urban areas with more than 5000 inhabitants are the most relevant locations for which the networks play their role but as is clear from Figure 9 below, these locations are very concentrated in the center of the continent and in the UK. Other regions like Scandinavia are poorly presented with just few locations from which their overall connectedness can hardly be deducted. If we want to get an impression of how network improvement has taken place over the whole area we therefore need a larger set of locations that is spread more evenly. For this purpose we have used a set of 2918 locations that was derived by dividing the network of 1970 into a set of equidistant points set at approximately 40 km from each other (see figure 9)[8].

Figure 9. Reference grid 1970

Table 4 shows that after applying the same method on this dataset as for the urban areas the structural network improvement per decade comes out 0,5% to 1% lower because the upgrading of main roads to highways is concentrated in more urbanized areas that have a lower share in this more dispersed dataset. Only in the period 1990 – 2001 the structural component is with 2,5% higher than for the urban areas which is most likely due to the opening of the Great Belt Bridge in 1998 that gets a higher weight due to relatively more grid points in Scandinavia.

[8] A simple regular grid was not chosen because many points of such a grid would be located far away from the closest network edge implying that a "snapping assumption" has to be made how to link to the network and many grid points then may snap to the same network point.

As discussed in section 2, when a travel time table $T_{ij}(t)$ is summed to $X_i(t) = 1 / \sum_j T_{ij}(t)$ and then scaled to $x_i(t) = X_i(t) / X^*(t)$ with $X^*(t) = \sum_{ij} T_{ij}(t)$, $x_i(t)$ represents the relative accessibility for each location which is comparable over time. Figure 10a-e shows the change of relative accessibility $x_i(t) / x_i(t\text{-}1)$ for each of the 811 urban centers per decade. Figure 10f shows the total change since 1970 because the maps for this period are relatively comparable.

The first period 1955 – 1970 shows a clear divide from the UK over the continent down to Italy with the center gaining at the cost of East and South-West. In this early period when mass car transportation is introduced road improvement has particularly been concentrated in the UK and the cluster Netherlands/Ruhr area. The gain of (South) Italy is due to the introduction of one long North –South highway which was a major improvement compared with relatively poor infrastructure in the South in the fifties. The gains become more dispersed between 1970 and 1980 with still a larger positive cluster in Germany and this time improvements in South-East Spain which are comparable with what happened in South Italy in the decade before. Between 1980 and 1990 it is again the clusters in the UK and the Netherlands who gain, added with North Italy and a catching up of Greece due to a better highway connection with the North through Yugoslavia. The period 1990 – 2001 shows for the first time a reverse picture with catching up of remote parts of Spain and Eastern Europe while the central clusters show a modest decline. There is also an effect of the Great Belt Bridge to be discussed below with the next figures. Finally, the last period 2001 – 2012 shows a clear effect of intensive highway construction in the whole of Spain which give the country an important catching up effect. In the central clusters highways are mainly maintained and broadened but relatively few new highways are added. In the east Poland is clearly gaining in relative accessibility.

The developments discussed above are much better illustrated when the reference grid of 1970 is used and the scores of all 2918 points are interpolated over the surface (see Figure 11). The loss for Greece during 1970 -1980 and its catching up in 1980 – 1990 is clearly visible. The same holds for the effect of the Great Belt Bridge in a large part of Norway during 1990 – 2001. The last period 2001 – 2012 is a sharp illustration of the effects of entrance of Eastern Europe to the EU and the highway developments in Spain. Together this period shows a system wide gain of the periphery EU relative to the center. Also remarkable is the relative decline of Scandinavia. The Great Belt Bridge was a major improvement but due to its low population density the need for further road improvement is limited. Only some parts of Norway are an exception to this due to more investment in tunnels.

Figure 10a - f % Changes in relative accessibility for EU urban centers 1955 -2012

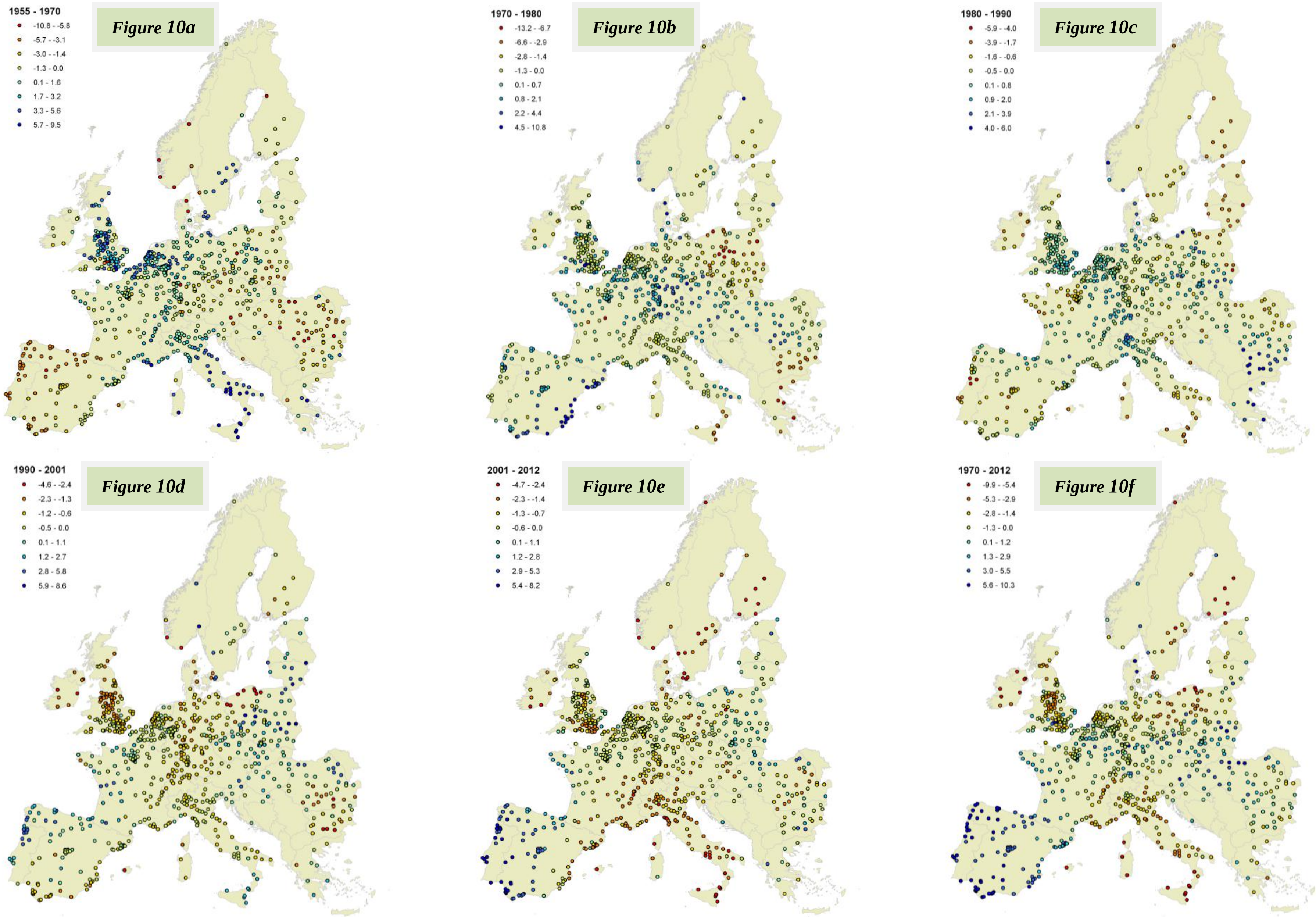
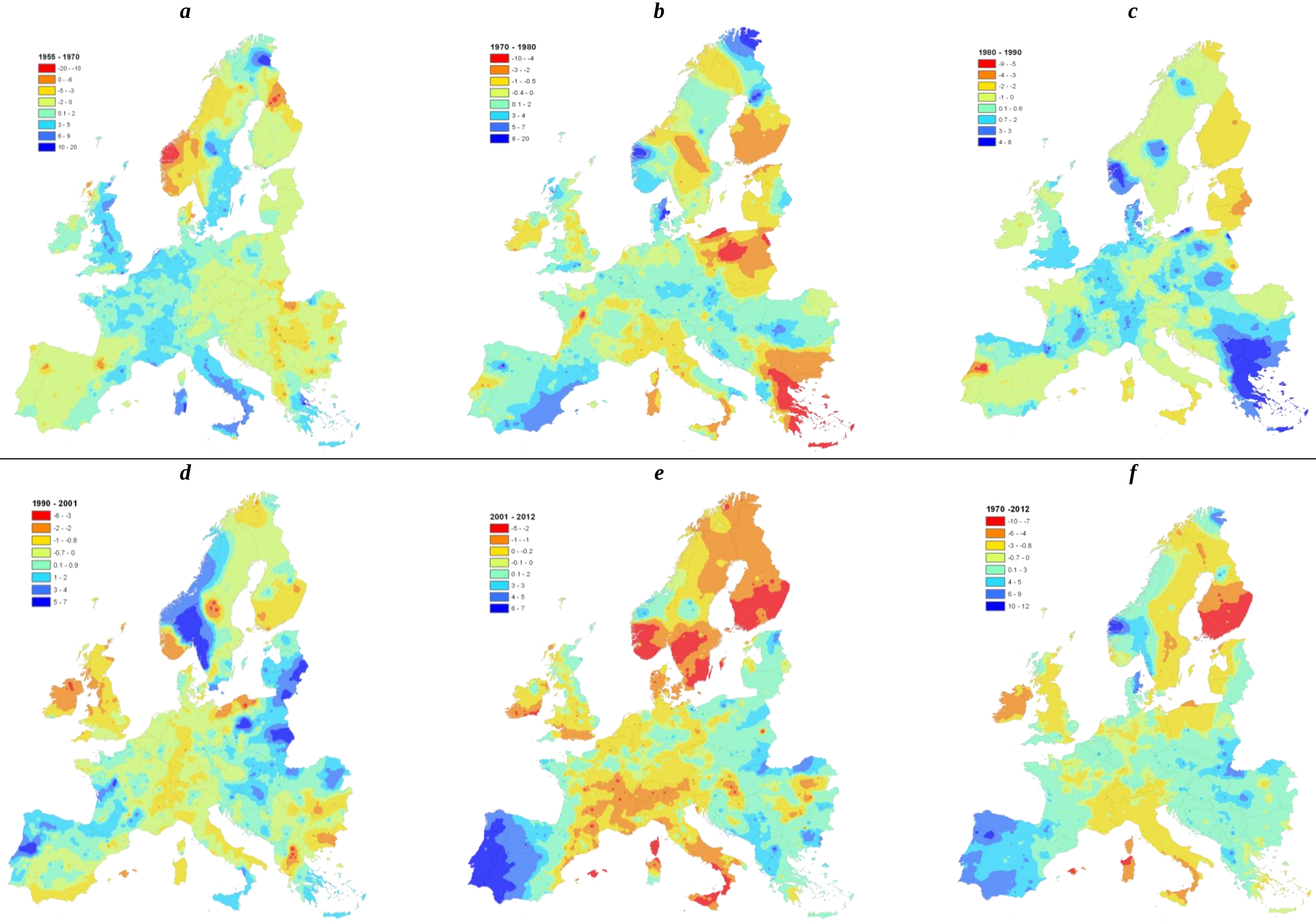


Figure 11a- f Changes in relative accessibility 1955 -2012
(%) Interpolated from accessibility changes for grid points 1970 in figure 9



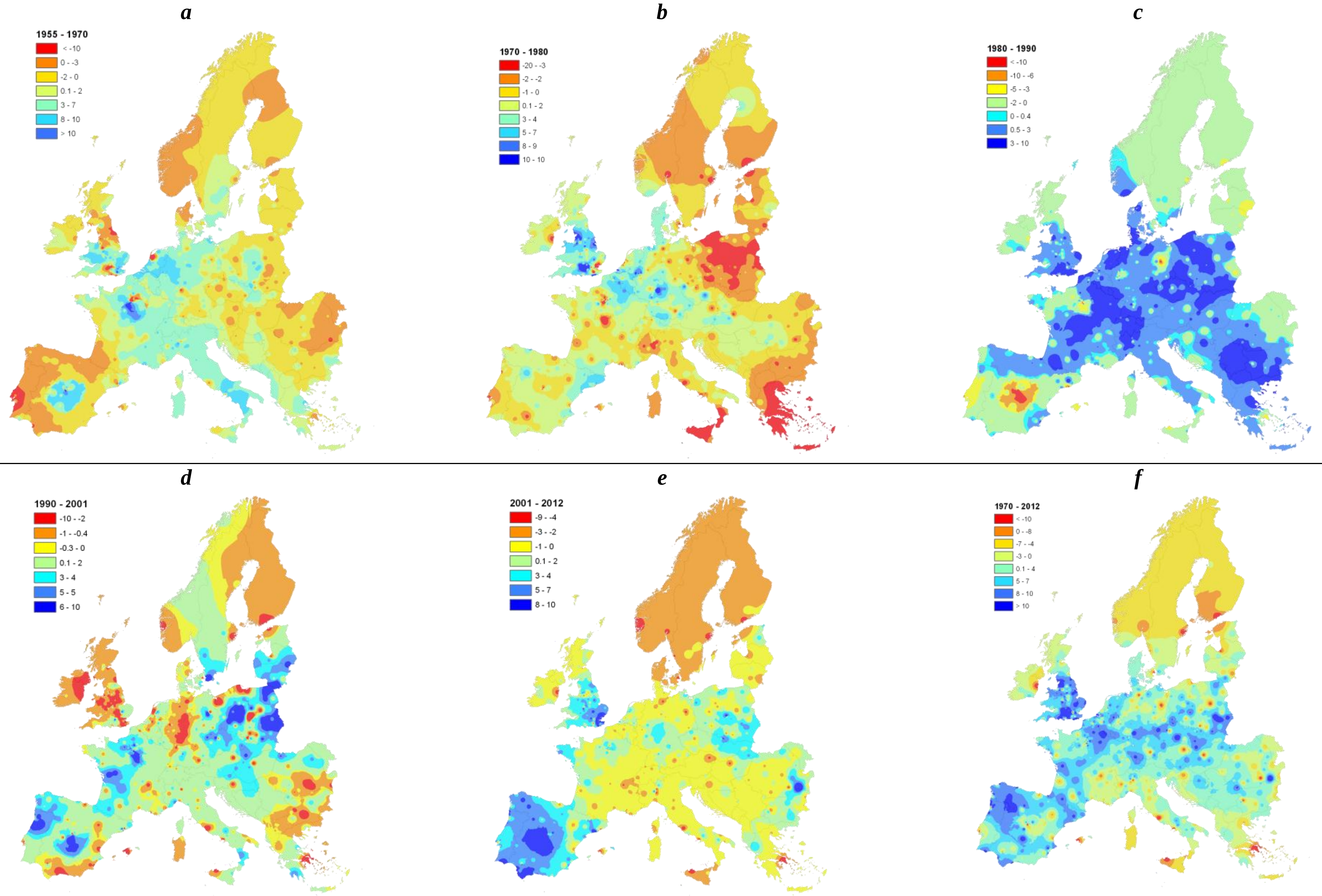
From the overall picture for 1970 – 2012 it is tempting to conclude that East and West have been catching up with the center but that would be a too simple conclusion from a straightforward travel time analysis. What matters for the economic impact of road infrastructure is not just the characteristics of the roads themselves but with whom the connected become connected. For an individual location access to surrounding markets is more improved when new or better roads connect it which large other locations. The standard way to measure this is potential analysis[9] which is here applied on the travel time tables combined with population data. Using the fixed population distribution $P=\{p_1,p_2,...,p_k\}$ from the urban area dataset used in Figure 10, the *potential Y* is defined as $Y_i(t) = p_i + \sum_{j\neq i} p_j/T_{ij}(t)$. For comparison over time, again $Y_i(t)$ is rescaled to $y_i(t) = Y_i(t) / Y^*(t)$ with $Y^*(t) = \sum_i y_i(t)$. The population p_i of the location itself is included to get a correct growth indicator which mimics the standard modeling of market power and local price indices as for example in the New Economic Geography literature. Because a large location has a large home market, a better connection to surrounding small locations is a smaller improvement of its potential than when a small location gets better connections with large neighbors. In addition, using the potential implies fewer gains from infrastructure improvement farther away. Figure 12 has the same setup as Figure 11 but now the growth of the relative potential $y_i(t) / y_i(t\text{-}1)$ of each of the 811 urban areas is interpolated over the surface[10].

The corresponding panels a –f of both figures lead to different conclusions. For the first period 1955-1970 the UK-Italy cluster in panel 11a is much less pronounced in 12a and there is a clear improvement in the center of Spain around Madrid which is invisible when plain accessibility is used. Isolated local road improvements in areas with low density like the one showing up in Lapland in Figure 11b disappear because they do not add much to the potential. The gains in potential are much less or even negative in the middle and North of the UK. During the second period 1970–1980 the potential gains in panel 12b are much more concentrated for the UK and the North West continent than in panel 11b which shows more relative improvements in Spain and Eastern areas. For 1980 – 1990 the major part of the central continent shows gains in panel 12c while large parts of Italy, Austria and Germany have a negative sign in panel 11c. This indicates that road improvement here have been modest when measured in pure travel time but have still given relatively more market access then elsewhere. The catching up of the periphery during 1990 -2001 is more pronounced in panel 12d than in panel 11d. The UK, Netherlands and the main center of Germany lose potential relative to (central) Spain, West France and Poland. The positive effects of the Great Belt Bridge for

[9] See for instance Beckmann & Puu (1985)

[10] The inverse distance weighed interpolation routine (IDW) of ArcGis was used. This routine is defined as $Z = [w(1)*Z(1) + ... + w(n)*Z(n)]/[w(1)+...+w(n)]$ with $w(i) = 1/Distance(P, P(i))^\alpha$. Z is the interpolated population value for any location P, given population $Z(i)$ for n surrounding locations $P(i)$. α is the exponential power of the inverse distance which is here set to $\alpha=2$.

Figure 12a- f Changes in relative potential 1955 -2012
(%) Interpolated from 811 urban areas

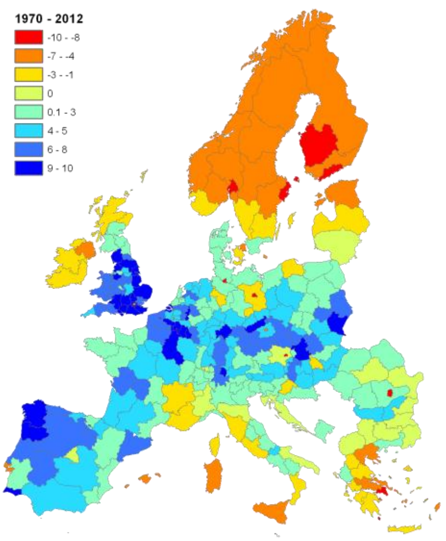
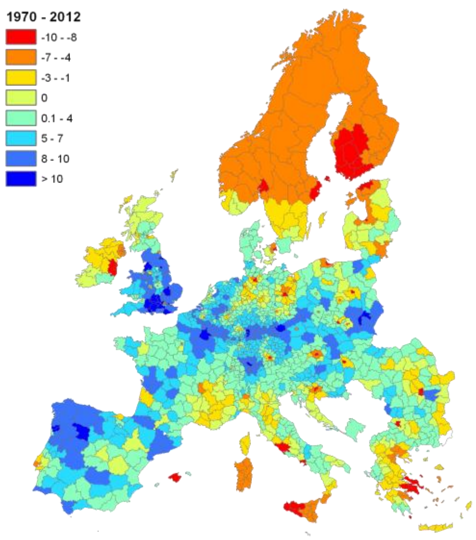


Scandinavia, however, are much less when expressed in market reach. Also the loss in relative accessibility for Finland in Figure 11e and 11f are much less pronounced in Figure 12e and 12f. For the most recent period both panels 11e and 12e are more similar except for the South-West of the UK which shows a gain in potential that is not visible in panel 11e.

Finally, the long term development between 1970 and 2012 reveals that measured in travel time Spain and the East are catching up with the center (panel 11.f) but measured in market access (panel 12f) the UK, the center of the continent and the East also show positive potential gains while the North and the South show a decline.

The interpolated potential surface can also be used for a correct estimate of accessibility changes for larger regions. A population-weighted centroid calculated for Nuts2 and Nuts3 regions was available from the urban dataset which has been applied to the networks directly but that implied “snapping” the centroids to one particular edge of the network which is not very accurate. These direct calculations are included in the database as descripted in Annex B. Here, as an alternative the results are presented when we take the sum of the interpolated potential surface for each region as a proxy for the average potential of the region. In Figure 13 the average potential change over the period 1970 – 2012 is presented for Nuts2 and Nuts3 regions as derived from the surface directly. Not surprisingly, the pictures are similar to Figure 12 because they are a mere spatial average of the surfaces.

Figure 13 Changes in relative potential 1970 – 2012 for Nuts2 and Nuts3 regions

<table>
<tr><th>Nuts2</th><th>Nuts3</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Alternative specifications of the potential Y by restricting it to a specified radius and/or an exponential inverse distance weighting like $Y_i(t) = p_i + \sum_{j \neq i} p_j \,/\, [T_{ij}(t)]^n$ can be thought of depending on their policy relevance. For spatial analysis of an individual country one may wish to restrict infrastructure improvement over time to national network effects only. A general radius restriction can be applied for logistics analysis depending on the ratio between fixed and variable shipping costs (McCann, 2005). When distance-related variable costs are very low the exponential value for n has to be set higher. As discussed in the technical annex, these alternative specifications can be applied on the database in the same way as the linear specification above without a limited search range.

5. Conclusions

The historical database of detailed transportation networks as has been set up in this project is the first of its kind and can be a valuable instrument for research in transportation, urban development, spatial economic modeling and for policy evaluation. Maintaining of historical network data should have a high priority, both for policy evaluation as for academic purposes, but surprisingly, the public interest and efforts in preserving and archiving of infrastructure networks have been extremely low in the past. Library archives of road maps are fragmented and systematic collections of road maps are scarce and incomplete. The quality of the current dataset can be improved when information on location and road quality coding can be added from other maps as the ones we have used in this project but those maps will most likely be national road maps from different publishers with different detail and road coding. This means that “backward” updating and improving of the dataset will require substantial research efforts and will most likely have to follow the type of research path that was used in this project (scanning of paper maps, georeferencing and manual drawing and revision). For future updating the situation is very different. As many companies have fully functional digital networks today, the only thing that needs to be done is to persuade them to make an annual frozen archive of their networks that can be used for future research. Informal discussion with mapping companies have pointed out that they are not unwilling to cooperate in such an archiving project but they want to protect their mapping assets for commercial use.

From the research point of view the first priority now is to convince them of the need for a good archiving process, even if that would mean that the scientific community would get access to those archives years later when the commercial value of older digital networks has expired. Archiving of frozen digital networks, however, requires time and resources. Government archiving institutions may therefore need to play a supporting role in this process.

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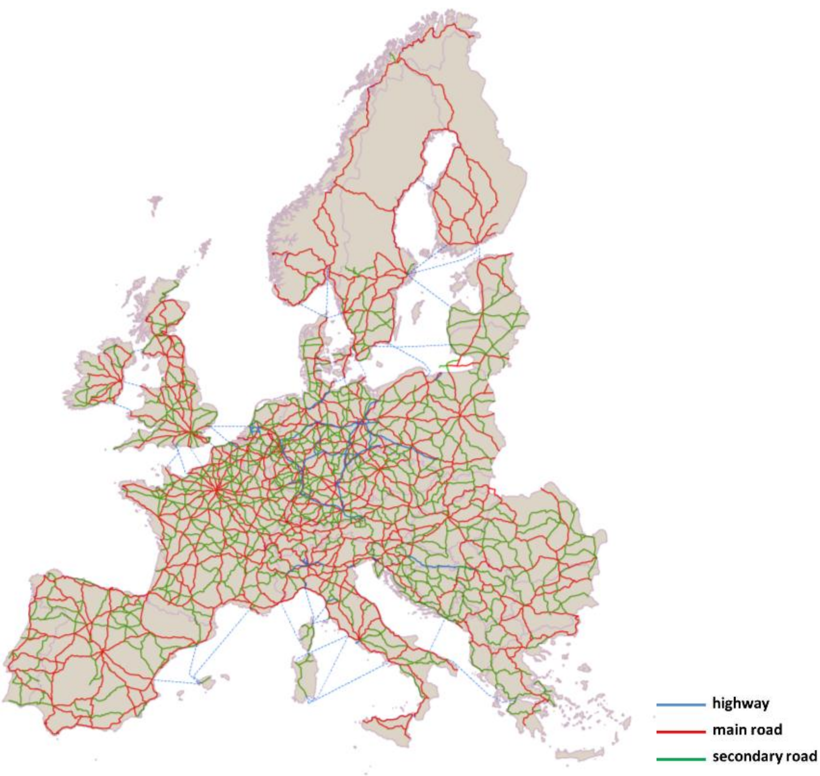
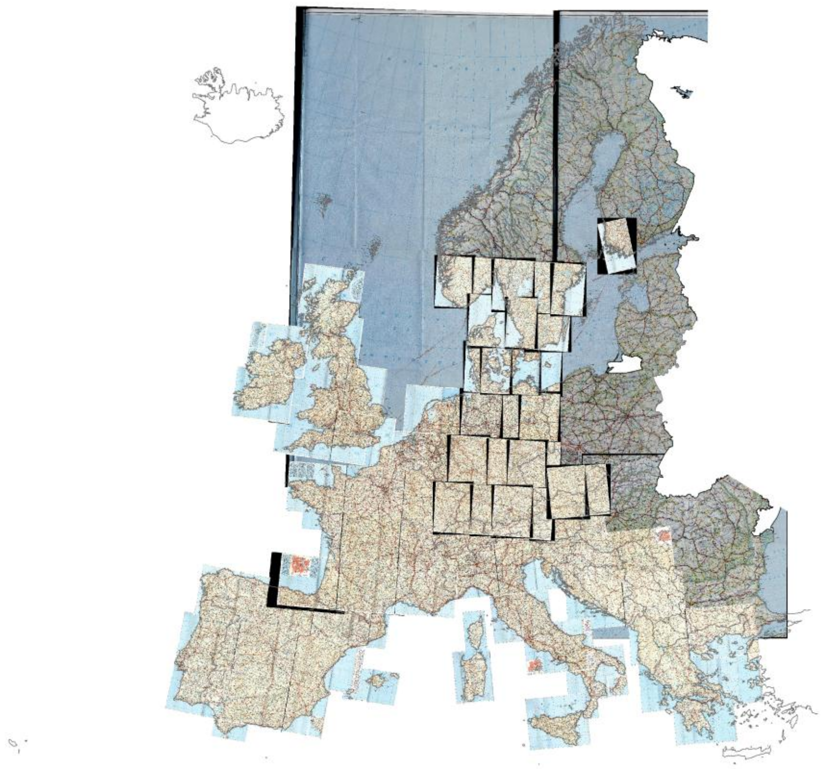
Annex A. Maps and roads 1955-2012

A1. Maps and roads 1955-1957

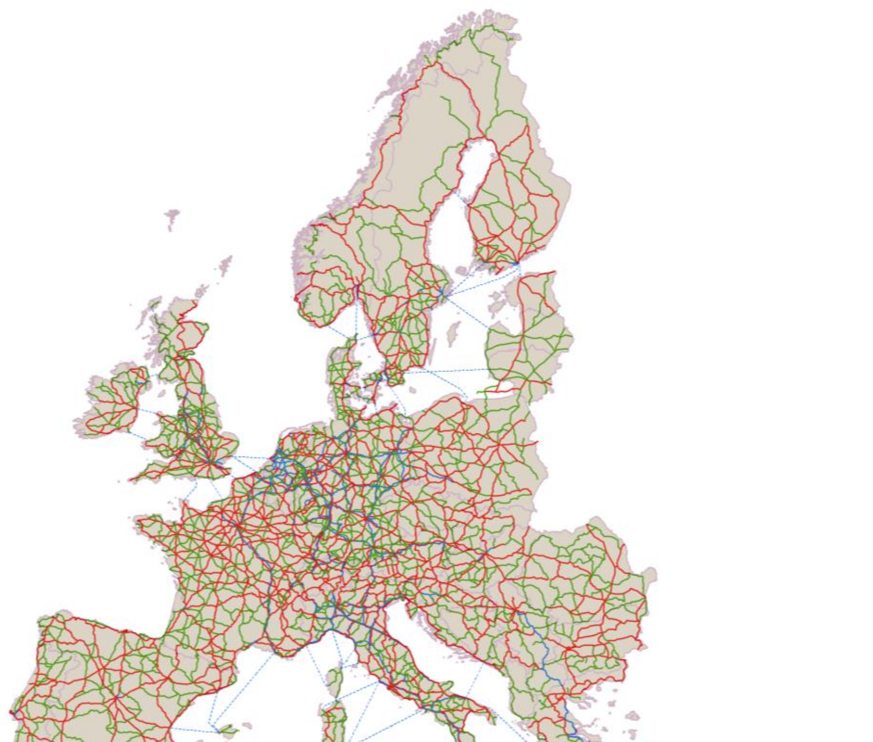
Kümmerley & Frey 1956 1: 2.500.000; Esso 1957 1: 4.000.000



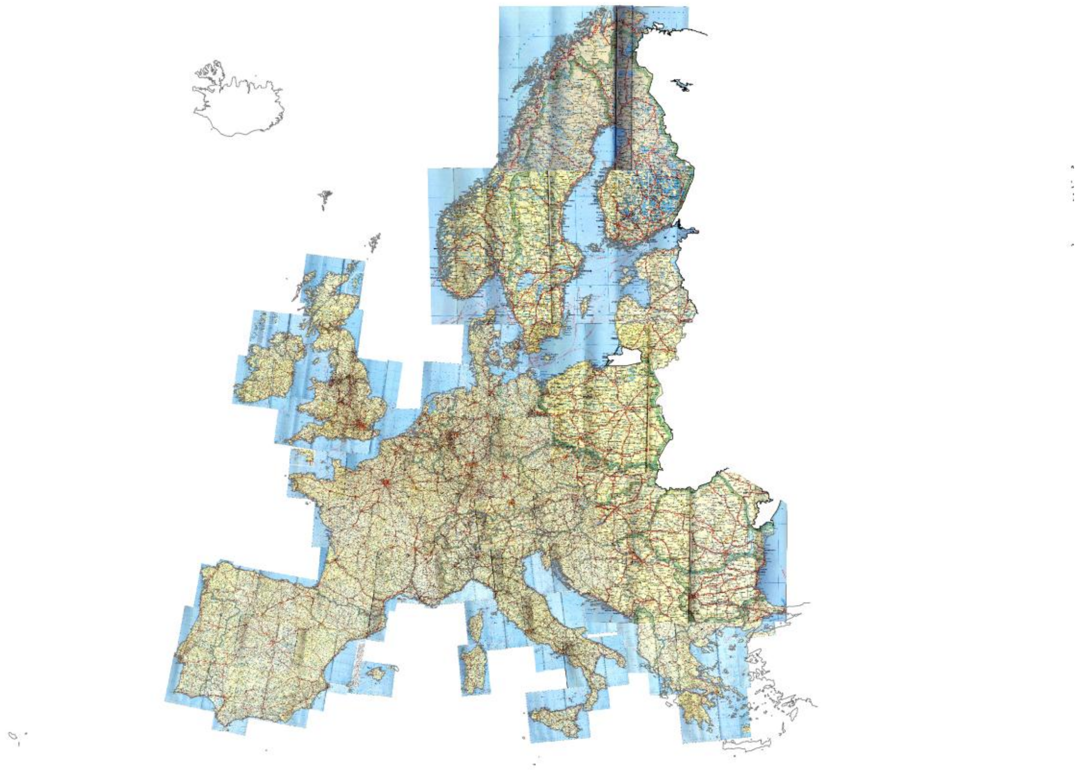
A2. Maps and roads 1970



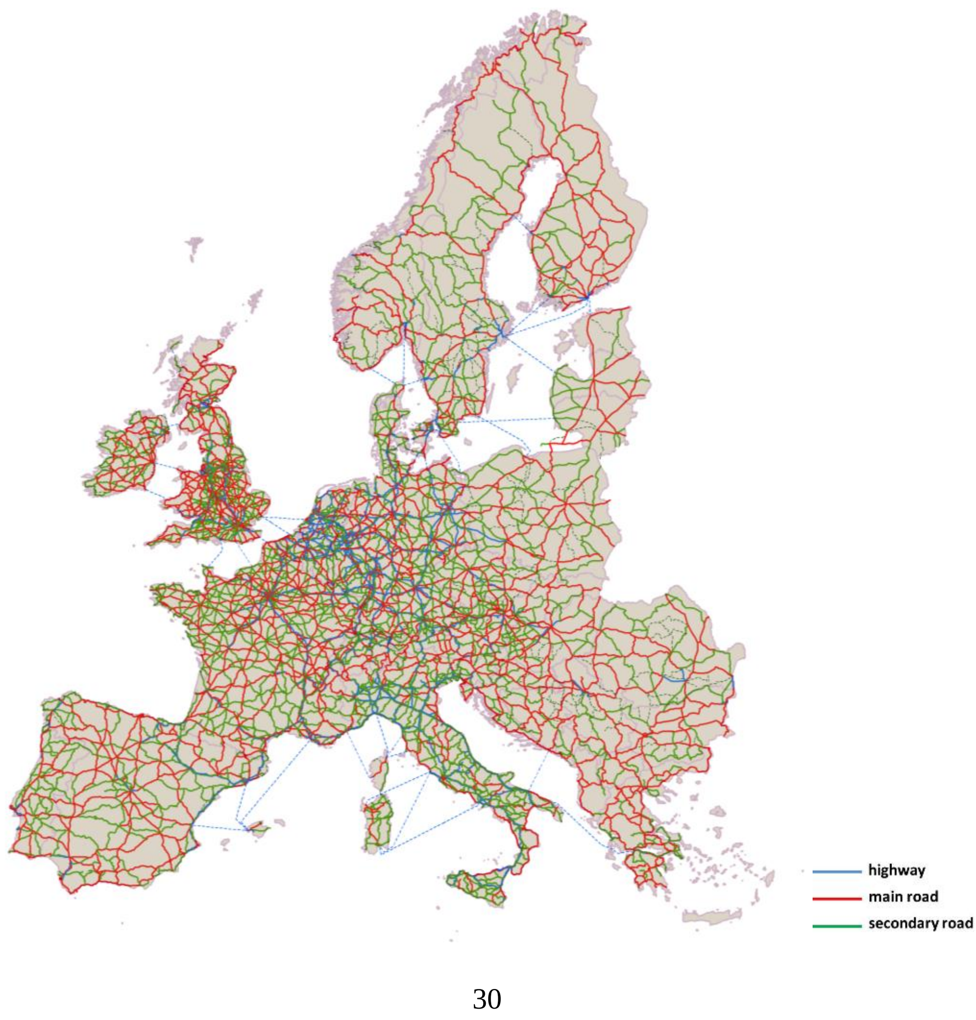
ANWB Het beste boek van de weg 1970, 1:1.000.000; Kümmerley & Frey 1970, 1: 2.750.000



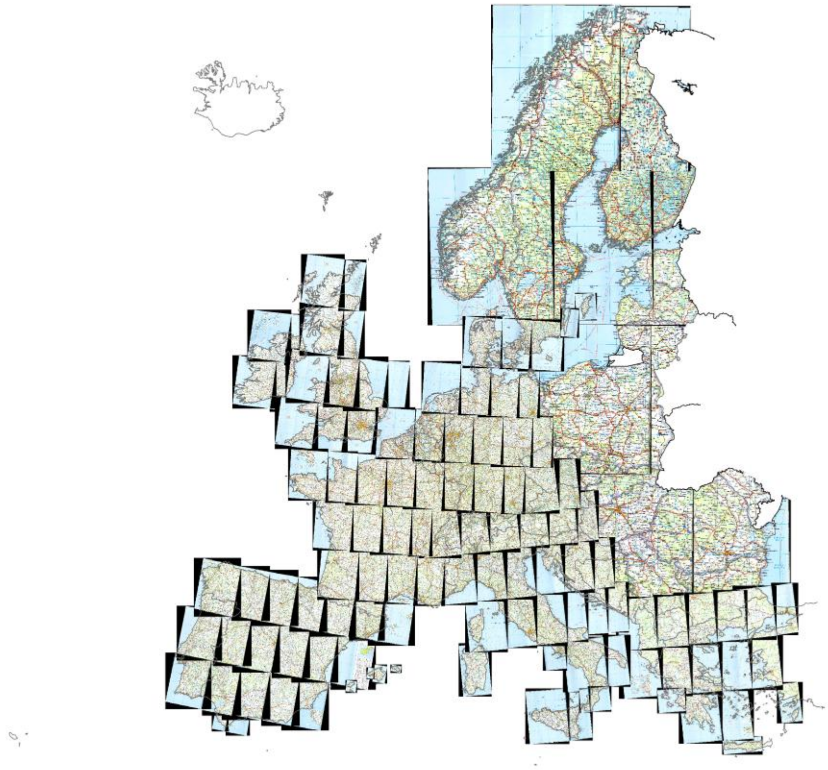
A3. Maps and roads 1980



ANWB, Het Beste Boek van de Weg, 1980, 1: 1.000.000 / 1: 3.000.000

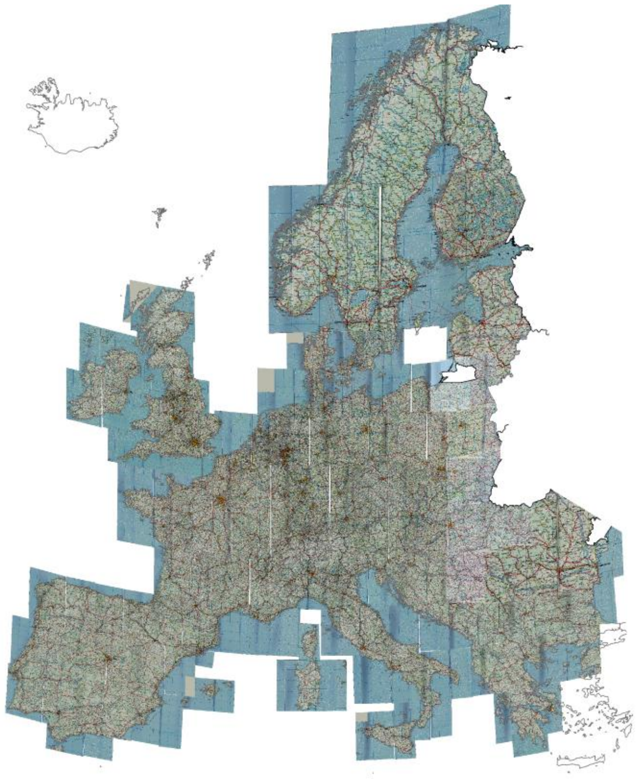


A4. Maps and roads 1990

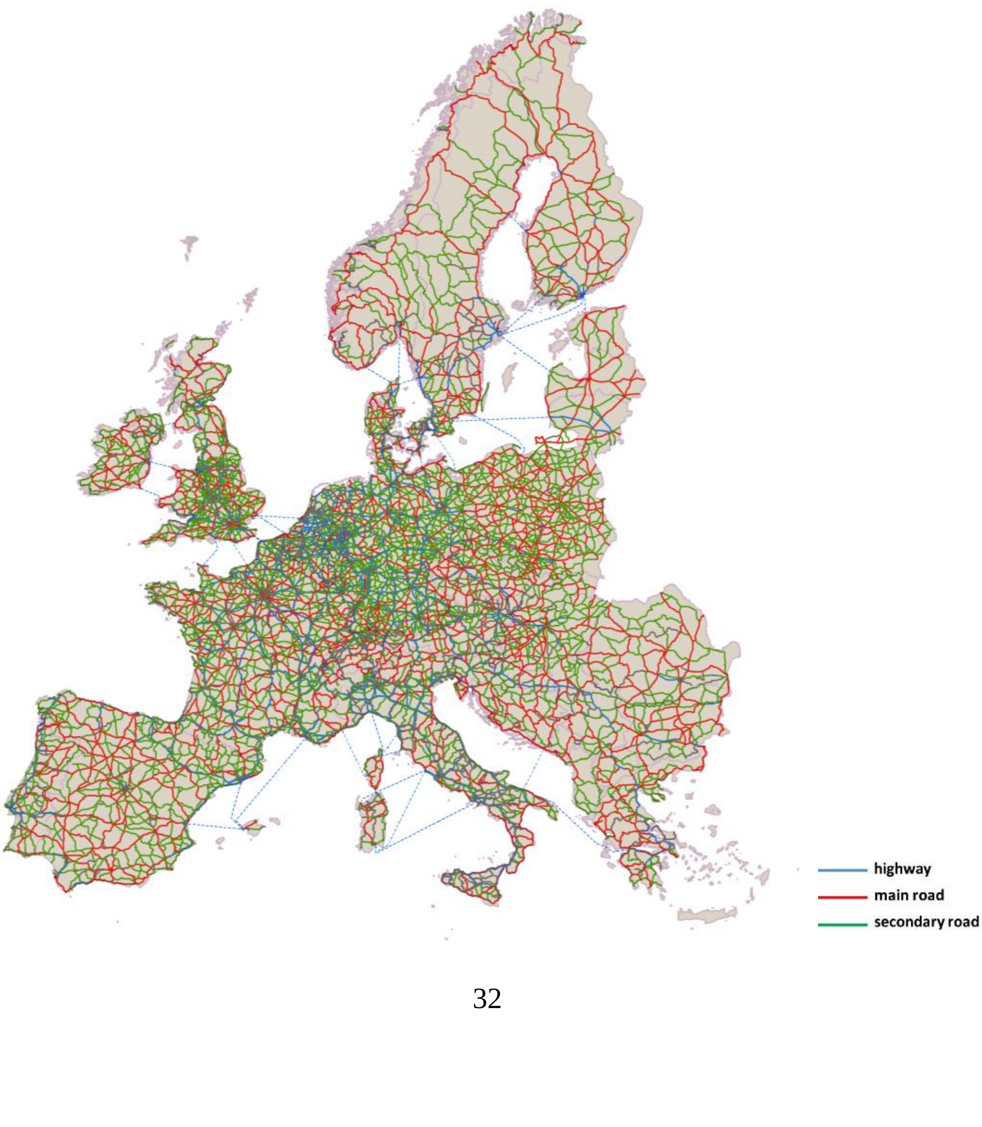


ANWB, Het Beste Boek van de Weg, 1990, 1: 1.000.000 / 1: 3.000.000

A5. Maps and roads 2001

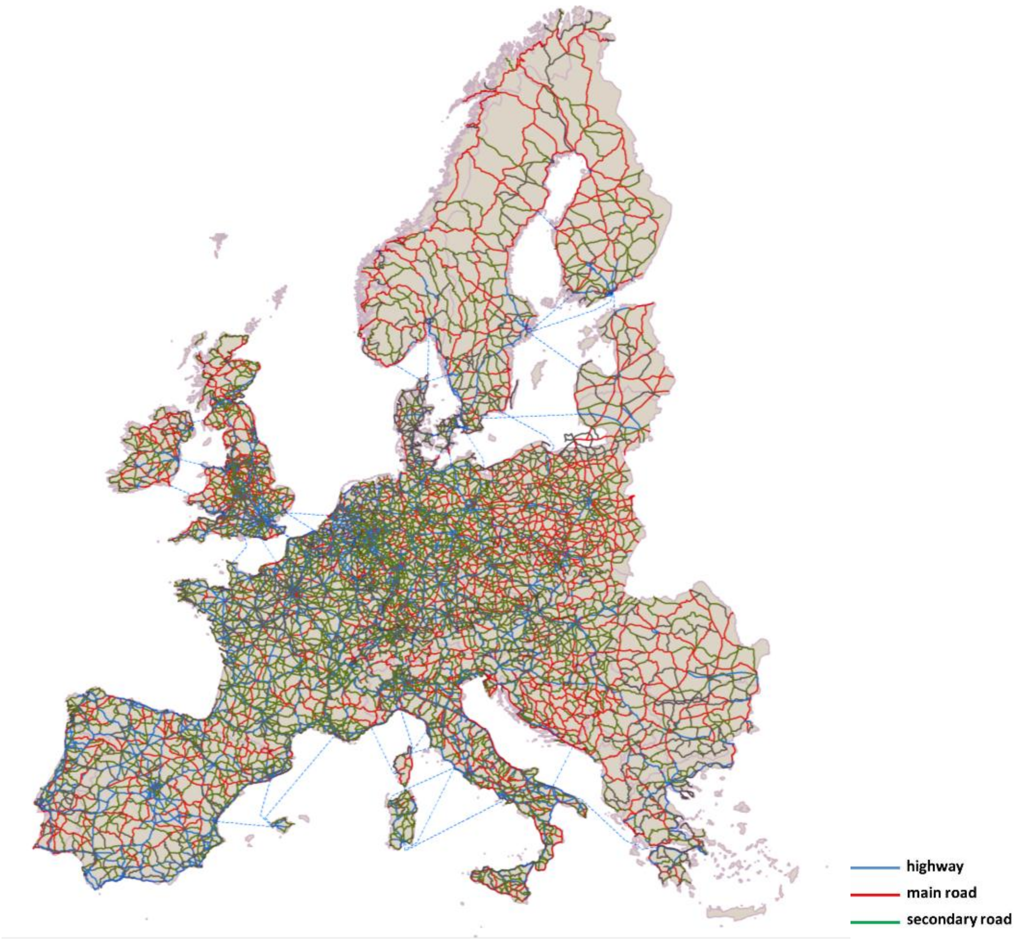


ANWB, Het Beste Boek van de Weg, 2001, 1: 1.000.000 / 1: 3.000.000



A6. Maps and roads 2012

ANWB wegenatlas Europa 2012, 1: 800.000



Annex B. Technical database description

This database uses GIS- and geodatabase formats processed with ArcGis 10. Users must be familiar with ArcGis software.

Main directory

background	Scanned maps used as reference background
centroids	Nuts2 and Nuts3 calculation of potential in Fig 13
cities	OD matrices and processing for 811 cities Fig 10 and Fig 11
countries	Reference background countries
grid	Accessibility rasters for reference grid points Fig11
roads_eu.gdb	Geo Database road networks 1955 -2012
code_table.class.atx	
code_table.dbf	Code table
maps_1955.lyr	Map background layers
maps_1970.lyr	..
maps_1980.lyr	..
maps_1990.lyr	..
maps_2001.lyr	..
maps_2012.lyr	..
road_network_1955.mxd	Base configuration for network analysis
road_network_1970.mxd	..
road_network_1980.mxd	..
road_network_1990.mxd	..
road_network_2001.mxd	..
road_network_2012.mxd	..
roads_1955.lyr	Road layers
roads_1970.lyr	..
roads_1980.lyr	..
roads_1990.lyr	..
roads_2001.lyr	..
roads_2012.lyr	..
roads_database.mxd	Main map file showing all road networks and backgrounds

Background

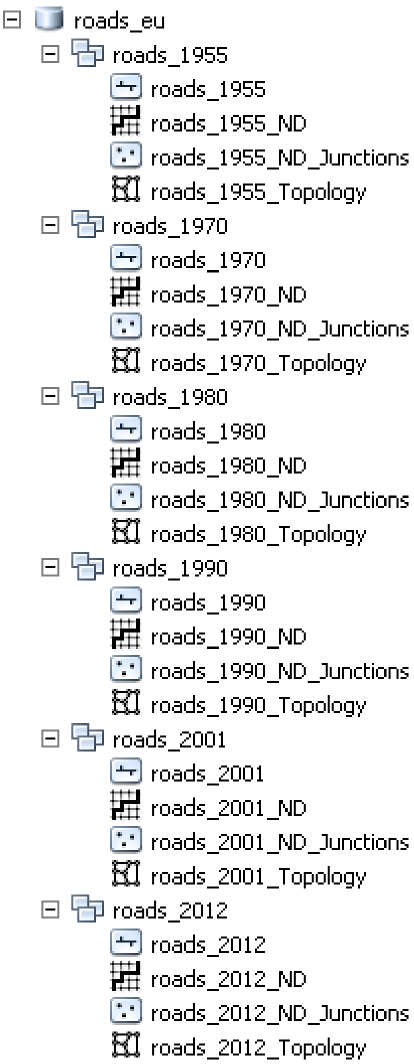
Five subdirectories, one for each year with geo-referenced map scans. The format is different for each year. Best used by loading one of the map background layers.

Centroids

Centroids and Nuts2 and Nuts3 regions as Shapefiles and the two rasters shown in Figure 13.

Roads_eu.gdb

This geodatabase has a separate feature dataset for each year. As an example for 1955, *roads_1955* is the line layer with three basic attributes: *class*, *travel time* and *length* in meters. It is embedded in *roads_1955_Topology* where it is controlled for having dangles or not (dead-end streets etc.). An error in the topology may indicate missing connections. Real dead-end roads are marked as an exception. *Roads_1955_ND* is the network linked to *roads_1955*. *Roads_1955_ND_Junctions* contains its nodes.



After each change made in *roads_1955*, either by adding, deleting or changing a road segment or by a change in its attribute table codes, the network needs to be rebuild (right click on roads_1995_ND in ArcCatalog and choose *Build*. Then the updated network is ready for use in Network Analyst to calculate new OD matrices or routes.

There is no dynamic link between *roads_1955* and *codetable*. For recalculating the network travel time, load *roads_1955* and *codetable*, join the second to the first with join on variable *class*. This gives a link to the variable *speed* from *codetable*. Then do *calculate field* on *traveltime* in the attribute table with the formula: traveltime = 0.06 * length / speed. This gives travel time in minutes because *speed* is expressed in km/h.

Important NB: travel time of all ferry segments are entered manually and must not be changed when a new code table is used. For this select features with class < 900 first. Then traveltime is only recalculated for non-ferry segments.

Cities

info	ArcGis content
potential	Potential calculations
Accessibility changes cities.mxd	Map overview of Fig 10
log	
odUREAU1955.xlsx	811x811 Travel time matrices for urban centres
odUREAU1970.xlsx	..
odUREAU1980.xlsx	..
odUREAU1990.xlsx	..
odUREAU2001.xlsx	..
odUREAU2012.xlsx	..
ra_1955_2012_ureau.xls	Processed accessibility data
schema.ini	
URAU_accessibility.dbf	Content of ra_1955_2012_ureau.xls in shape file format
URAU_accessibility.prj	..
URAU_accessibility.sbn	..
URAU_accessibility.sbx	..
URAU_accessibility.shp	..
URAU_accessibility.shx	..
URAU_CITIES_GR_CITIES_20...	Original shape file of urban areas
URAU_CITIES_GR_CITIES_20...	
URAU_CITIES_GR_CITIES_20...	
URAU_CITIES_GR_CITIES_20...	
URAU_CITIES_GR_CITIES_20...	
URAU_CITIES_GR_CITIES_20...	
URAU_CITIES_GR_CITIES_20...	

Cities\potential

potential_UREAU_55_12.xls contains the potential results calculated from the OD matrices above
URAU_potential.shp is the same in shape file format

Countries

Shape file of countries (from ESRI and Eurostat). The latter one is used in various maps.

Grid

info	ArcGis content
ras_01_12c	Raster relative accessibility
ras_55_70c	..
ras_70_01c	..
ras_70_12c	..
ras_70_80c	..
ras_70_90c	..
ras_80_90c	..
ras_90_01c	..
Accessibility changes_grid.mxd	Maps of Fig 11
grid_1970.dbf	Reference grid points of Fig 9
grid_1970.prj	
grid_1970.sbn	
grid_1970.sbx	
grid_1970.shp	
grid_1970.shp.xml	
grid_1970.shx	
grid_1970_data.dbf	Reference grid points with linked calculations
grid_1970_data.prj	
grid_1970_data.sbn	
grid_1970_data.sbx	
grid_1970_data.shp	
grid_1970_data.shp.xml	
grid_1970_data.shx	
ra_1955_2012_grid.xls	Calculations of relative accessibility
ras_01_12c.aux.xml	
ras_55_70c.aux.xml	
ras_55_70c.ovr	
ras_70_01c.aux.xml	
ras_70_12c.aux.xml	
ras_70_80c.aux.xml	
ras_70_90c.aux.xml	
ras_80_90c.aux.xml	
ras_90_01c.aux.xml	
od1955.mat	Travel time matrices in Matlab format
od1970.mat	
od1980.mat	
od1990.mat	
od2001.mat	
od2012.mat	

The OD matrices are included as Matlab files. When opening a network in ArcGis, a new OD cost matrix can be defined with loading the origins and destinations simply from the *grid_1970* shapefile. This, however, cannot be solved because of computational limits for desktop PC's. Instead, we have solved a partial OD matrix by defining a cut-off point of 1150 minutes which includes the longest ferry connections. This partial OD matrix has then been completed with separate shortest path software, its rows are summed up and these sums are archived in *ra_1955_2012_grid.xls*.

Additions

An addition to the database (dated June 7, 2013) contains the following:

1) OD_NUTS2_NUTS3_URBAN.mdb

This Access file contains all OD matrices in standard database format (one line per travel time) for each year, NUT2 and NUTS3 centroids and urban areas.

2)
potential_1955.xlsx
potential_1970.xlsx
potential_1980.xlsx
potential_1980.xlsx
potential_2001.xlsx
potential_2012.xlsx

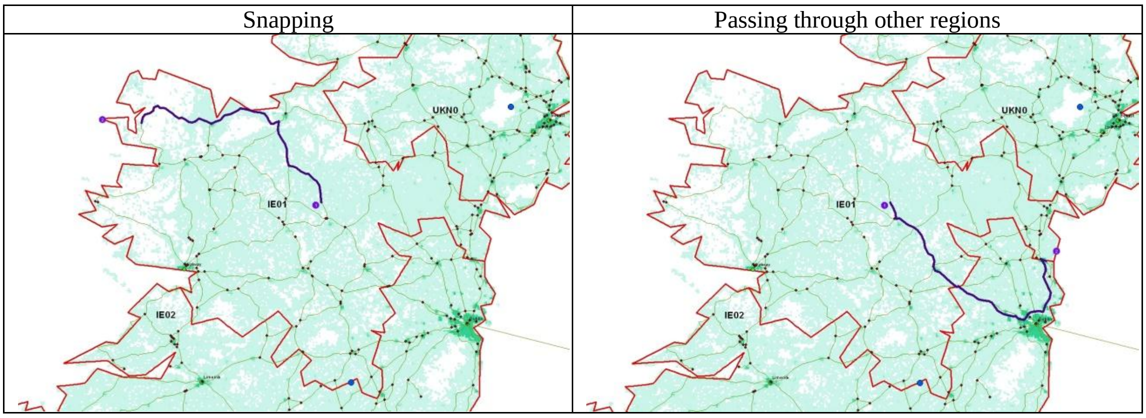
These files calculate the population potential for urban areas with some options to be specified:

- Search radius (a cut-off value for travel time)
- Exponent for inverse distance weight
- Scale of time dimension (minutes, hours)
- Inclusion of own region

Annex C. Internal travel time within NUTS2 and NUTS3 regions

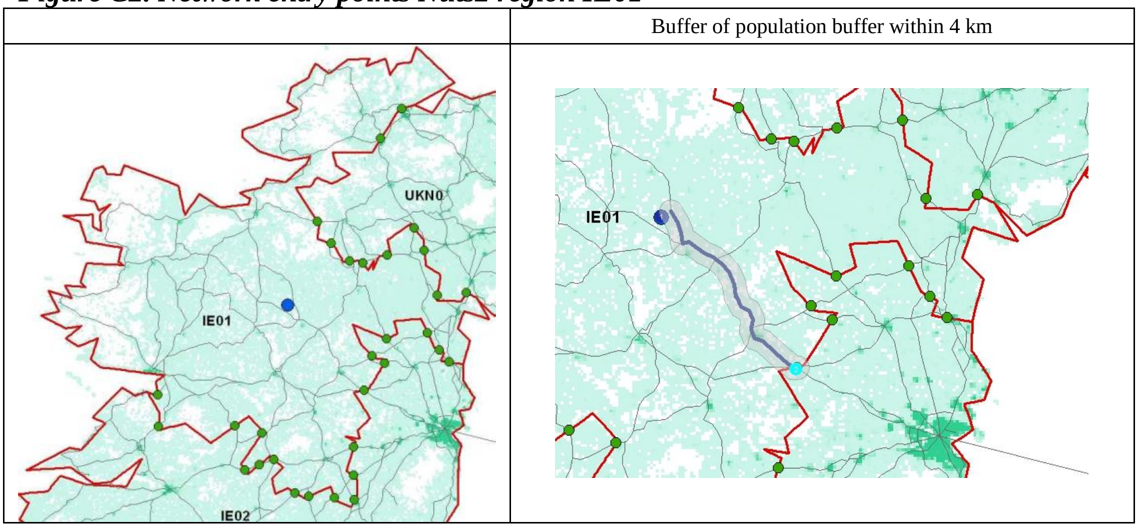
Internal Travel Time (ITT) for a region is best thought of as an average travel time from its borders to its centroid. With a sufficiently detailed road network this can be done for a discrete number of border points at - say - an interval of 10 km. As Figure C1 shows, however, even with the most detailed network of 2012, border points need to be snapped to the network, which is not very accurate. More important, a shortest route from a border point to the centroid may go through another region (see the right panel of Figure C1). This procedure means that the network of another region j codetermines ITT (i) which is strictly speaking not correct because ITT(i) should be a characteristic of region i itself.

Figure C1. Border point examples Nuts2 Ireland
Location 1 =centroid



A second issue is that the left panel of Figure C1 is not very relevant because the coastline is not where the network enters the region, except for ferries and/or bridges. The ITT is only relevant and should only be calculated for border points where the region is entered, as indicated in Figure C2.

Figure C2. Network entry points Nuts2 region IE01



If we accept the option of a shortest path that partly goes through another region and calculate the average travel time for all entry points in the left panel of Figure C2 to the centroid, the final question is how to give the correct weights to each entry point. This should be the relative importance of each point in terms of daily traffic volumes but that information is not available. As an alternative, we have a population grid of 1km by 1km for 2006 available as depicted in both figures above which could be used as a proxy for transport intensity. The right panel of Figure C2 shows a buffer of 4 km around the shortest route of one entry point to the centroid which can be used to count the population from the 1km by 1km grid within a distance of 4 km from the route.

This relatively simple procedure would produce a population weighted internal travel time for each region. But (partly) travelling through neighboring regions must be accepted as a shortest route option.

KN-03-13-421-EN-N

Publications Office

ISBN 978-92-79-31566-4