Club d'échanges sur le transport de marchandises

Actes de la séance n°5
du 11 juin 1999

Thème :
L'accessibilité :
concepts, mesures, applications

avec le concours de la société *ESA Consultants*

ESA Consultants
B.P. 19 67085 Strasbourg Cedex 2
Tél. (33) 03 88 27 72 61 * email : jaeger@cournot.ustrasbg.fr

Service Economique et Statistique
Département des Etudes Economiques

Accessibilité :
concepts, mesure, applications

Pièce ABC niveau - 2 (Tour Pascal B)

Vendredi 11 juin 1999

- ***Les notions d'accessibilité, de potentiel et de lissage : une introduction***
  Claude Grasland (Université Paris I - équipe P.A.R.I.S.)

- ***Comparing accessibility concepts from a conceptual and empirical viewpoint***
  Piet Rietveld (Department of Spatial Economics - Faculty of Economics - Université Libre d'Amsterdam)

- ***Les différentiels d'accessibilité des villes moyennes en France***
  Nadine Cattan (Université Paris I - équipe P.A.R.I.S)

- ***Accessibilité et théorie des graphes : quels indicateurs pour quelle mesure ?***
  Laurent Chapelon (Maison de la Géographie de Montpellier, UMR ESPACE)

- ***L'accessibilité aux activités vacantes et surplus des consommateurs de transports***
  Fabien Leurent (Inrets)

- ***L'Accessibilité dans les réseaux de production : vers un concept organisationnel***
  Antje Burmeister (Inrets/Traces)

- ***Espace et transport : développement d'un SIG pour le calcul d'indicateurs d'accessibilité au niveau européen - programme de recherche EUNET***
  Jérôme Carreau (Inrets)

Coordonnées des intervenants

Dr. Piet Rietveld
Department of Spatial Economics
Faculty of Economics
Vrije Universiteit
1081 HV Amsterdam
The Netherlands
Office: 4A39, main building
tél. : 31-20-4446097
fax : 31-20-4446004
e.mail: prietveld@econ.vu.nl

Nadine Cattan
OCDE
2, rue André-Pascal
75775 Paris Cedex 16
tél. : 01.45.24.82.00

e.mail : Nadine.CATTAN@oecd.org

Antje Burmeister
Chargée de recherche
Inrets - Traces
20, rue Elisée Reclus
59650 Villeneuve d'Ascq
tél. : 03.20.43.83.58
fax : 03.20.43.83.59
e.mail : antje.burmeister@inrets.fr

Claude Grasland
CNRS-UMR Géographie-cités
Equipe P.A.R.I.S.
13, rue du Four
75006 PARIS
tél. : 01 40 46 40 03
fax : 01 40 46 40 09
e.mail : claude.grasland@pareisgeo.cnrs.fr

Laurent Chapelon
Université Paul Valéry - Montpellier 3
UMR 5651 ESPACE
Maison de la Géographie
17 rue Abbé de l'Epée
34000 Montpellier
tél.: 04.67.14.58.01
fax : 04.67.72.64.04
e.mail : Laurent.Chapelon@mgm.fr

Fabien Leurent
INRETS
2 Avenue du Général Malleret-Joinville
94114 Arcueil Cedex
tél. : 01 47 40 72 71
fax. 01 45 47 56 06
e.mail : fabien.leurent@inrets.fr

Jérôme Carreau
INRETS
2 Avenue du Général Malleret-Joinville
94114 Arcueil Cedex
tél. : 01 47 40 72 35
fax. 01 45 47 56 06
e.mail : jerome.carreau@inrets.fr

Participants

Agnès Arabeyre-Petiot	Let
Elie Arnal	Dre Champagne-Ardenne
Pierre Baillet	Cete du Sud-Ouest
Michel Baudrin	Cete Nord-Picardie
Jean-Paul Bazin	Dre Basse-Normandie
Jean-Pierre Benoît	Cete du Sud-Ouest
Charles Bergano	Ses
Agnès Binet	Cete du Sud-Ouest
Brigitte Blanchard	Inrets - Traces
Christophe Bodard	Setra - Cstr
Pascaline Boyer	Sncf - Direction de la Stratégie
Francis Bugeaud	Cete du Sud-Ouest
Géraldine Chagny	Let
Moon-Kie Chung	Let
Joël Creusat	Sgare Alsace
Nolwenn David-Nozay	Ses - Dee
Joseph Dornbusch	Ses - Dee
Sandrine Durand	Let
M. Falaise	Cofiroute
Alain Gaudefroy	Ort Pays de la Loire
Luc Goutard	Dre Pays-de-la-Loire
Marie-Elisabeth Hassan	Direction Régionale de l'Insee
Ali Hachid	Dre Rhône-Alpes
Benoît Hiron	Cete de Lyon
Michel Houée	Ses - Dee
Guy Joignaux	Inrets - Traces
Olivier Joly	Cirtai - Université du Havre
Alain L'Hostis	Inrets - Traces
Anne Lenormand	Sncf - Direction de la Stratégie
Sophie Masson	Let
Jean-Claude Meteyer	Ses - Dee
Estelle Morcello	Géode
Françoise Piozin	Inrets - Dest
Tapio Poteau	Inrets - Traces
Catherine Roy	Daei
Patrice Salini	Imtl
Oscar Sanchez	Université de Cergy-Pontoise - THEMA
Jean-Paul Sinsou	Université du Havre
Christophe Terrier	Datar
André Turcot	Dre Poitou-Charentes
Lisa Williams-Demarey	Dre Picardie

European Spatial Development Project / France

SEVEN PROPOSALS FOR THE CONSTRUCTION OF GEOGRAPHICAL POSITION INDEXES (potential, accessibility, concentration)

Application to the measure of demographic accessibility and population potential of European Union and neighbouring countries.

by

Claude GRASLAND

CNRS
UMR Geographie-Cités (Equipe P.A.R.I.S.)
GDR-LIBERGEO
Hypercarte Research Group

Preliminary version, January 1999

Adress :	Claude GRASLAND UMR Géographie-Cités / Equipe P.A.R.I.S. 13, rue du four F-75006 Paris Tel. 33 01 40 46 40 03 Fax. 33 01 40 46 40 09 e-mail : claude.grasland@parisgeo.cnrs.fr

INTRODUCTION

The *European Spatial Developement Project (E. S.D.P.)* tries actually to define different sets of indexes which could characterize the spatial differenciation of regions and cities of the *European Union (E.U.)* in order to produce analytic or synthetic maps according to those indexes. A working group including researchers of 15 member states of the E.U. tries actually to summarize proposals for the realisation of those maps and indexes. The goal is to provide high level scientific material in order to help future political decisions about territorial planification of the European Union and to insure a good fit between local, regional, national and international levels of territorial organisation.

One of the sets of target indexes defined by the ESDP is related to *'Geographical Position'* , and researchers from Germany, France and Finland has the task to summarize the proposals of the 15 national research networks (focal points). Another research group is preparing another synthesis about *'Spatial Integration'* but the member of both group are in contact because those criteria of differenciation are clearly very connected and difficult to distinguish.

In the framework of the french scientific network of ESPD *(GDR-Libergéo)*, many proposals have been made by different research groups (**GEOSYSCOM, Caen ; CIRTAI, Le Havre ; IMAGES & VILLES, Strasbourg ; GEOGRAPHIE-CITES, Paris**) for the measure of those criteria of *Geographical Position* and *Spatial Integration* and each research group will present a short synthesis of proposals which could be included in ESDP project if the research networks of the 14 other states agree with those proposals. As the proposal of the different french teams working on accessibility are rather different (according to data, methods and assumption) it was decided to present each proposal in an independant manner and to avoid a "national synthesis" which would be in contradiction with the spirit of the E.S.D.P. project.

Accordingly the present working paper is neither a synthesis of european research network proposals or a synthesis of french research network. It is only a synthesis of different researches or studies about accessibility, potential and concentration realised by C. Grasland and other members of the research group P.A.R.I.S. ("For the Advancement of Research on Spatial Interaction") during the last ten years.

The author of this working paper is particulary grateful to **N. Cattan** and **H. Mathian** which helped him to develop and to criticise the concepts of multiscalar accessibility or potential. Thanks also to informaticians (**J.M. Vincent, LNC-IMAG**) and statisticians (**G. d'Aubigny, LABSAD**) from Grenoble which are actually engaged with him in the development of a new multiscalar spatial analysis software based on the concept of multiscalar neighbourhood (*The Hypercarte Project*).

This work is divided in seven parts related to **seven proposals for the mesure of indexes of geographical position**. The proposals are mainly theoretical but are applied to a very simple but concrete example (**distribution of population according to euclidian distance in E.U. and neighbouring countries**) in order to show what could be done with better material

I. EACH RESEARCH ABOUT GEOGRAPHICAL POSITION INDEXES SHOULD START WITH THE DEFINITION OF THREE AREAS : THE TARGET AREA (1), THE STUDY AREA (2) AND THE INFORMATION AREA (3)

The fact that the purpose of ESDP is to examine the accessibility or the potential of the places located *inside* the 15 European Union's states does not imply that we should limit the investigations and the collect of information to this area. Our first proposal is that : ***"Each research about geographical position indexes should start with the definition of three areas : (1) the target area, (2) the sudy area, (3) the information area"***

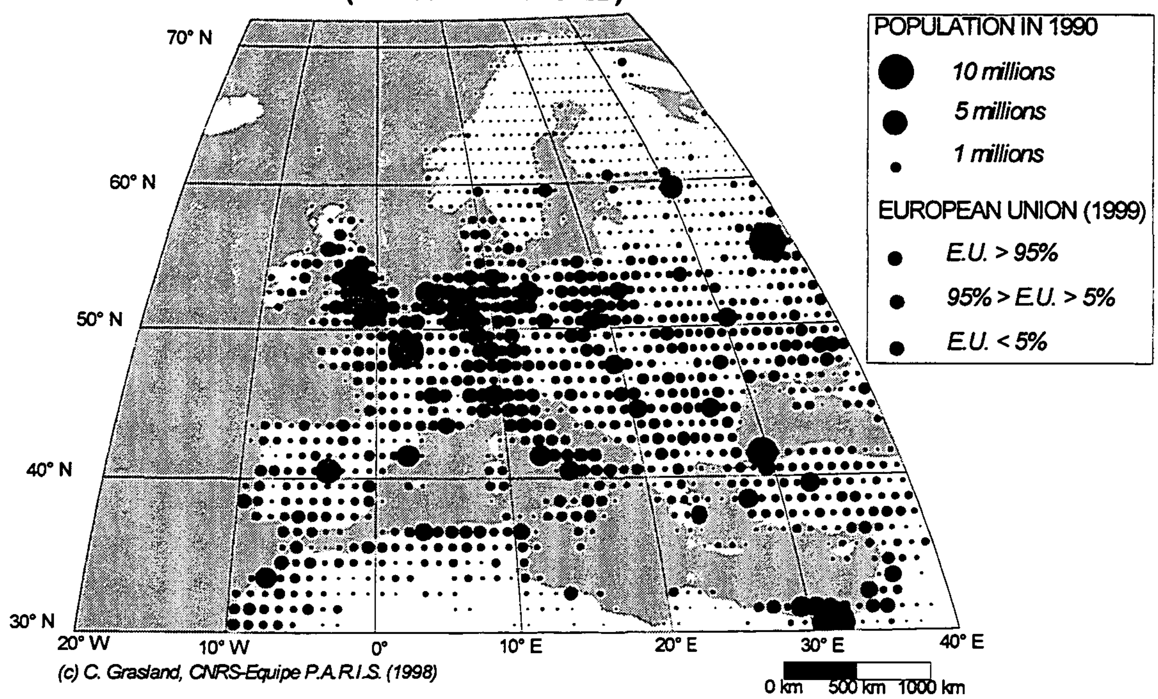
(1) **The target area** can be defined *as the territory of higher interest for the researcher which realise a study and/or the actors (policymakers, citizens, private firms, ...) which give money and orders for the realisation of this study.* In our example (ESDP project) the target area is clearly defined by the territory of the 15 states which are members of the European Union. Indeed, the aim of the ESDP project is to help the decision of policymakers which will produce proposals for the territorial planning of the European Union and all researchers which are involved in ESDP are citizens of one of the 15 states of the European Union.

(2) **The study area** can be defined as *the territory which is necessary to take into acccount in order to propose a correct evaluation of potential and accessibility inside the target area.* In a more simple way, we can say that the study area defines the territory where measure of potential and accessibility will be established and where it will be possible to map the results. In our example, it is very clear that neighbouring states like Switzerland (fully enclosed in the E.U.) have to be taken into account when we try to evaluate potential and accessibility. Indeed, European Union is not cuted off from the rest of the world and a correct analysis of its geographical position should take into account : (a) *the influence of ressources or actors of neighbouring countries on ressources or actors of the European Union* and (b) *the influence of ressources or actors of the European Union on ressources or actors of neighbouring countries.* But the definition of the study area is not simple because it has to take into account the mental representations of the researchers or the policymakers, their objectives, their implicit or explicit opinions and, more generally speaking, their "**Weltanschauung**". Generally, the discussions on this point are avoided and some considerations of **"availability of data"** are presented as justification of a delimitation which is in fact based on political and psychological considerations. Accordingly, the case of UNEP-GRID database is very interesting because it is an exhaustive information on world population and we are obliged to justify or choices in the delimitation of the study area. It is theoretically possible to compute world indexes (as we have done in another working paper) and to consider the accessibility or population potential of European Union territory compared to the same information above all the earth. But we can also decide to focus on a smaller area if our interest is to analyse the potential relation between people and territories of European Union and neighbouring countries at a medium scale of analysis. In this working paper, we have decided to use a geometrical definition of the study area which is the portion of earth surface comprise between 20°W and 40°E for longitude and 20°N and 73°N for latitude (**Map. 1**). Accordingly, eastern Europe but also all mediteranean countries are involved fully or partly in the studied area. We are perfectly aware that it is a subjective choice based on our own political or ethical opinions and on our own subjective representations. But it is better to make it explicit than to invoke a so-called 'neccessary' or 'natural' choice.

(3) **The information area** is much more easy to define because it depends only on the information which is necessary to collect out of the study area, according to the definition of indexes we propose to compute. In certain cases, the information area can be equal to the study area or even

to the target area. If we decide (for example) to compute an accessibility index like the mean distance to the population distributed inside the european Union, our information area is equal to European Union (target area) but the computation can be realised also for neighbouring countries (study area). But if we decide to compute a potential index like the number of inhabitants located in a radius of 1000 km around each place (of the study area), we are obliged to extend the collect of information within a buffer zone of 1000 km all around the study area. The informations collected in the buffer zone will not be mapped but they are necessary for a correct computation of the results according to the proposed definition of the index.

Map 1. GRID REPARTITION OF THE POPULATION OF EUROPEAN UNION AND NEIGHBOURING COUNTRIES IN 1990 (source : UNEP-GRID)



II. THE EXISTENCE OF A GREAT NUMBER OF INDEXES OF ACCESSIBILITY OR POTENTIAL IS RELATED TO THE GREAT DIVERSITY OF THEORETICAL ASSUMPTIONS THAT CAN BE MADE WHEN THOSE INDEXES ARE APPLIED TO EMPIRICAL SITUATIONS

As it exists many variants of accessibility or potential indexes, many authors has proposed (1) to elaborate strict definition of accessibility or potential or (2) to classify existing solutions proposed by different authors. Those attempts are interesting and necessary, but they have to take into account our 2nd proposal which is : **"The existence of a great number of indexes of accessibility or potential is related to the great diversity of assumptions that can be made when those indexes are applied to empirical situations".**

People which try to propose definitive and normative proposals for the definition of concepts are generally more interested in the defense of their paradigmatic or institutional positions than in the research of the best tools for empirical purposes. In our opinion, the aim of a project like ESDP is not to arbitrate academic discussion but to propose the most efficient solutions in each practical case submitted by policymakers. Accordingly, we would like to avoid the questions of *authority* and our intention is not to propose a review about the *state of art* or a synthesis of the *normal science*.

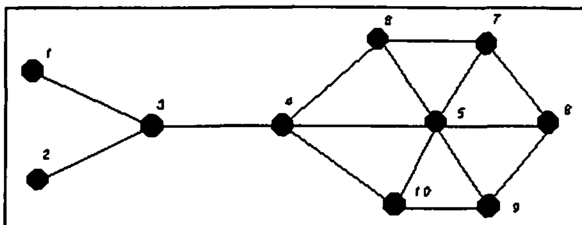
In our opinion, the existence of a great diversity of solutions for the measure of accessibility or potential is not a problem but a guarantee that it is possible to find in any empirical situation a tool which will be really adapted to the problem. It would be foolish to limit our "toolbox" to one or two measures if we are able to obtain a greater number of statistical or cartographical tools with specific advantages. But precisely, the multiplication of tools and solutions for the measure of geographical position is interesting only if we can demonstrate the specific interest of each tool according to the problem to be analysed.

As much readers of this paper are probably specialists from the question of geographical position (with paradigmatic preferences, institutional positions, ...), we have decided to discuss the question of the relation theory/measure on some theoretical examples which, in a first step, are not geographical but sociological. This choice is based on the assumptions *(1) that it is more easy to evaluate theoretical proposals when personal interest are not engaged and (2) that the comparison of statistical methods or tools of different social sciences is an interesting way for the developement of relations at a higher level (theoretical or conceptual).*

What we try to demonstrate with 7 short theoretical examples is the fact that it is impossible to define 'best measure' of accessibility or potential from a theoretical point of view, but that each solution has specific advantage in certain circumstances and according to the assumptions made by the researchers or the policymakers on the problem to be analysed.

A social network example : Consider for example a social network of relation between a population P of n individuals $1..i..n$ which form a social group and we suppose that a subgroup R of k individuals ($1..j..k$, $k<n$) member of the social group has a ressource (e.g. power, knowledge, ...) that the other individuals of the group do not have and try to obtain. We suppose that the volume of ressource is proportional to a given quantitative variable M with values $M_1..M_j..M_k$ and can be obtain by direct or indirect relation between individuals (e.g. friendship). Relations are defined as an oriented graph G defined on PxP with value $G_{ij}=1$ if the individuals i and j have a relation and $Gij=0$ if it is not the

case. We can derive from the graph ***G*** a shortest-path topological distance of relation ***D*** between individuals which is the minimum number of contact D_{ij} necessary for an individual *i* which tries to contact an individual *j*.



In the example of social network presented above, the social network distance between individuals are shortest parth defined by : $D_{1,1}=0$, $D_{1,2}=2$, $D_{1,3}=1$, $D_{1,4}=2$, $D_{1,5}=3$, ...

This distance of relation is purely sociological, even if it is well known that social network distances are correlated with geographical distances [1]. With this non-spatial example, we hope that it is possible to present different measures of **social position** which are more or less interesting according to the assumptions made of the nature of actors and ressource located in the social network. But those measures and the related assumptions can easily be transposed to **geographical position** analysis by the reader.

- Theoretical example 1 : *We suppose that the quantity of ressource M is not important* and that it is sufficient for each individual of ***P*** to be in contact with **one** individual of ***R*** (e.g. the ressource is the fact to be able to write and the demand is to send a letter). In this situation, the most logical index for the description of the sociological position of individuals **is *the minimum distance to the ressource*** D^{min} which can be computed for each individual [2]. Other measure of accessibility (like mean distance) are not interesting in this case because the problem of individuals is to access to one ressource and not to all ressources.

- Theoretical example 2 : *We suppose that the quantity of ressource M is important and that each individual tries to develop contact with the whole ressource available in the group*. In this case, each individual of ***P*** tries to be in contact with **all** individuals of ***R*** (e.g. the ressource is books which are lend by individuals to the others. We suppose that all books are different). In this situation, the most logical and simple index which evaluates the position of individuals (actors) is ***the total distance of individuals (P) to the ressource (R) weighted by the quantity of ressource (M)***. This total distance is proportional to the mean distance of individuals to resource D^{mean} which is more easy to analyse and which can be transformed into a classical accessibility index ***A*** ($A_i = 1 / D^{mean}{}_i$). All those indexes are mathematically equivalent and the choice of one of them has no influence on the results. In this situation, it is also interesting to use the criterium of maximal distance from each individual to a ressource D^{max} which is well-known in graph theory and social network analysis (mean distance and maximum distance are 2 of the 3 centrality indexes proposed by Freeman[3] for the measure of centrality in social network).

---

[1] **Milgram S. (1967)**, "The small world problem", *Psychology Today, 1*, pp. 61-67

[2] $D^{min}{}_i$ equal to 0 if *i* is member of ***R***, 1 if *i* is unable to read but in direct relation with a member *j* of ***R***, 2 if *i* can be in contact with a member *j* of R through another individual *k* , ... and an infinite value if *i* is unable to read and can not established any path of relation with a member *j* - in this case the graph is not connex.

[3] **Freeman L. (1979)**, "Centrality in social networks. Conceptual clarification", *Social Networks, 1*, 215-239.

- Theoretical example 3 : *We suppose that each individual tries to obtain a given amount of ressource which is a quantity **M** of ressource or a proportion **m=M/M**$_{tot}$ of the total ressources **M**$_{tot}$ available in the system* (e.g. the ressource is the ability to write and individuals are looking for two or four witnesses which will sign an administrative register). In this situation, the most logical indexes of accessibility are based on ***the frequency (quantiles) of the distribution of distance*** between each member of ***P*** and the ressource ***M*** distributed between the members of ***R***. If one individual tries to obtain relations with 50% of available ressource in the system, the related measure of accessibility is the median distance D^{med}. But more generally, if the individual tries to obtain a quantity *M* or a proportion *m* of the ressources available in the system, the associated index of accessibility is the quantile *m%* of the cumulative distribution of ressources with social distance ***D(M)*** .

- Theoretical example 4 : *We suppose that the individuals tries to obtain the maximum of ressource but are unable to reach the ressources located at a distance greater than a given value* ***D*** (e.g. people which possess the books in the previous example do not accept to lend it to indirect relation of length greater than 2). In this situation the index we try to measure is the maximum number of books that each individual is able to obtain, i.e. the amount of ressource located at a distance lower than ***D***. The result will be express in the unit of measurement of ***M*** (amount of rerssource) or as a percentage ***m*** of the total amount of ressources available in the system (which is better for comparison of different ressources). Accordingly, it is not an ***accessibility*** index but a ***potential*** index because the result of the measure is an ***amount of ressource (available opportunities)*** and not a ***distance***. But it is clear that the two notions are very close and the curve ***M(D)*** which gives for each individual the amount of ressource located at a distance lower than ***D*** is simply the inverse of the curve ***D(M)*** of the previous application.

- Theoretical example 5 : *We suppose that the individuals try to obtain the maximum of ressource but that their success in access to ressource is defined by a probability inversely proportional to the social distance where the ressource is located.* (e.g. people which possess the books in the previous example do accept to lend it to other people with a probability which depends on the length of the shortest path distance in the social network). The influence of proximity on the probability of access to a ressource is obvious in spatial as in social or economic frameworks. But the ways of this influence of distance are manifold and it is important to have an empirical and theoretical idea of the different ways distance and proximity can influence the accessibility to ressources.

Some empirical and theoretical explanations of the decrease of interactions with distance (Grasland, 1998)

Briefly said, we can distinguish between three families of explanation of the influence of proximity on the developement of relation and on the possibility of access to ressource[4]. **(1) The economic explanation** (Reilly, Zipf, Pareto) is based on the idea that the cost of relation has a negative influence on the developement of relations because it reduces the marginal advantage (utility) of the ressource. This cost can be proportional to distance according to a continuous function (e.g. transportation of goods) but it can also be influenced by discrete variables like spatial discontinuities (e.g. political boundaries which produce a sudden increase of cost due to taxes or time of control). **(2) The information theory explanation** is based on the idea that each material relation is preceded and accompanied by a flow of information. If actor's information about opportunities or ressources is limited and decrease with a given distance, we can expect that the relations he will develop and the ressource he will access are negatively correlated with this distance. This information distance can be geographically defined but also politicaly, psychologicaly or sociologically if we take into account the different barriers which can reduce actor's information and, by the way, actor's interactions. **(3) The time-budget or travel-budget explanation** are based on the fact that an individual has a limited quantity of time or money to spend for relations (as a day has only 24 hours and as actors has a limited amount of money for travelling). Accordingly, the probability that this individual tries to develop contact or to obtain ressources located at a great distance is lower than his probability to do the same at shorter distance. We can also observe that if we consider **multipurose travels** and not only single destination travels, an actor will frequently be in path-contact with the opportunities located at a short distance around him and has a lower probability to be in path-contact with opportunities located at a longer distance. **In empirical situations, those three families of explanation should generally be combined** and it is difficult to distinguish their relative influence. It is the reason why the *proximity interaction function* (which summarizes the effect of a given distance, geographical or not) are generally based on empirical observation rather than on a theoretical deductive approach. A classical example of this empirical approach is the pareto function $f(d) = d^{-\beta}$ used in spatial interaction models where the parameter of distance is estimated in each situation and generally not assigned to a given value which could be deducted from theoretical considerations. But this pareto function is not necessary adequate to the phenomenon to be analysed and, in certain cases, has many disadvantages.

In our sociological example of people lending books we can suppose that the probability for someone to lend a book to another individual during a given period of time is equal to 0.5 if this individual is in direct relation and 0 in other cases. Accordingly, the function which describes the probability for an individual *i* to obtain a book from an individual *j* located at the social distance ***D*** during a longer period of time is proportional to a **probability function like** $\mathbf{(1+d)^{-2}}$. And the sum of ressources weighted by this interaction function (modified pareto function) produced a measure of potential which is more easy to interprete than the pareto function because the result is a quantity of ressources (book) and not a quantity of ressources divided by distance as in classical formulation of population potential (for more details on this point, *see Proposal VI*).

- Theoretical example 6 : *We suppose that each individual is a ressource for other individuals and that each individual has equal importance for the others* (***P=R*** *and* $M_1=...M_n = 1$*)*. This theoretical example can be considered, in our theoretical framework, as **a particular case**, even if it is the most frequently analysed by sociologist (or geographers) which are working on centrality and accessibility. In this particular case, it is possible to distinguish two great families of indexes accroding to the assumption made on the distance variable and its underlying mathematical and topological properties . **(1) Network analysis of accessibility or potential** are based on the study of a graph ***G*** of links between individuals which is not complete. In other words the information provides a list of couples of individuals (edges) which are connected by links (vertices) which can be assigned to a value or not. But some couples of individuals are not

[4] For more details, see. **Grasland C., 1997,** *Contribution à l'analyse géographique des maillages territoriaux,* Mémoire d'habilitation à diriger des recherches, Université Paris 1, Volume A, pp. 93-99

connected (or not directly). In this case, a great amount of indexes can be derived which can be classified in three families *(a) description of the whole graph , (b) description of the edge of the graph, (c) description of the vertices of the graph*[5]. **(2) Geometric analysis of accessibility** can be derived from the previous information but have the property to be based on a complete matrix of distance ***D*** between individuals (with possibility of infinite value if two individuals can not be in relation under the assumption made). A classical example of this are, in socioly : the shortest path distance of relation between members of a social network and, in geography : the minimum time or cost of travel between a set of cities. Different methods can be applied for the analysis of this information but the description is theoreticaly limited to only two families of indexes *: (a) description of the whole matrix of distance ; (b) description of the specific position of individuals.* If the distance matrix is not symetric or if different weights are allocated to places for emission and reception, it is necessary to produce a *distinction between in- and out- measures of accessibility or potential.*

- Theoretical example 7 : *Assumptions are the same than in Theoretical example 6 but with the additional hypothesis that individuals are a representative sample of a population which has a continuous distribution in a given geometrical space **S** with known mathematical properties.* This theoretical example is apparently specific to spatial analysis of accessibility or potential but it can (and has many times) also be applied to the analysis of sociological networks and social integration. The basic idea of those kind of researches is to identify unknow coordinates of indiviuals in a given space S with *k* dimensions, according to a knowledge of effective distances **D** between a sample of individuals. Most authors have formalised this problem as the resolution of the problem $D=f(X1..Xk)$ where **D** is an available information about distance between individuals and $\mathbf{X}^1...\mathbf{X}^k$ unknown vectors of coordinates of those individuals in the geometrical space S. The number of parameters *k* and the function *f* define the form of the model, i.e. the assumptions made on the mathematical and geometrical properties of ***S***. The most simple model of this type is **factorial analysis** (principal component analysis or correspondance analysis) applied to a matrix of distance between individuals, where the coordinates of individual for the two (or more) first factors are the coordinates to be estimated by the model. As an example of this method, you can have a look at the Factorial Analysis realised after the first ESDP meeting on the research subject choosed by the researchers of the 15 states of the E.U.[6] In this example the distance ***D*** was equal to the chi-square distance between the profile of choices $(x_1...x_z)$ made by the research of each states (rank of preferences) and the 1st and 2nd factorial coordinates (F_1,F_2) are supposed to be a planar representation of a kind of "*scientific interest proximity*" between research groups of the different states of the European Union. Specific solution to this problem has been proposed in the case of spatial accessibility, especially by german and french authors which proposed innovative maps of accessibiliy based on geographical position transformation in two or three dimensions [7].

[5] See. for example : **Degenne A., Forsé M. (1994),** *Les réseaux sociaux*, Paris, Colin, 288 p.

[6] See. The annex of the report of French research group about the 1st ESDP meeting in Brussels (7 Dec. 1998).

[7] See. the works of **Wegener** (Dortmund), **Cauvin & Reymond** (Strasbourg), **Lhostis, Chapelon & Mathis** (Tours).

III. THE MINIMUM INFORMATION NECESSARY FOR THE COMPUTATION OF INDEXES OF ACCESSIBILITY OR POTENTIAL IS THE EXISTENCE OF (AT LEAST) THREE SETS OF VARIABLES : (1) DISTRIBUTION OF RESSOURCES, (2) DISTRIBUTION OF ACTORS AND (3) DISTRIBUTION OF DISTANCE.

The previous proposal has illustrate the great diversity of solutions which can be used for the measure of potential or accessibility according to the objectives of the research. And there is no doubt that an infinite number of measures could be proposed through a single combination of the previous assumptions or with additional hypothesis. But it is important to observe (and it is our third proposal) that ***"The minimum information necessary for the computation of indexes of potential or accessibility is the definition of three set of variables related to (1) one distribution of ressources, (2) one distribution of actors, (3) one distribution of distances between ressources and actors".***

We propose to examine the consequence of this third proposal in spatial case and to produce a concrete application to UNEP-GRID database on european distribution of population in 1990 (**Map. 1**).The most classical measure of accessibility which can be produced with UNEP-GRID information is the mean orthodromic distance *(d)* between an actor located on a given place *(i)* and all inhabitants of the 15 states of the European Union *(j)*. As the accurate position of the inhabitant is unknown (and changing through time), we use an approximation which is the mean distance between each cell *(i)* of the studied area and each cell of the european union *(j)* weighted by its population *(P_j)*.

$$\bar{d}_i = \frac{\sum_{j=1}^{k} P_j . d_{ij}}{\sum_{j=1}^{n} P_j}$$

with:

k : *number of cells where E.U. population is located*

P_j : *inhabiants of E.U. located in cell j*

d_{ij} : *orthodromic distance between place i and the center of cell j*

The results are presented on **Map 2** where an interpolation was realised in order to produce a continuous representation of mean accessibility to the population of the European Union.

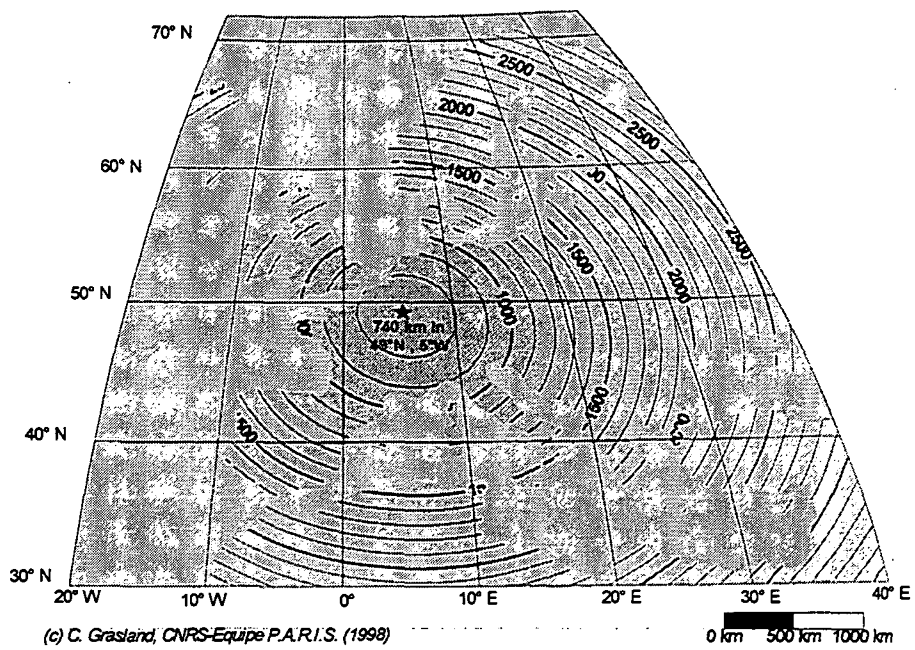
Map.2 indicates that the most acessible place according to the criterium is located in France, near *Valmy* (49°N, 5°W) which is at a mean distance of 740 km from the inhabitants of the European Union in 1990 [8]. The less accessible places of the European Union are located in northern Finland and Sweden (mean distance of 2500 km to E.U.'s inhabitants). And the examination of places located out of the E.U. demonstrate clearly that many places which are out of the territory of E.U. are closer to its population than places located inside the territory of the E.U. . It is obviously the case of Switzerland (one of the lower mean distance to the population of E.U.) but also of east central Europe and

[8] But the database is not very precise and this result is an estimation (with + or - 2° in latitude and longitude).

northern Africa which are located at a mean distance of only 1000-2000 km to the population of European Union. According to our criterium of mean distance to population of E.U., *Porto, Séville, Palerm and Stockholm* (located in the E.U.) have more or less the same accessibiliy (1500 km) than *Alger, Tunis, Tirana, Lvov, Kaliningrad or Oslo* (located out of the E.U.). And *Prague* has more or less the same accessibility (1000 km) than *Firenze, Barcelona, Toulouse, Manchester or Lübeck.*

It is possible to produce many other comments of this first result, but it is more important in our opinion to recognize the weakness and limitations of the index of accessibility which is proposed (and which is not only related to the choice of distance and ressource). The map of accessibility measured by mean distance is certainly more interesting and more precise than the single distance to the gravity center of population or to a representative point (like the distance to Maastricht in the first ESDP report). But the results which are obtained are not very different and *the fundamental question is : "What are the practical and theoretical interest of a measure of <u>mean distance</u> ?" and "Which kind of actor (individual, group, firm, institution) would be interested in such an index ?".*

Map 2. MEAN ORTHODROMIC DISTANCE TO THE POPULATION OF EUROPEAN UNION IN 1990



(c) C. Grasland, CNRS-Equipe P.A.R.I.S. (1998)

If we transpose the results of our previous analysis (Cf. *Theoretical example 2*), we can answer that *an actor will be interested in <u>mean distance</u> if he intend <u>to be in relation with the whole inhabitants of European Union with equal probabilities</u>*[9].

Accordingly, we can say that very few actors are potentially interested by such an index ! Mean distance to population can be interesting for members of great multinational firms (which have a strategy covering whole Europe) but they would probably prefer an equivalent measure of distance to economic activity based on time or cost distance. It could probably be more interesting for members of European Union agencies or institutions (Commission, Parlement, EEA, Eurostat, ...) which have to be theoretically in contact with all citizens of the Union, but the simple sum of distance to selected

[9] *Or to be in relation with a sample of E.U. inhabitants <u>randomly distributed</u>.*

places in each state is probably more interesting for individuals members of those agencies which do not have contact with all inhabitants but only with *focal points* of member states. Finally, we can suspect that the most interesting use of the results of **Map 2** is probably a publication in the *Guinness Book of Records* !

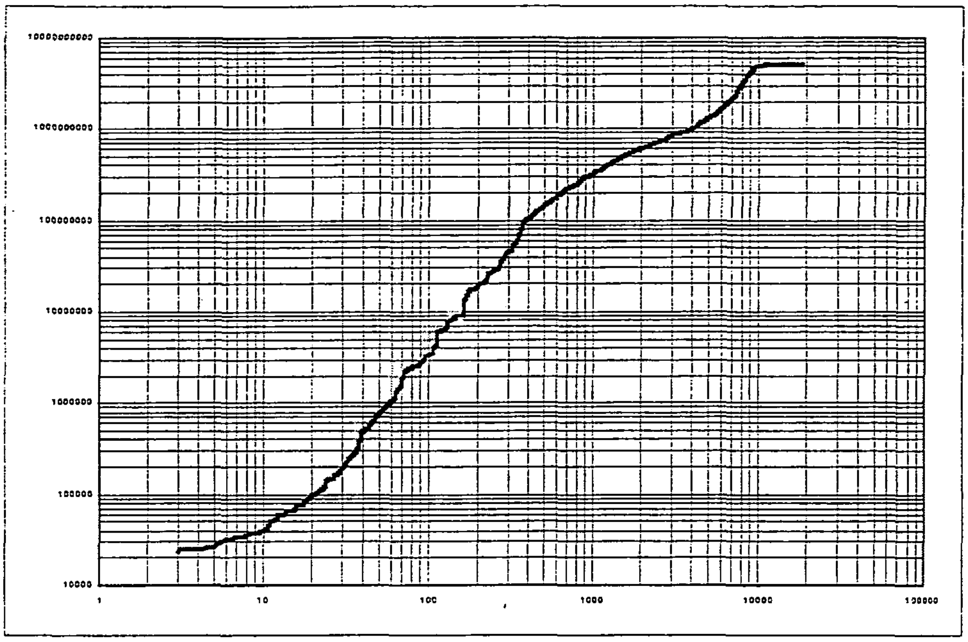
This conclusion is crual (especially for *Valmy*) but the problem with mean distance (and with any other single measure of accessibility like median distance, maximum distance, etc.) are :

(1) **from an empirical point of view** single measure of accessibility are based on the overoptimistic assumption that it is possible to summarize the position of a place according to a ressource and a distance with a single index without consideration of who is interested in the relation to the ressource and for which purpose.
(2) **from a theoretical point of view**, the general problem with single measures of accessibility is related to the fact that they try to summarise all the informations contained in a distribution of distance (a curve) with a single value (a scalar).

If we compute for a given place *(i)* the cumulative curve $P_i(d)$ of population located at a distance lower than a given value to *i* (*Cf. Theoretical Examples 3 and 4 in previous section*) , we obtain a much more interesting information on the accessibility of a given place to a ressource spatially distributed. As an example, we have realised for the *International Festival of Geography of Saint-Dié-des Vosges* the complete curve of cumulative population according to euclidian distance to this town[10] between 10 and 20000 km around Saint-Dié (**Figure 1**).

[10] The curve presented in **Figure 1** has been established through the combination of three databases describing population of places and their orthodromic distance to Saint-Dié in 1990 (French communes, European regions Nuts 3, UNEP-GRID database for the rest of the world).

Figure 1 : Cumulative population acccording to the euclidian distance to St-Dié



With this curve, it is of course possible to calculate the mean distance of Saint-Dié-des-Vosges to world population in 1990 (*6750 km*) and to compare the result with the distance of other places of the earth to world population. The inhabitants of Saint-Dié will probably be happy to know that their accessibility to world population is better than the one of New-York (10000 km) or Tokyo (7000 km) but lower than the one of Moscow or Pekin (6000 km). But what is the practical interest of this result ?

Nobody in *Saint-Dié-des-Vosges* has the project to develop relation with all inhabitants of the world (an exception may be provided by the organiser of the International Festival of Geography). For actors which are located in Saint-Dié or which could decide to locate in this city it is much more interesting to consider the curve which give answer to any questions like : *(1)"What is the minimum distance necessary to cumulate P inhabitants around St-Dié ?" or (2) "What is the amount of population located at a distance lower than D of Saint-Dié".*

According to their time-budget, power, objectives,... some actors will be interested to know that 50 000 inhabitants are located in a circle of 10 km around Saint-Dié, 2 millions in a circle of 100 km, 300 millions in a circle of 1000 km ... Or they can compute that they need a circle of 20 km to cumulate 100 000 inhabitants around Saint-Dié, 70 km for 1 millions of inhabitants, 150 km for 10 millions of inhabitants,... Those are concrete and practical results which could be taken into account by an industrial, a trader, or any actor interesting in the development of contacts at local, regional or international scales.

The results would certainly be more interesting with different distances or different ressources, but the single curve of cumulative population with orthodromic distance provides by itself a large set of interesting informations. The slope of the curve and its discontinuities reveal for example the distance where a brutal increase of population can be observed and are a good information on the position of great concentration of population around Saint-Dié (important towns, industrial regions, ...).

IV MOST INDEXES OF ACCESSIBILITY OR POTENTIAL CAN BE CONSIDERED AS AN ATTEMPT TO SUMMARIZE THE CUMULATIVE CURVE OF RESSOURCE ACCORDING TO DISTANCE

Our 4th proposal is that : ***"The cumulative curve of ressource according to distance can be considered as a fundamental information on the geographical position of a place and that most indexes of accessibility (or potential) can be considered as an attempt to summarize this fundamental curve under different assumptions."***

Before to compare the cumulative curve of ressource according to distance for different places, it is necessary to established a reference curve for the whole system where places are distributed. This can be realised easily through the construction of a curve based on all distances between places and ressources. This curve is obtain in two steps :

*(1) construction of the distribution **d'(M)** of distances between all couples of actors and ressources.*
*(2) construction of the cumulative distribution **d(M)** of distance between all couples of places and ressources (this curve is the integral of the previous one which is its derivate).*

As an example, we have compute those curves for the distribution of distance inside the European Union under three assumptions :

(a) distance between territories (each area is a ressource and the potential location for an actor)
(b) distance between populations (each individual is a ressource and a potential location for an actor)
(c) distance between population and territories (each individual is a resource and each area is a potential location for an actor)

The computation where realised with UNEP-GRID database and each cell of the grid which belong to the european union was characterised by a population and a superficy[11]. For cells which are located on the boundary of the European Union, only population located inside states members of the E.U. are taken into account in the computation. The distribution of distances was established by classes of 50 km and the irregularities of the distribution were smoothed by polynomial interpolation.

The results are presented on *Figure 2* and *Figure 3 :*

[11] As UNEP-GRID does not furnish an evaluation of superficy by degree of latitude and longitude, our results about the distribution of distance between territories or between territories and population are just a first approximation. Only distances between populations can be considered as correct (according to the level of agregation of information). Anyway, all those results should be recomputed later with better datasets like EUROSTAT Nuts3 or Nuts5 informations and with other ressources (GNP, active population) and other distances (time, cost). But this first estimation is sufficient for our methodological approach.

Figure 2 : Distribution of distances between populations and territories of the E.U.

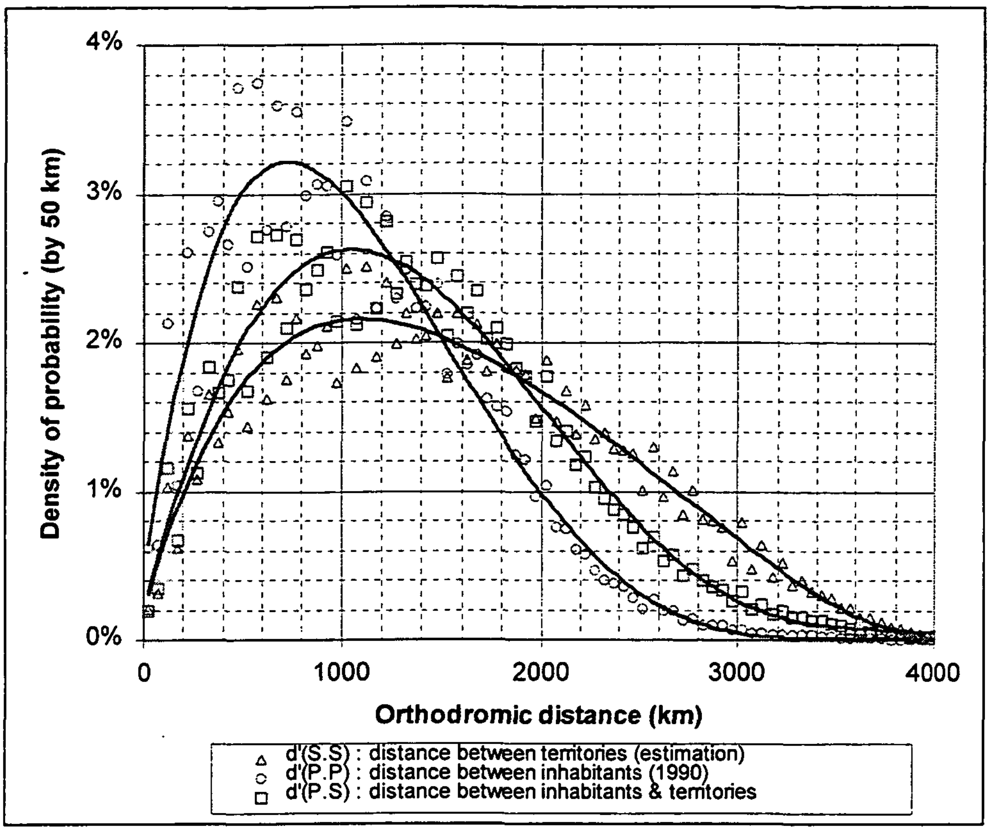
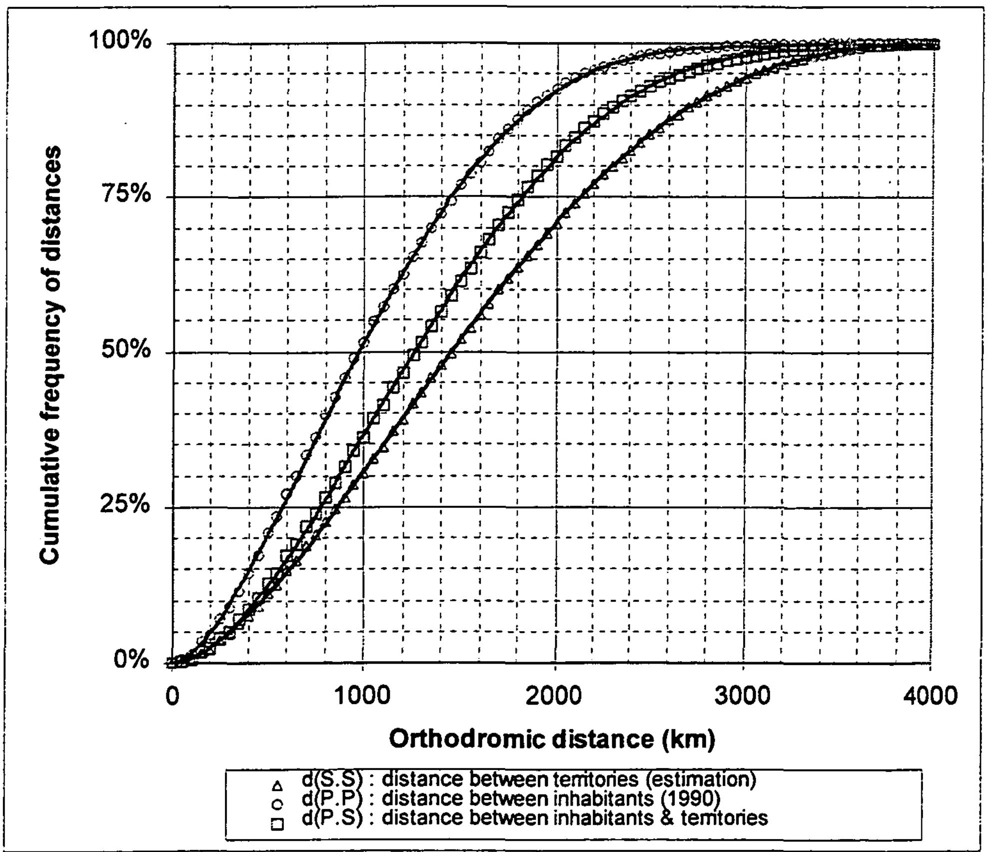


Figure 3 : Probability of distances between populations and territories of the E.U.



With those curves, it is now possible to evaluate and compare **three families of geographical parameters** related to **(1) spatial distribution** (distance between territories), **(2) social distribution** (distance between inhabitants) and **(3) socio-spatial distribution** (distance between inhabitant and territories). And according to those parameters, it is possible to evaluate the **spatial concentration of population** as a comparison of distance between territories and distance between populations under different assumptions (γ_1, γ_2, γ_3).

Table 1 : Characteristic parameters of the spatial concentration of population in E.U.

Statistical summary of distances	Criterium of distances			Concentration indexes		
	(1) social	*(2) spatial*	*(3) socio-spatial*	*(2) / (1)* γ_1	*(3) / (1)* γ_2	*(2)/(3)* γ_3
Modal distance	750	1100	1050	1.5	1.4	1.0
Mean distance	1050	1550	1350	1.5	1.3	1.1
Median distance	1000	1450	1250	1.5	1.3	1.2
d(10%)	300	450	450	1.5	1.5	1.0
d(25%)	550	850	750	1.5	1.4	1.1
d(75%)	1450	2150	1800	1.5	1.2	1.2
d(90%)	1900	2700	2300	1.4	1.2	1.2

- **Modal distance** which is *the most frequent distance* between two places according to a criterium can be evaluate from *Figure 2.* The most frequent distance between populations of the European Union (random sample of inhabitants of the E.U.) is 750 km but the most frequent distance between territories of the E.U. (random sample of places, inhabited or not, located inside the E.U.) is 1100 km and the most frequent distance between populations and territories of the E.U. (random samples of places and inhabitants) is 1050 km.
- **Mean distance** provides another approach of the distributions which take into account all couples of distance and is more precise than the previous modal distance. As the distribution of distances is not symetric (greater amount of short than long distance), the values of mean distance are greater than the values of modal distance but the ranks are the same as before : 1050 km for means social distance, 1350 km for mean socio-spatial distance and 1550 km for mean spatial distance.
- **Median distance** is a compromise between the two previous approaches and is probably the best summary of the distributions. It indicates than 50% of the inhabitants of the european are located at a distance lower than 1000 km to each other. The median distance between territories and populations is 1250 km and the median distance between territories is 1450 km.
- **Quantiles of distance** are a complementary approach of the previous one which give more indications on the distribution of very short or very long distances. For example, it is possible to demonstrate that 50% of the couples of inhabitants of the European Union are located at a distance to each other included between 550 and 1450 km and that 10% are located at a distance lower than 300 km and 10% at a distance greater than 1900 km. Equivalent observation can be done for spatial or socio-spatial distances (*see Table 1*).

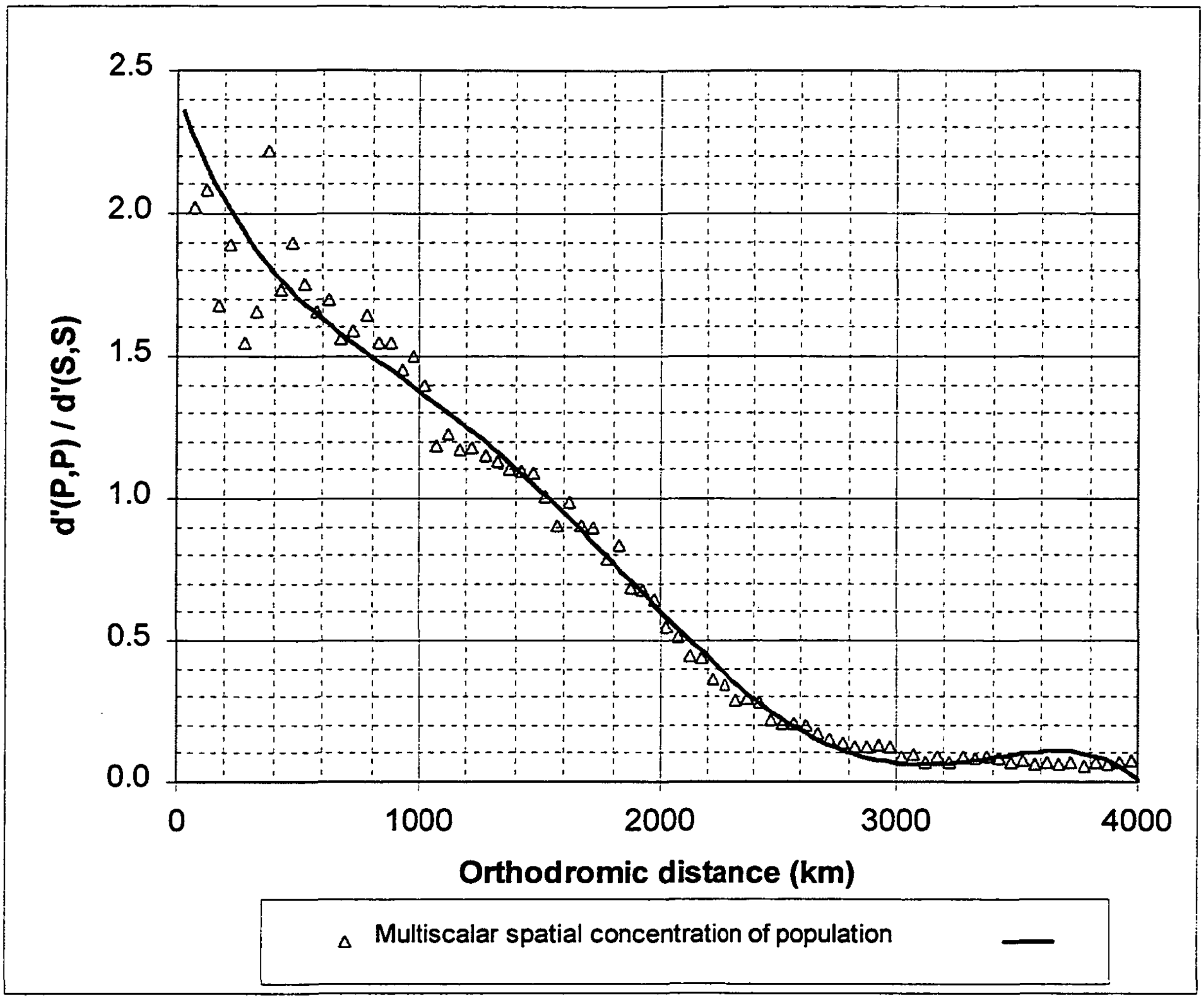
From the above results, it is possible to deduce different **measures of spatial concentration** as for example the ratio of a summary of distance between territories and distance between inhabitants (γ_1). We can observe that whatever the criteria choosen for the summary of the distribution of distances the value of this concentration index is more or less equal to 1.5 which indicates that *the distances between two random places (inhabited or not) are generally*

50% greater than distancesbetween two random inhabitants of the European Union. This result can of course be explained by the global concentration of the population of E.U. around the geometric center of the common territory of the 15 member states. But it is not directly related to the existence of local concentration of population like towns or industrial regions. In France, for example, the value of the γ_1 index is equal to 1 because population is concentrated both in the center and the periphery of the national territory. Accordingly, we obtain an over-representation of both short distances and long distances between inhabitants (compared to the distribution of distances between territories) and the mean social and spatial distance are more or less equal. In a state where the population is located mainly in peripherical areas, the value of the γ_1 index could be lower than 1, (i.e. the mean distance between inhabitants would be greater than the mean distance between territories). May be it is the case of Spain, but it is not quite sure because of the concentration of population around Madrid.

This γ-family of spatial concentration indexes has very interesting mathematical and statistical properties and is conceptually very different from usual measures like the classical Gini or entropy indexes of concentration used by economists or geographers.

- *Classical indexes of spatial concentration are necessary based on a territorial division* of space in spatial units and it is well-known that the spatial concentration measured with those classical indexes increases with the number of territorial units used for computation. This is not the case with the γ-family indexes where the value of spatial concentration remain more or less the same whatever the territorial division used for computation. With a great number of territorial units, the exactitude of the measure will be better but the estimated value will not be different with the one obtain with a lower number of territorial units.
- *Classical indexes of spatial concentration do not take into account the spatial distribution of population (i.e. the relative position of territorial units with high or low population density).* This proposal is obvious if you examine the information necessary for the computation of the so-called indexes of spatial concentration like Gini or equivalent : only population and superficy of territorial units are necessary and not the contiguity or distance matrixes beween territorial units. In other words those indexes are not 'spatial' or only in a very indirect manner (the choice of territorial units used for computation).
- *Classical indexes of spatial concentration are not able to take into account the multiscalar dimension of spatial concentration.* With **γ-family indexes it is possible to compute measure of spatial concentration at different scales,**for example through the computation of the ratio between the curves d'(P,P) and d'(S,S) which will provide a very usefull information on the most frequent distances between high/low population density areas. In the case of European Union the curve $\gamma'_1(d)$ =d'(P,P)/d'(S,S) presented on **Figure 4** is strictly decreasing, what indicates a general decrease of population density around a maximum located near the center of the European Union. But it is possible (it is for example the case in France) to obtain curves with different maxima which will indicates the existence of different *'typical distances'* between different areas of concentration of population. With a more precise database than UNEP-GRID, we would probably observe different maxima between 0 and 200 km, related to the distribution of distances between towns according to their population size (if central place theory is valid at the scale of the European Union ...).

Figure 4 : Multiscalar concentration of population according to superficy in E.U.



Finally it is important to observe that the γ-family of spatial concentration indexes could be apply to any distribution of ressources inside the European Union and provide the very interesting opportunity to compare the intensity of the spatiale concentration of those ressources or to evaluate the evolution of those indexes at different time period. We can suppose, for example, that the spatial concentration of population in the European Union has decrease during the 1970-1990 time period because the increase of population was much higher in peripherical area with high fertility (Ireland, Spain, Portugal, Southern Italy) than in central regions (Benelux, Germany, Northern Italy), especially after the reduction of immigration policies. But the fall of the iron curtain in 1989 has probably modify the tendancies with a brutal increase of immigration to western part of germany or Austria during the last ten years.

It is also important to observe that the **γ-family of spatial concentration indexes can be applied to the analysis of the co-distribution of two ressources** (and not only to a ressource and the territory.) For example, we can compare the spatial concentration of population and the spatial concentration of wealth (GNP or equivalent measures) in order to examine at **different scales** the distances between peoples and wealth ... In our opinion, the results obtained with the very simple example realised with UNEP-GRID database and orthodromic distance demonstrate how exciting would be the results with better information...

V. EACH PLACE CAN BE CHARACTERIZED BY DIFFERENT CURVES OF CUMULATIVE RESSOURCE(S) ACCORDING TO DISTANCE(S). A CLASSIFICATION OF THOSE CURVES PROVIDES A BETTER SUMMARY OF GEOGRAPHICAL POSITION OF PLACES THAN SINGLE INDEXES OF ACCESSIBILITY OR POTENTIAL.

In previous section, we have focus on the establishment of global curves of ressource according to distance for all couples of places (actors or ressources). But it is also possible to produce particular curves for each place where an actor or a ressource is located (or could be located). In the first case, we will obtain a cumulative curve of ressources according to distance (how many ressources can be reached by an actor located in a given place). In the second case, we will obtain a cumulative curve of actors according to distance (how many actors are located around the place where a ressource is located). Both analysis are interesting and should be combined in the evaluation of geographical position. But the most important fact, and it is our 5th proposal is that : ***"Each place can be characterized by different curves of cumulative ressource(s) according to distance(s). A classification of those curves provides a better summary of geographical position of places than single indexes of accessibility or potential".***

As an example, we have established the curve of cumulative population of Bonn and Berlin according to orthodromic distance with a distinction between population of E.U. state members and population of other states (**Figure 5** and **Figure 6**).

- *If we consider the total amount of population (E.U. + non E.U.)* located around the former and the new capital of Germany, we can first observe that the comparative advantages of each location are different according to the span of neighbourhood which is choosen. In a circle of radius 500 km, the davantage is for Bonn with a cumulative population of 135 millions of inhabitants located all around when Berlin has only a cumulative population of 110 millions of inhabitants for the same criterium. But with a radius of 1000 km, the advantages are more or less equivalent (320 millions of inhabitants around Bonn and 310 millions of inhabitants around Berlin). And with a radius of 1500 km the population located around Berlin is greater (500 millions of inhabitants) than the population located around Bonn (450 millions of inhabitants). In other words, the advantage of each location are differents according to the assumptions made on the distance at which potential relation could be established and it is not possible to define the 'best location' without an explicit formulation of those assumptions.
- *If we proceed to a distinction between the contribution of E.U. state members and non-E.U. state* members to the population potential of each city, the conclusions will be more precise and more interesting because we can suppose that, whatever the assumptions, the probability of relationship is higher with states located inside the European Union than with others (because of barriers, control, taxes, ...). As an example, the amounts of population located in a radius of circle 1000 km around each city are more or less equivalent (310-320 millions) but we can point out an important difference of contributions of the populations of E.U. member states in this total potential : 260 millions (more than 80%) in the case of Bonn and only 195 millions (63%) in the case of Berlin.

Our purprose is not to analyse more precisely those results, but they are sufficient to demonstrate *(1) the interest of cumulative curves of ressource according to distance* and *(2) the interest of the decomposition of cumulative curves of ressources in different classes when it is possible* (for example, it could be interesting to add to the previous analysis a specific examination of the contribution of german population within E.U. contribution of potential).
As a funny complement to previous analysis, we have established equivalent curves for the capitals of E.U. Bruxelles **(Figure 7)** and Strasbourg **(Figure 8).** But as this question is ... 'politically uncorrect' we refuse to comment the results. Do it yourself !

Figure 5 : Cumulative curve of population (E.U. or not E.U.) in 1990 according to orthodromic distance to Bonn

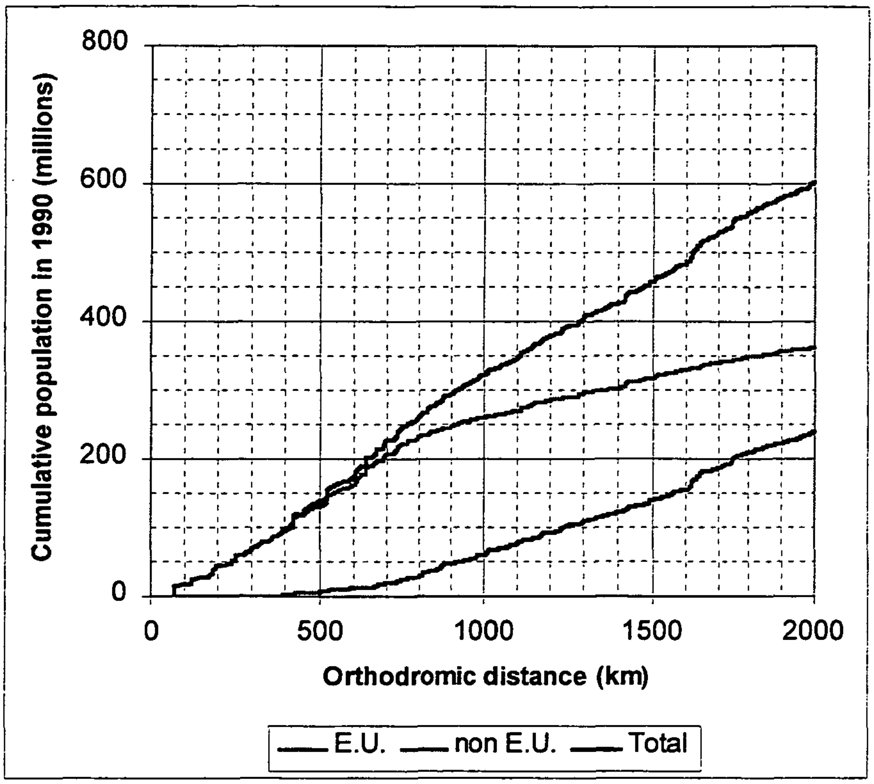


Figure 6 : Cumulative curve of population (E.U. or not E.U.) in 1990 according to orthodromic distance to Berlin

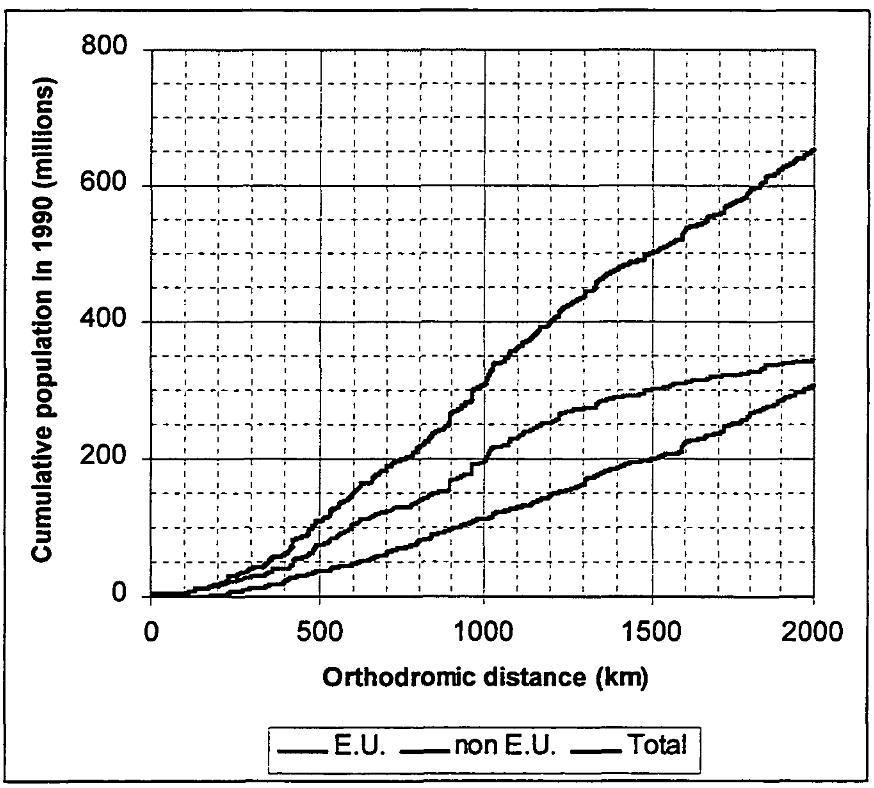


Figure 7 : Cumulative curve of population (E.U. or not E.U.) in 1990 according to orthodromic distance to Bruxelles

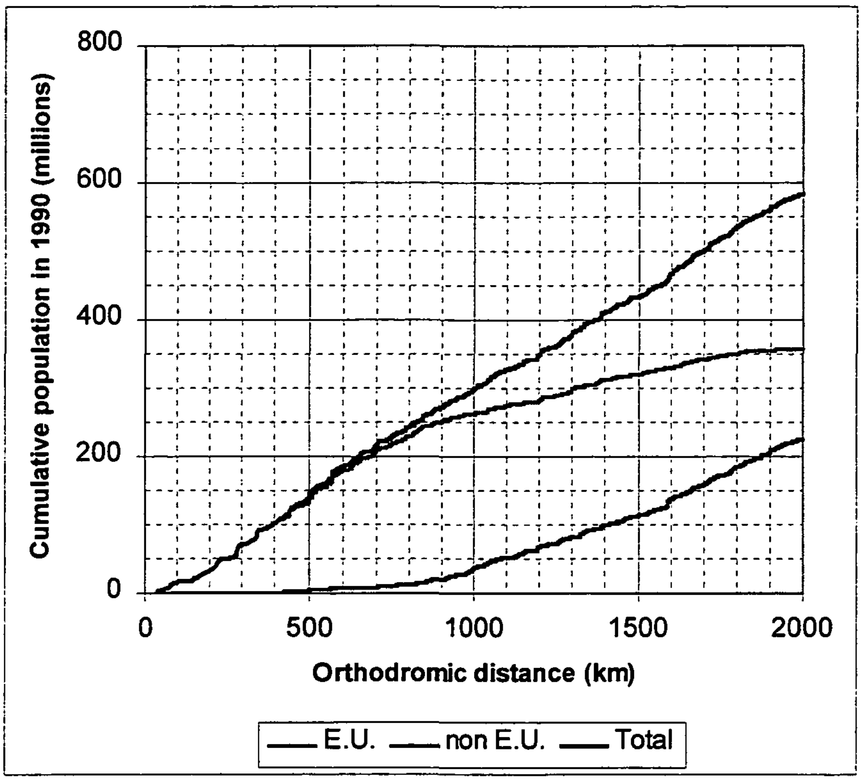
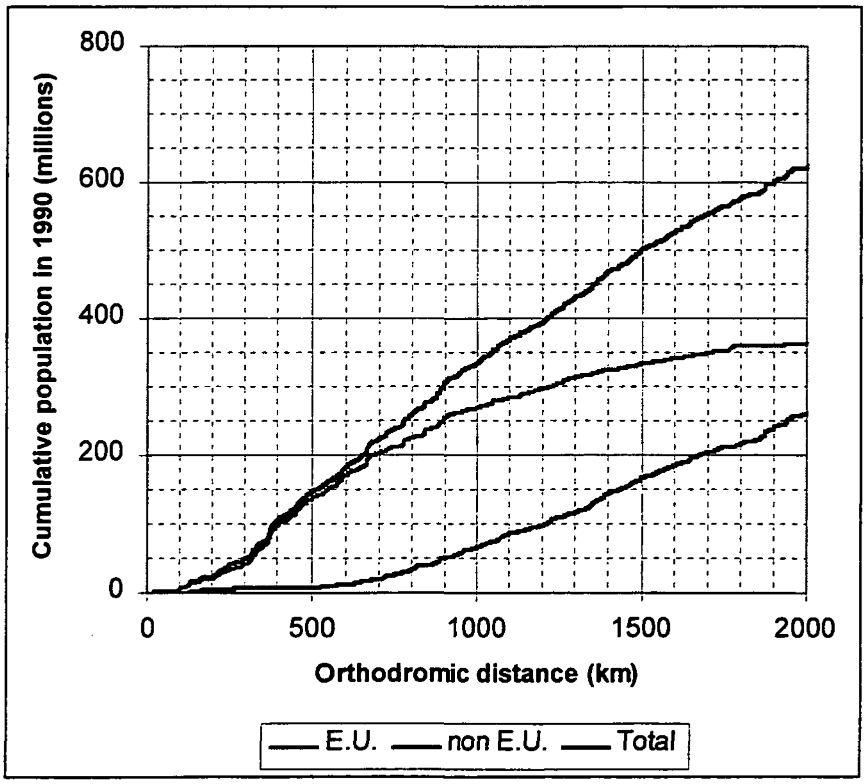


Figure 8 : Cumulative curve of population (E.U. or not E.U.) in 1990 according to orthodromic distance to Strasbourg



VI. CLASSICAL FORMULATION OF POPULATION OR ECONOMIC POTENTIAL ARE AN INTERESTING WAY TO SUMMARIZE THE INFORMATION CONTAINED IN CUMULATIVE CURVE OF RESSOURCE WITH DISTANCE. BUT THOSE CLASSICAL FORMULATION HAS TO BE IMPROVED AND CAN BE REFORMULATED IN A MULTISCALAR NEIGHBOURHOOD APPROACH

We have established previously the interest of a multiscalar approach of geographical position based on the analysis of cumulative curves of ressource(s) according to distance(s) and we expect to have demonstrate that one of the main interest of this approach is to insure a best fit between assumptions made on a phenomenum and resulting maps or indexes derived from those assumptions.

But this good adequation between assumptions and measure - which is based on a generalisation of classical accessibility indexes - has a counterpart which is to provide *an infinity of solutions* for the measure of accessibility related to a given ressource and a given distance. And it is clear than when policy makers has to take *general decisions of territorial planning* they can not base their decision on very precise asumptions because they have to take into account a great number of possible situations or events who could happen in the future. Thus, they are obliged to propose *general criteria* and the task of the scientist is precisely to propose *general measure* in order to help political decision.

This implicit criticism of our previous proposal does not imply that we are oblige to go back to basic indexes of accessibility (like distance to Maastricht or mean distance to population or GNP) but rather that we have to find a relevant method, efficient but simple, in order to summarize the multiscalar information contained in cumulative curves of ressource(s) according to distance(s).

This solution does exist and lead us to our 6th proposal which is that : ***"Classical formulation of population or economic potential are an intersting way to summarize the information contained in cumulative curves of ressource(s) with distance(s). But those classical formulation has to be improved and can be reformulated in a multiscalar neighbourhood approach".***

Classical measure of population potential established by Stewart in 1940 was based on a strict analogy with physics (electric potential) :

Initial formulation of population potential by Stewart (1940)

$$Pot(i,P,d) = \sum_{j=1}^{n} \frac{P_j}{d_{ij}}$$

As the interpretation of such a measure in social sciences was not very clear, many scientific works of geographers or economist has tried to explain the interest of the transposition of such a physical notion in social sciences. Many criticism was adressed to Stewart initial proposal and alternative formulations has been proposed concerning :

(1) the choice of ressource and distance variables introduce in the computation of potential. Most authors working on territorial planning has underline the fact that it is more interesting to use a measure of economic activity as weight (for example GNP) and a measure of generalised cost (including travel time,

price/km, barriers effects across the boundary, ...) as measure of proximity. But this is not really criticisms but only specific implementations of Stewart's formula in particular contexts.

(2) *The proposal of alternative spatial interaction function* were more serious criticism because they refuted Stewart's favourite hypothesis of a strict analogy between human behaviour and the natural laws of physics[12]. During the 1950's and the 1960's many empirical research on spatial interaction models has been developped in economy, geography, demography or sociology. They demonstrated that human or economic behaviour did not conform to the parameters of physical laws and that better descriptions of flows could be obtained through a relaxation of initial hypothesis made by Stewart, Zipf or Paréto about the decrease of human interaction with distance. According to those empirical results proposed a reformulation of the different spatial interaction model through the introduction of a negative power function of distance $d_{ij\beta}$ with a variable exponent β not necessary equal to *-1* or *-2* as in previous formulas. In the case of population potential, the combination of both families of criticisms adress to Stewart's formulation lead to a new proposal adopted by most scientifics working on accessibility and potential during the 1970's and the 1980's.

First generalisation of Stewart formula of potential (Pareto function)

$$Pot(i,M,c)=\sum_{i=1}^{N} M_i \,.\, c_{ij}^{\beta}$$

where:

M : is a ressource distributed in N places (not necessary the population)

c : is a measure of general cost of relation between actors and ressources (not necessary euclidian distance)

β : is a negative parameter which indicate the intensity of the decrease of interaction when cost increase (not necessary equal to −1 or −2)

One of the most typical example of the research on potential developped during this period is the set of works realised by Keeble, Owens & al. for the DG XVI about the consequences of the enlargement of the European Economic Community[13] from 6 member states to 9 and 12. But equivalent

[12] They are some terrific sentences in Stewart's work about this point. Stewart (as Christaller which proposed to 'adapt' the urban network of Polant to central place theories during the second world war) was absolutely convince of the trueness of his proposals and thought that if social reality did not conform to theory, it should be modified... This scientist paradigm derived form Pareto's theory of rational human activity is well expressed in the following extract from 1942 :

> *The way of progress is obstructed by the opinion, common among authorities on economics, politics and sociology, that human relationships never will be described in mathematical terms. There may be some truth in this as regards the doing of individual persons. Even the physicist has given up the idea that the behavior of individual particles can be precisely described thus and necessarily contents himself with discussion of averages. But the time to emphasize individual deviations is after the general averages have been established, not before [...].*
>
> *There is no longer excuse for anyone to ignore the fact that human beings, on the average and at least in certain circumstances, obey mathematical rules resembling in a general way some of the primitives « laws » of physics. « Social physics » lies within the grasp of scholarship that is underprjudiced and truly modern. When we have found it, people will wonder at the blind opposition its firsts proponents encountered. Meanwhile, let « social planners » beware ! Water must be pumped to flow uphill, and natural tendancies in human relations cannot be combated and controlled by singing to them. The architect must accept and understand the law of gravity and the limitation of materials. The city or national planner likewise must adapt his studies to natural principles.*
>
> **Stewart J.Q., 1942,** Empirical mathematical rules concerning the distribution and equilibrium of population, *Geographical Review, 48*, p. 461

[13] See, for example **Keeble D., Owens P.L., Thompson C., (1982)**, "Regional accessibility and economic potential in the EEC", *Regional Studies, 16, 6*, pp. 419-432

researches was developped by scientist of other states, expecially by german authors[14] which proposed alternative formulations of the spatial interaction function introduced in the computation of population potential like the two followings :

Some alternatives to pareto spatial interaction proposed by german authors

$$f(d_{ij}) = \frac{1}{1+\frac{d_{ij}}{\beta^2}} \qquad (Hussman, 1976)$$

$$f(d_{ij}) = (1+\beta) - d_{ij} \qquad (Adlung \,\&\, al., 1979)$$

It is not the place to detail the assumptions of each proposed formulation of population potential during the 1970-1990 period, but it is sufficient to say that most proposals are based on the introduction of a spatial interaction function f(dij) under diffrent assumptions of decrease of relation with distance and where the pareto function appears as a particular case. Accordingly the situation at the beginning of the 1990's can be described through a new formulation of potential which is a generalisation of the previous ones :

Second generalisation of Stewart formula of potential (spatial interaction function)

$$Pot(i, M, c, f) = \sum_{i=1}^{N} M_i \cdot f(c_{ij})$$

where:

M : is a ressource distributed in N places (not necessary the population)

c : is a measure of general cost of relation between actors and ressources (not necessary euclidian distance)

f : is a spatial interaction function (decreasing with distance) which indicate the form and the intensity of the decrease of interactions when cost increase (not necessary of Pareto function family)

At the beginning of the 1990's a research group on population potential was established in the french research team Equipe P.A.R.I.S. (For The Advancement of Research on Spatial Interaction) in order to examine how it could be possible to actualise Keeble's work on economic potential in Europe and apply his method to an analysis of the consequence of the fall of the iron curtain in Europe. The basic idea was to measure the places which will obtain important gains of accessibility due to new opportunity of relations with states from east central Europe and to produce related maps. This working group (D. Pumain, T. Saint-Julien, F. Guérin-Pace, C. Rozenblat, I. Boursier-Mougenot, N. Cattan, C. Grasland) decided first to summarize the publications available on the subject of population potential and to review the different available solutions before to decide which solution would be choosen.

But it appeared quickly to the working group that the different formulations proposed by different authors during the 1970's and the 1980's should be modifies in order to introduce new theoretical

[14] **Adlung R., Gotzinger H., Lammers K., Shatz R.-W., Seitz J., Thoore C. (1979),** *Konzeption und Instrumente einer potentialorientierten Regionalpolitik,* Institut für Kommunalwissenschafen Konrad-Adenauer-Stiftung E.V., St. Augustin.
Hussman E. (1976), "Das Lagepotential des Arbeitsmarktregionen der Bundesrepublik", *Die Weltwirtschaft,* H1, pp. 66-80.

results of spatial analysis (e.g. information theory & entropy maximisation, fuzzy-set theory, behavioural approach, barriers effects, ...). This decision to enlarge the concept of potential lead the working group to very interesting but animated discussion ... and it appears difficult to find a consensus between the members.

A minority of members of the working group propose a complete breakdown with usual assumptions of population potential (based on spatial interaction theory) and suggested a **concept of neighbourhood potential** (based on a probabilistic approach related to fuzzy sets theory). As an experiment of this new concept of neighbourhood potential, C. Grasland realised in 1991 an empirical applications about the consequences of the reunification of Germany[15]. As the result appeared more interesting than with classical formulations of potential, it was finally decided by the working group to apply the concept of neighbourhood potential to the target research about the whole Europe which was published in 1993 by four members of the working group[16]. After the publication of this paper, the working group "population potential" stopped his activity and as both papers about this new method has been published in french (and in a french review), the diffusion of the results in other states of Europe remained very limited[17].

The notion of *neighbourhood* is based on mathematical fuzzy sets theory[18] and sociological and geographical mean information field theory[19]. The basic idea of neighbourhood method is that it is possible to define between each couple of place and ressource *(i,j)* a measure Ω_{ij} which is the probability of truth of the proposition *"i is located in the neighbourhood of j"*. Accordingly the value

[15] **Grasland C. (1991),** "Potentiel de population, interaction spatiale et frontières : des deux Allemagnes à l'unification", *Espace Géographique, 3,* pp. 243-254.

[16] **Boursier-Mougenot I., Cattan N., Grasland C., Rozenblat C. (1993),** "Images de potentiel de population en Europe", *Espace géographique, 4,* pp. 333-345.

[17] It was probably a mistake because it appears only a few years later that the consequence of this new formulation of potential was very important from a theoretical point of view and could have important consequences for the resolution of crucial questions of spatial analysis (resolution of the 'Modifiable Area Unit Problem', generalisation of maps at different scales of neighbourhood, analysis of the percolation of spatial heterogeneity, etc.). The **Hypercarte Project** which is a network of researcher in geography, mathematics and statistics tries actually to formalize those consequences and to produce new softwares for multiscalar spatial analysis and cartography.

[18] **Kaufman A. (1973),** *Introduction à la théorie des sous-ensembles flous. Tome 1 : éléments théoriques de base,* Masson, Paris.
Ponsard C. (1980), « Fuzzy economic spaces », *Doc. de travail de l'IME,* Dijon
Ponsard C. (1984), « A theory of spatial general equilibrium in fuzzy economy », *Doc. de travail de l'IME,* Dijon
Ponsard C. (1988), « Fuzzy Mathematical models in Economics », *in Fuzzy Sets and Systems, 28,* 273-283
Ponsard C., Tranqui P. (1978), « La régionalisation de l'économie française par une méthode de taxinomie numérique floue », *Doc. de travail de l'IME,* Dijon.
Ponsard C., Tranqui P. (1982), « La régionalisation floue de l'économie européenne », *R.E.P.*

[19] **Hägerstrand T. (1952),** « The propagation of innovation waves », *Lund Studies in Geography, série B, n° 4*
Hägerstrand T. (1953), *Innovation diffusion as a spatial process,* Translation by A. Pred, 1967, University of Chicago Press
Stouffer S.A., 1940, « Intervening opportunities : a theory relating mobility and distance », *American Sociological Review, V,* pp. 845-867.
Stouffer S.A., 1960, « Intervening opportunities and competing migrants », *Journal of Regional Science, 2,* pp. 1-26

of Ω_{ij} is a scalar strictly comprised between 0 and 1 with no unit of measurement. The potential of a place *i* according to a ressource *P* and a neighbourhood Ω is defined by :

General definition of neighbourhood potential

$$M(i,\Omega)=\sum_{j=1}^{n} M_j \,\Omega_{ij}$$

where

M: *is a ressource located in N positions (not necessary spatially defined)*

Ω : *is a matrix which define between each position of actor (i) and each position of ressource (j) a value of neighbourhood* $\Omega_{ij} \in [0;1]$ *which is the probability of truth of the proposal "i is located in the neighbourhood of j"*

This formulation is of course theoretical and can be applied to any type of position (geographical, economical, sociological) but it provides a general solution for the construction of a family of measure of potential *in the particular case of spatial neighbourhood.*

According to the physical and mathematical properties of *space*, we can say that **a neighbourhood Ω is a spatial neighbourhood if it can be defined as a function *f* of a given distance *d* between geographical positions (places) with following properties :**

Properties of spatial neighbourhood functions

(1) $f(0)=1$

(2) $f(\infty)=0$

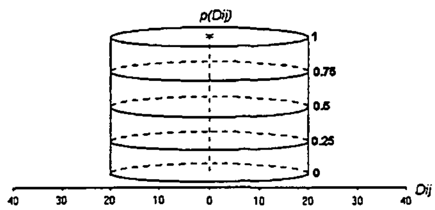
(3) $\forall(d_1,d_2)\ \ d_1 < d_2 \ \Rightarrow\ f(d_1)\geq f(d_2)$

The most simple spatial neighbourhood function is **the rectangular function of neighbourhood f^1_R (Figure 9)** which is based on the very simple assumption that the probability of neighbourhood is maximum ($f^1_R = 1$) for a distance lower or equal to a parameter R and minimum ($f^1_R = 0$) for a distance lower to the parameter *R*. The potential $M(i, f^1_R)$ associated to this neighbourhood function is the amount of ressource *M* located in a circle of radius *R* around a given place *i*. In other word, the potential asociated to the rectangular function R is equal to the value $M_i(R)$ of the cumulative curve of ressource according to distance that we have defined in previous sections (*see. IV*).

Figure 9 : The rectangular function of neighbourhood

$$f^1_R(d) = 1 \ if \ d \leq R$$
$$f^1_R(d) = 0 \ if \ d \succ R$$

example : R=20

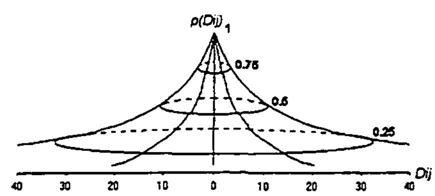


The spatial interaction function used by Stewart (1/d) is not a spatial neighbourhood function because the value of this function are not strictly comprise between 0 ant 1 (infinite value at distance 0). But it is possible to produce spatial neighbourhood function which are very close from Stewart formulation and are consistent with empirical observations on spatial behaviour. For example, it is possible to propose a **modified Pareto function $f^2_{\alpha,\beta}$ (Figure 10)**

Figure 10 : modified pareto function of neighbourhood

$$f^2_{\alpha,\beta}(d) = (1 + \alpha . d)^\beta$$

example : $\alpha = 0.1$ $\beta=-1$



The parameter β of the modified pareto function define the **form** of the spatial neighbourhood function and the parameter α define the **span (or scale)** of this neighbourhood. Once the parameter β

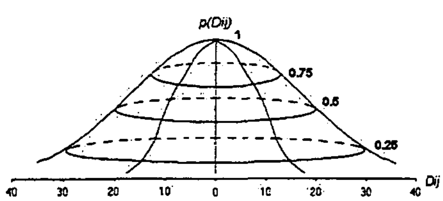
has been defined (generally according to theoretical considerations), it is possible to modify the value of the parameter α in order to produce multiscalar analysis of potential in the same way as we have done with rectangular neighbourhood function controlled by parameter *R*. But the results are more interesting than before because the potential calculated with modified pareto function take into account all ressources located in the area (with different probabilities) and not only ressources located in a given circle.
The result obained with modified Pareto function of neighbourhood are not very different from the ones which could be obtained with classical formulation (especially if we take into account the fact that many authors introduced a minimum distance in the computation of pareto function) but **a great advantage of the probabilistic formulation, from a theoretical and practical point of view is to eliminate the unit of measurement of distance (time, cost, km) and to produce a measure of potential which is a concrete amount of ressource and not of ressource/km or ressource/km^2**. For the transmission of results to people whch are not specialist from theoretical geography , it is really more easy to say that *"20 millions of inhabitants are located in a neighbourhood of 100 km around this place" than "this place has a centrality (an energy ?) of 20 millions of inhabitants per square kilometer"*. In the first case, it is relatively easily to explain what we call "neighbourhood" with a picture like the example of *Figure 10* ; in the second one, it is much more complicated to explain what are inhabitants per kilometer or inhabitants per square kilometer (imagine how to explain the results if the choosen exponent β of the Paréto function is equal to -1.5 ...).

As the concept of neighbourhood spatial function is directly derived from information theory, it is logical to propose a third family of neighbourhood functions which are more consistents with empirical researches of Hägerstrand on mean information field of actors and theoretical research of Wilson on spatial interaction and entropy. The **exponential neighbourhood family** $f^3_{\alpha,\beta}$ is from this point of view a logical solutions which present many advantages :

Figure 11 : exponetial function of neighbourhood

$$f^3_{\alpha,\beta}(d) = \exp(-\alpha \ . \ d)^\beta$$

example : α = -0.00693 β=-2



As in the case of modified Pareto function, the parameter β of the exponential neighbourhood function define the **form** of neighbourhood and the parameter α the **scale** of neighbourhood.

A particular case of exponential neighbourhood is ***the gaussian spatial neighbourhood*** *(β= -2)* which has interesting mathematical properties and is consistent with empirical results on spatial behaviour of actors and spatial perception (Cf. Hägerstrand). In this particular case he **scale** of neighbourhood can be defined by a parameter *R* which is the distance where the value of the probability of neighbourhood is equal to 0.5 (and is the charachteristic parameter of the gaussian function).

Accordingly, the formula of gaussian neighbourhood can be written as a function g_R with only one parameter of scale R :

Definition of multiscalar gaussian neighbourhood function

$$g_R(d) = \exp\left(\frac{\ln(0.5)}{R^2} \,.\, d^2\right)$$

The span of the gaussian neighbourhood (R) can be modified under different assumptions and it is thus possible to produce a continuum of map of population potential at different scales with this method. With a small value of R, local concentration of population can be observed. With large value of R, it is the more important concentration of population at international scale which will be revealed.

This multiscalar function of neighbourhood has many theoretical and practical advantages which are discussed in previous papers about population potential in Germany (*Grasland C., 1990*) and Europe (*Boursier-Mougenot & al., 1993*) and in working papers of the Hypercarte Research Group (*The Hypercarte Project, 1997*).

A short application to UNEP-GRID database is presented in order to help the reader to evaluate our proposals on a concrete application.

VII. WHATEVER THEIR SCIENTIFIC QUALITIES, THEORETICAL PROPOSALS FOR THE MEASURE OF GEOGRAPHICAL POSITION OR SPATIAL INTEGRATION SHOULD BE EVALUATED BY EXPERT ON CONCRETE SITUATIONS BEFORE TO BE ADOPTED (OR ADAPTED).

The object of this (too) long working paper was not to propose definitive solutions to the problem of the measure of geographical position or spatial integration but, on the contrary, to furnish material for further discussions between experts of each member state of the European Union. We expect that our proposals are sufficiently general to provide a good starting point of discussions but we are aware that it is only a starting point, rather theoretical, which has to be implement onto concrete situations. Accordingly, our 7th and final proposal is : ***"Whatever their scientific qualities, theoretical proposals for the measure of geographical position or spatial integration should be evaluated by experts on concrete situations before to be adopted (or adpated)".***

With the limited information contained in UNEP-GRID database, we propose as an example of our method to **define the peripherical region and the margins of the European Union** according to the criteria of population (ressource) and orthodromic distance (proximity) under different assumptions of scale of relations (gaussian neighbourhood with span 100 and 250 km).

- **Peripherical regions of the E.U.** are defined as part of the E.U. territory which are characterised by (1) a low access to ressources of the E.U. and/or (2) important opportunities of access to ressource located out of the E.U.
- **Margins of the E.U.** are defined as part of countries located out of the territory of the E.U. characterised by (1) important ressources which located near the border of the European Union and/or (2) important influence of ressources located inside the European Union.

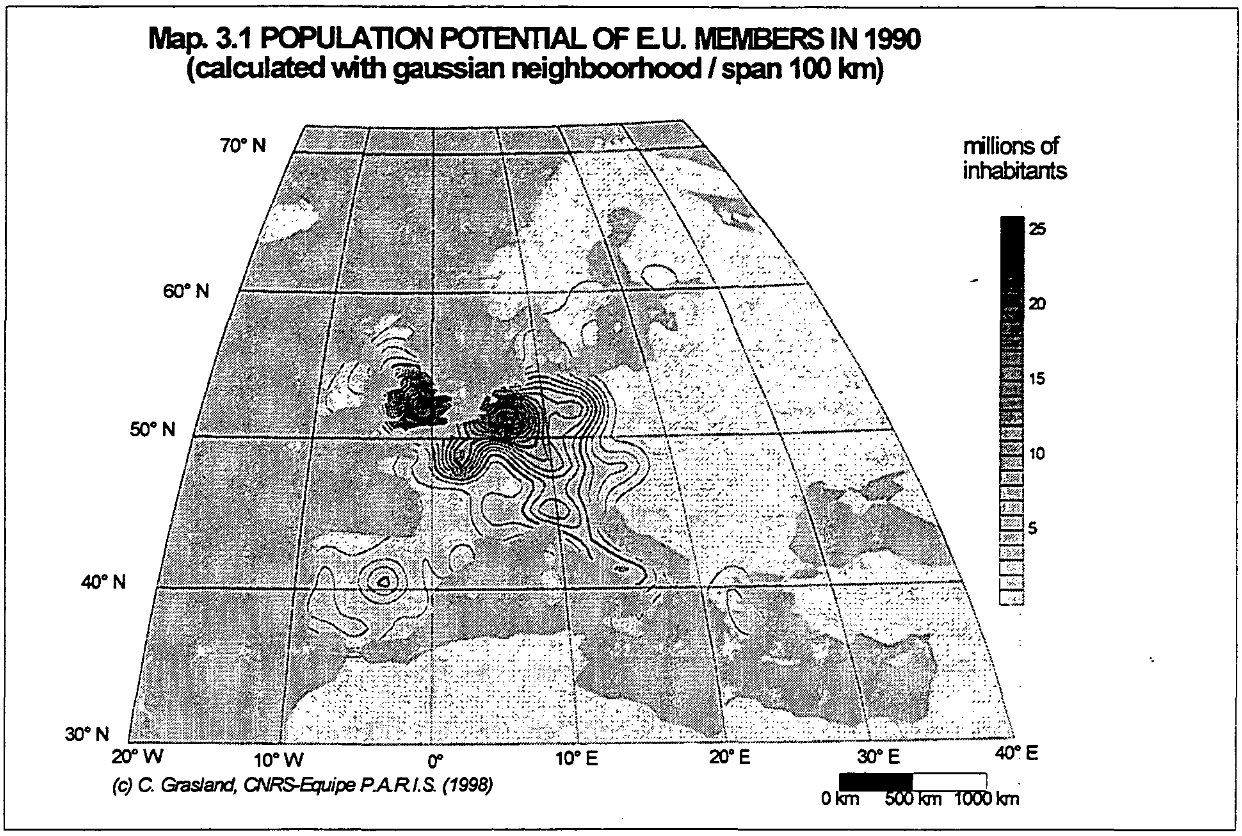
(a) Demographic ressources of the European Union

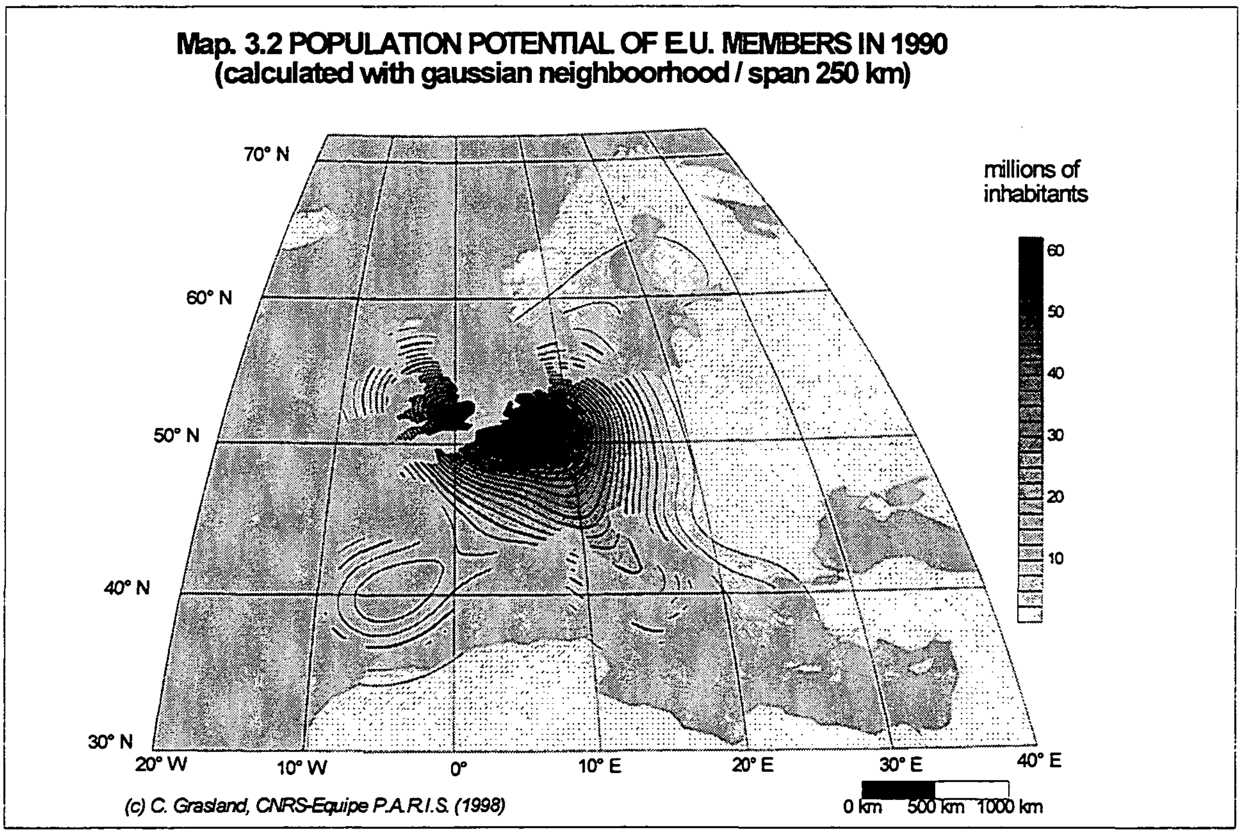
Map 3.1 present the potential of E.U. state members population in a gaussian neighbourhood of span 100 km applied to orthodromic distance. At this scale of analysis the most important concentrations of demographic ressource appears to be located in England (midlands) and low Rhein valley (Benelux-Rhur) but it is possible to locate other important maxima of population around Paris, Milano, Berlin or Madrid and maxima of lower importance around Stockholm, Athens, Napoli, Porto, Barcelona or Helsinki. This map is well known (it is rather near to classical maps of population potential established with Stewart's method) and it is not necessary to produce longer comments.

Map 3.2 has been realised with the same information but with a gaussian neighbourhood of span 250 km. At this scale of analysis, all the European Union appears to be organised around a major concentration of population located in the low Rhein-Valley and all other maxima of population has disappear except in Spain (because of the form of coastal line) and may be also in Greece and England (for the same reason).

It is possible to establish other maps with different spans of neighbourhood and to follow the reduction of the number of maxima of population when the span of neighbourhood is increasing. And it is also possible to propose a classification of places according to their potential at those different scale in order to evaluate their relative position in qualitative terms like 'center of the center', 'center of the periphery', 'periphery of the center', 'periphery of the periphery'.

But it is also possible (and it is the object of the study) to examine if low potential are related to the lack of opportunity of relations (as in the case of places located on the coast of sea or ocean) or if the low potentials are related to barriers which could be modified in the future (as in the case of places located near the continental border of the E.U.).


Map. 3.1 POPULATION POTENTIAL OF E.U. MEMBERS IN 1990
(calculated with gaussian neighboorhood / span 100 km)
70° N
60° N
50° N
40° N
30° N
20° W
10° W
0°
10° E
20° E
30° E
40° E
millions of inhabitants
25
20
15
10
5
(c) C. Grasland, CNRS-Equipe P.A.R.I.S. (1998)
0 km 500 km 1000 km


Map. 3.2 POPULATION POTENTIAL OF E.U. MEMBERS IN 1990
(calculated with gaussian neighboorhood / span 250 km)
70° N
60° N
50° N
40° N
30° N
20° W
10° W
0°
10° E
20° E
30° E
40° E
millions of inhabitants
60
50
40
30
20
10
(c) C. Grasland, CNRS-Equipe P.A.R.I.S. (1998)
0 km 500 km 1000 km

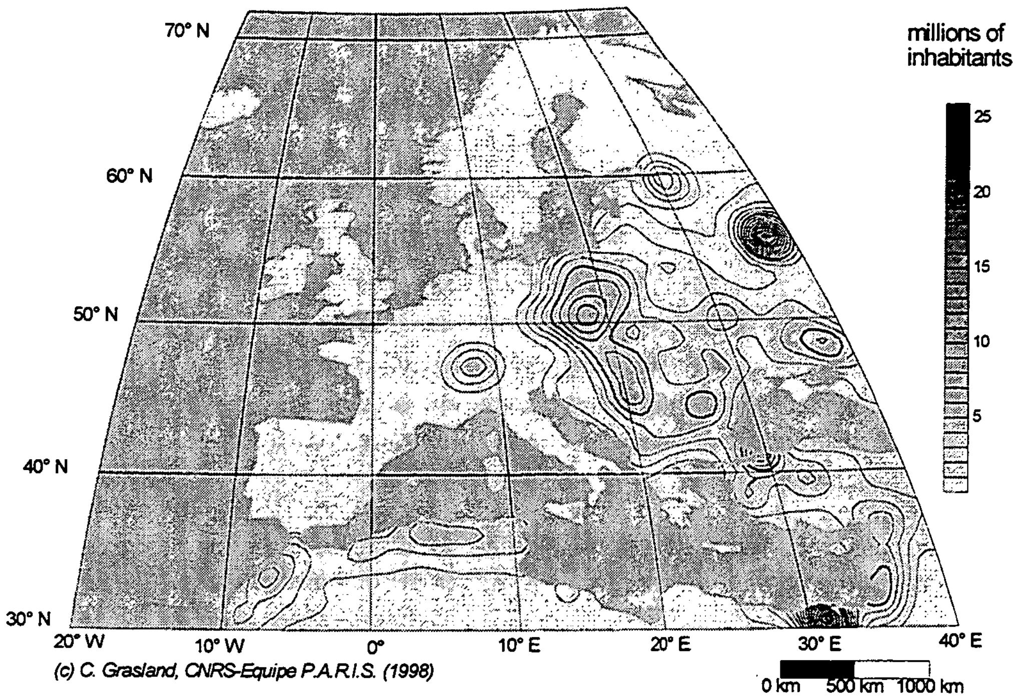
(b) Demographic ressources of neighbouring countries of the European Union

If we apply the same computation than before but with a ressource defined as the population of states located out of the European Union, we can evaluate the importance of demographic ressources located near the European union under the same assumptions of gaussian neighbourhood (100 km and 250 km).

Map 4.1 indicates the location of local concentration of population in neighbouring countries. The most important concentration in the studied area are located in Russia (Moscow, Petrograd), Ukrainia, Egypt, Turkey, and East Central Europe (Silesia). Secondary concentrations of population are located in northern Africa, Middle-East, Balkans ... and Switzerland (situations would have been very different with economic ressource!).

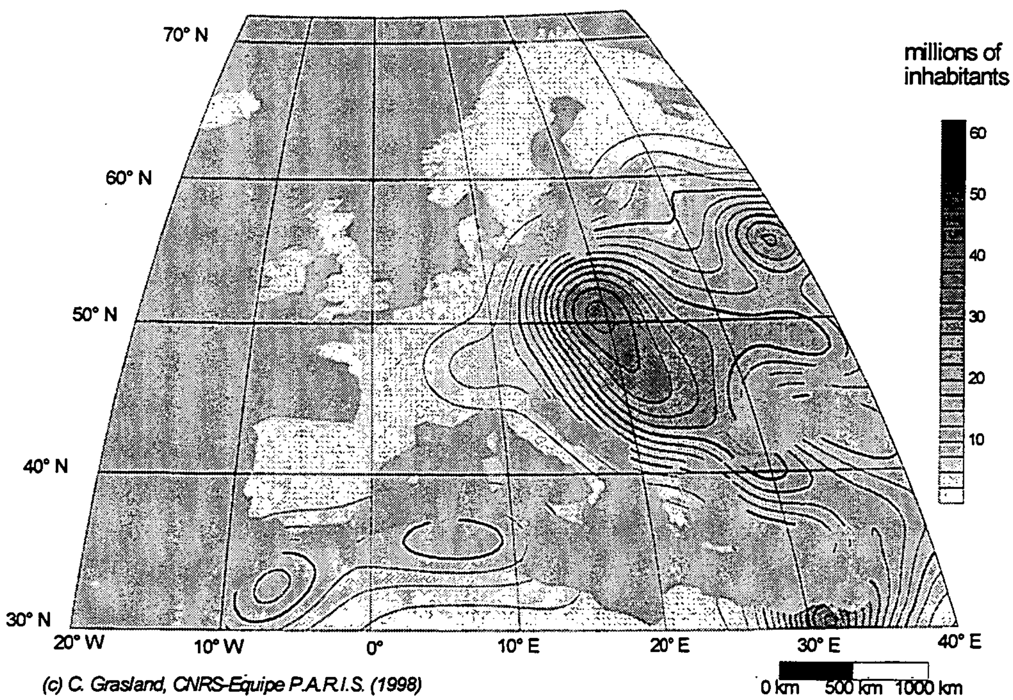
Map 4.2 which is established with a different assumption of neighbourhood (250 km) provide a picture which is rather different form the previous one. The main concentration of population at this scale is located in East-central Europe with value much higher than in Russia (where local concentration of population are surrounded by wide low-density areas). Egypt remains an important peak of concentration connected with the rest of Middle-East regions. Northern Africa is organised by two maxima of population potential but with much lower intensity than the previous ones.

Map. 4.1 POPULATION POTENTIAL OF NON-E.U. MEMBERS IN 1990
(calculated with gaussian neighboorhood / span 100 km)



(c) C. Grasland, CNRS-Equipe P.A.R.I.S. (1998)

Map. 4.2 POPULATION POTENTIAL OF NON-E.U. MEMBERS IN 1990
(calculated with gaussian neighboorhood / span 250 km)



(c) C. Grasland, CNRS-Equipe P.A.R.I.S. (1998)

(c) Global demographic ressources without barriers effect

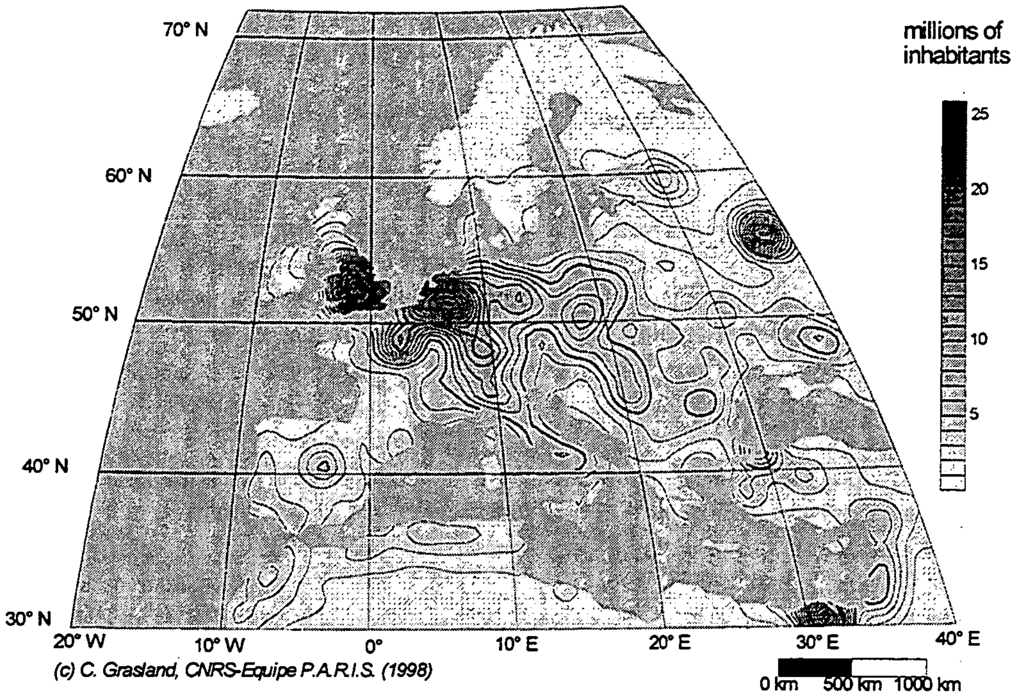
If we had internal and external demographic ressource of the European Union, we obtain a global picture of the distribution of population in the studied area under the assumptions of the absence of barrier effect between E.U. and neighbouring countries. This is the picture of an "Europe without boundaries" in north, south, east or west directions.

Map 5.1 provide a classical view of population potential in Europe, but with the intersting perspective to take also into account the influence of countries located in southern and eastern part of Mediterrania. Many coments of this map are possible and we will suggest limit our remark to a confirmation of Kunzman's hypothesis about the existence of two parallel "Bananas" in central part of Europe : the classical western "blue banana" from Glasgow to Roma and the less classical "eastern banana" from Gdansk to Beograd.

Map 5.2 is very interesting because it shows that the maximum of potential located in low-Rheine Valley has very wide extensions in southern and eastern directions. If we take the gradient of density as criterium of delimitation of the influence of maxima of population (limits are 'valley' between two 'mountains') we can observe that the limits of the low Rheine-Valley maxima involves all central eastern Europe and a large part of Ukrainia and Turkey. With a higher value of scale neighbourhood (500 km), Northern Africa would be also involved in this influence area and only Egypt and north central Russia would remain as independant peaks of population concentration.

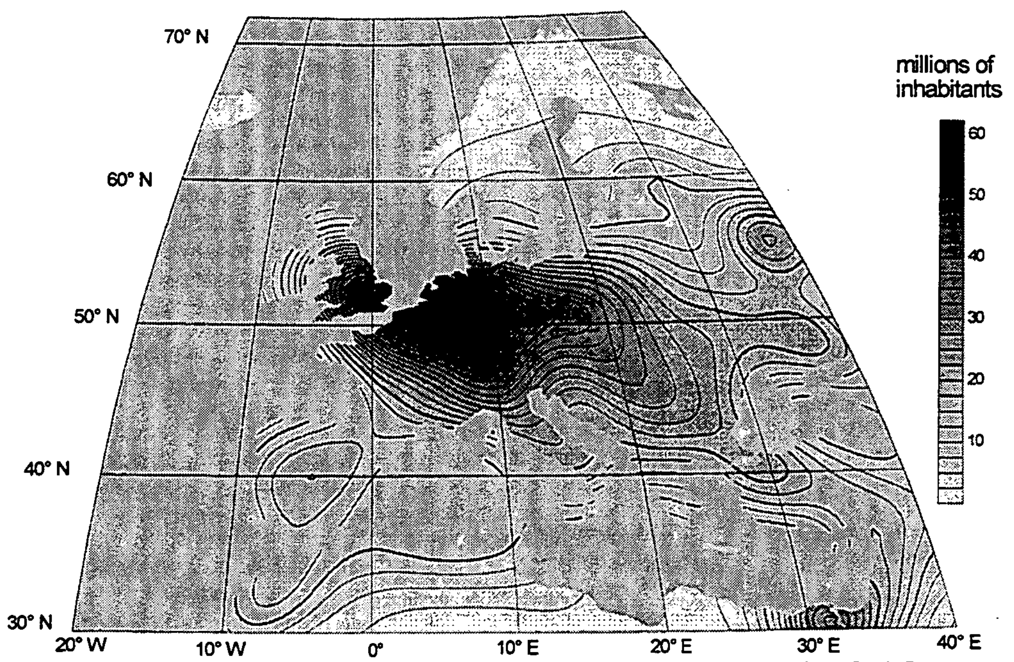
Map 5.3 which is the ratio between population potential at scale 100 km et 250 km provide an interesting picture of relative concentration of population i.e change in the relative position of place according to the span of neighbourhood. *The dark red area* are charactrised by an important relative decrease of their potential between 100 and 250 km and can be considered as local concentration of population surrounded by area with lower density of population. This situation can be explained by a location in certain cases by the influence of the sea (England) but can also be observed in continental area when a metropol is surrounded by rural area with low density (Moscow, Madrid). And frequently, both explanantion should be combined (North Africa, Cairo, Istambul, Stockholm ...). The *dark blue area* are characterised, on the contrary by the existence of a low density area surrounded by high density areas. A typical example is given by the french rural region of Champagne which is surrounded by the concentration of population of Paris, Benelux, Rhur, ... and has a very important increase of population potential between 100 and 250 km. Another typical example is given in Russia by the regions located between Moscow and Petrograd. As it is a ratio, relative concentration is not correlated with potential : Lofoten island in Norway are for example a peak of relative concentration of population (compared to surrounding areas) but Paris agglomeration is not a peak of relative concentration because its potential at 100 km is more or less proportional to its potential at 250 km (according to general tendancy of potential increase according to scale observed in the rest of Europe). Of course, this measure is scale-dependant and the results would be different if we had choosen other references for the computation of the ratio (Paris would certainly have been a peak of concentration if we had compared the potentials at scale 25 and 100 km).

Map. 5.1 POPULATION POTENTIAL IN 1990
(calculated with gaussian neighboorhood / span 100 km)



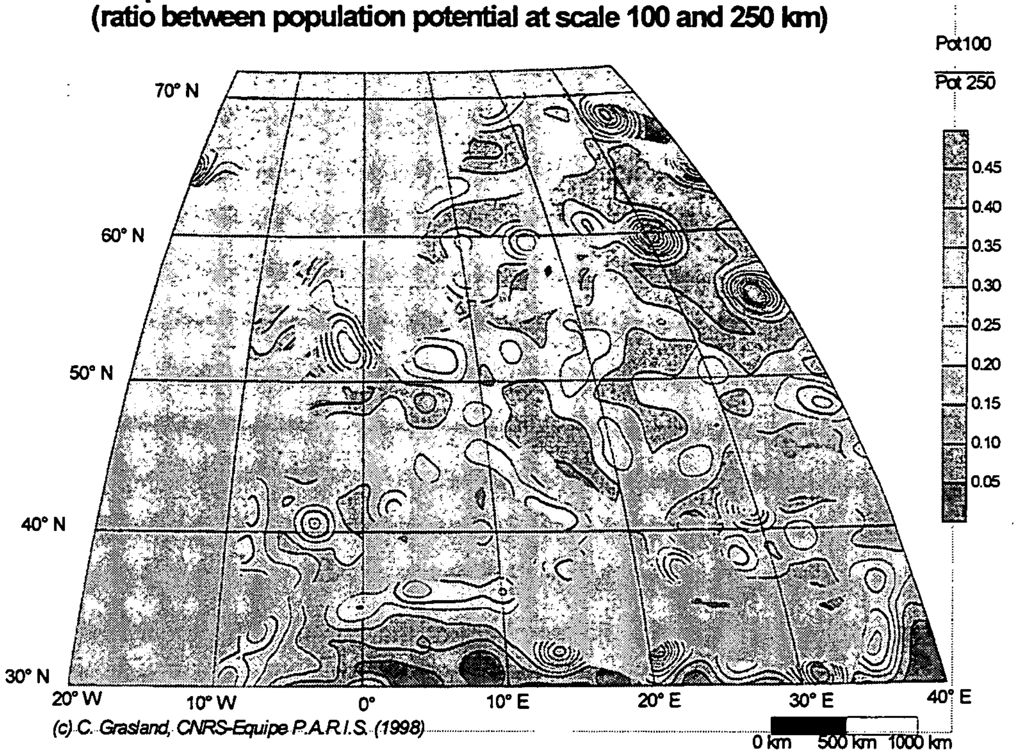
(c) C. Grasland, CNRS-Equipe P.A.R.I.S. (1998)

Map. 5.2 POPULATION POTENTIAL IN 1990
(calculated with gaussian neighboorhood / span 250 km)



(c) C. Grasland, CNRS-Equipe P.A.R.I.S. (1998)

Map 5.3 RELATIVE CONCENTRATIONS OF POPULATION (ratio between population potential at scale 100 and 250 km)



(c) C. Grasland, CNRS-Equipe P.A.R.I.S. (1998)

(d) Definition of demographic periphery and margins of the European Union

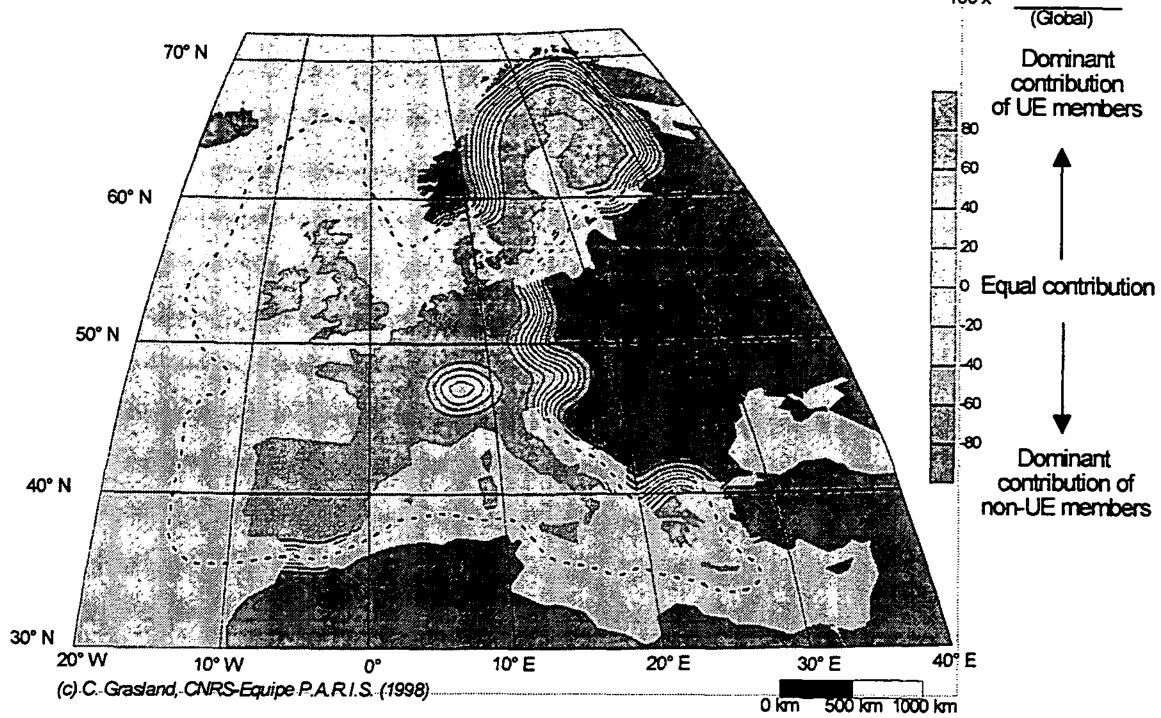
Finally, it is possible to compute for each place of the studied area the relative contribution of populations of the European Union and population of neighbouring states to its potential of population. This has been done with an index comprise between 100% (all contributions to potential are related to the populations of E.U. memeber states) and -100% (all contributions to the potential are related to the populations of non U.E. member states).

Map 6.1 indicates that at a local scale (gaussian neighbourhood with scale parameter 100 km) the limits of demographic influence are more or less equal to the limits of the European Union, which is not a trivial result. Indeed, this result is obtaines only because on each side of the continental border of the European Union, the population densities are more or less equal. But they are some excpetions to this general rules like in the case of Switzerland which is clearly involved in the demographic influence area of E.U. at this scale of analysis. This is also the case, at a less degree of Czech republic and south-eastern part of Norway. On the countrary the northern part of Greece is mainly influenced from a demographic point of view by populations located in countries out of the European Union.

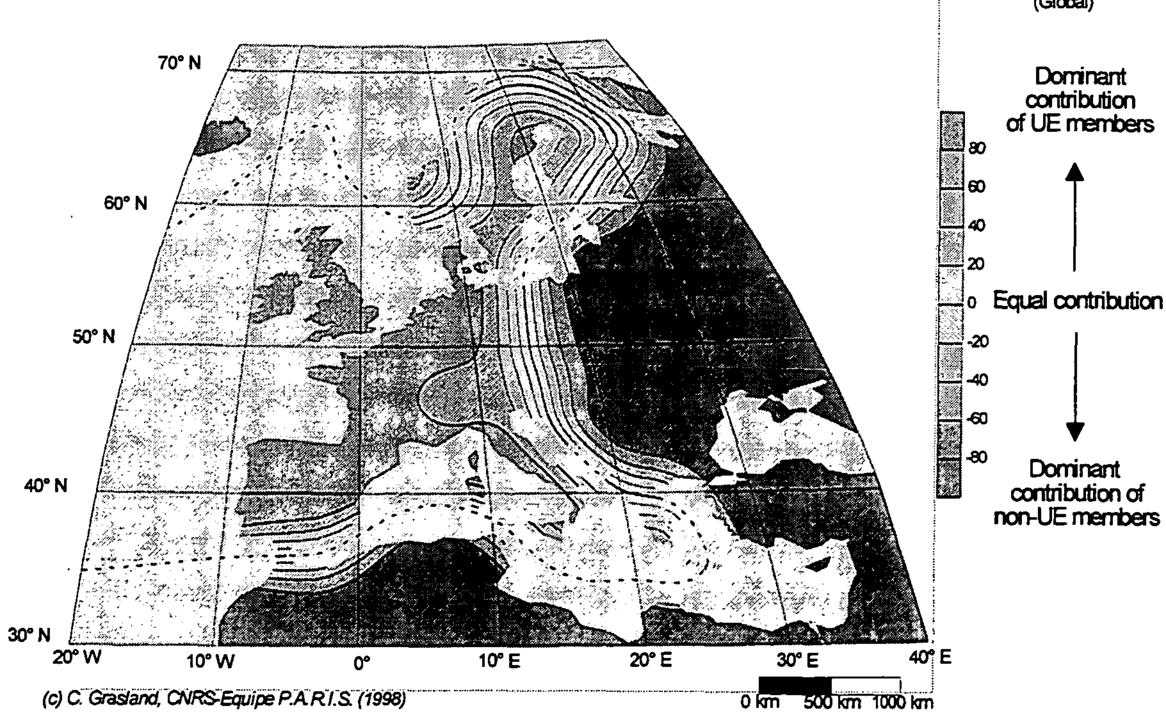
Map 6.2 provides another picture of margin and periphery of the European Union because the scale of neighbourhood is greater and a greater number of territories have discriminant indexes of contributions to their potential which are comprised between -50% and +50% (a possible definition of margins and peripheries). We can observe that, at this scale of analysis the lign of isoinfluence (0) of E.U. and neighbouring countries is generally deplaced in northern and eastern direction because of the influence of the great concentration of population in low-Rhein valley. This enlargment would be much more important with economic criteria like GNP.

N.B. Those short comments are just illustration of the proposed method and the interpretation of results in political, economical or sociological terms should be very cautious because term like *'influence area', 'margins', 'periphery'* or even *'potential'* has a psychological dimension which should not be neglected.

Map 6.1 CONTRIBUTION OF E.U. MEMBERS TO POPULATION POTENTIAL (calculated with gaussian neighboorhood / span 100 km)



Map 6.2 CONTRIBUTION OF E.U. MEMBERS TO POPULATION POTENTIAL (calculated with gaussian neighboorhood / span 250 km)



ANNEX : THE UNEP-GRID DATABASE

The database used for this experimental research is the **UNEP-GRID distribution of world population in 1990 by 1° of latitude and longitude according to political division of grid cells between states**. We are aware that it is a very raw[20] material (each cell of the studied area has a superficy comprise between 4000 and 10000 km) and that the assumption made for the measure of potential or accessibility are oversimple. Of course, more interesting results would be obtain with more precise databases (population at level Nuts 5), more interesting measure of ressource (urban population, GNP, ...) and more accurate measure of distance (time, cost, mode of transportation). But the UNEP-GRID database is sufficient for a first exploration of geographical position in the European Union and for an examination of theoretical proposals which could be applied later on better information.

[20] As an example, we have discovered important mistakes in the grid distribution of population for France in UNEP-GRID database and we have realised a correction which was sent to UNEP-GRID coordinators. Apparently the information is correct for other states of E.U. and neighbouring countries but a complete verification should be done if the preliminary results presented above has to be published or used in ESDP reports.

Environment and Planning A 1998, volume 30, pages 499 – 521

The accessibility of European cities: theoretical framework and comparison of approaches

F Bruinsma, P Rietveld
Vrije Universiteit, Faculty of Economics and Econometrics, Department of Spatial Economics, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands;
e-mail: fbruinsma@econ.vu.nl; prietveld@econ.vu.nl
Received 13 September 1996; in revised form 25 November 1996

Abstract. A brief overview is given of the different approaches employed to measure the accessibility of cities. In addition, the results of seven studies on the accessibility of cities within Europe are compared. The comparison is focused on two aspects: the rankings of the cities as a result of the different conceptualizations and the type of infrastructure involved; and the equity in accessibility given the conceptualization and the type of infrastructure. When one is interested in a ranking of cities in terms of accessibility the choice of the accessibility concept tends to be less important than the choice of the type(s) of infrastructure to be considered. When one is interested in inequalities in accessibility among cities, operationalization appears to have a much larger impact compared with rankings per se.

1 Introduction

During most of the 20th century the infrastructure policy of national governments was mainly focused on the—further—extension of the national infrastructure networks in order to improve *internal* accessibility. However, the opening of the European market and the incentives given by the European Commission to construct 'Trans European Networks' have led, in recent years, to an emphasis on *international* infrastructure networks. To create a competitive market all the major urban regions will need to have good access to the common European market, and hence they will all need to be connected to highway networks, high-speed rail networks, and so on. Considering the resulting maps made by the European Commission, Europe will be covered by a dense pattern of infrastructure networks. We now need to consider what the effects would be of such an investment policy on the accessibility of European cities.

Recently, several studies on the accessibility of European cities have been produced. In these studies it is noticeable that accessibility was defined and/or operationalized in different ways. In section 2 we give an inventory, comparison, and classification of definitions and operationalizations of the concept of 'accessibility'. Then the results of seven studies on the accessibility of cities in Europe are compared. For each study, accessibility indices have been constructed which are then analyzed in both a qualitative and a quantitative way in section 3. We conclude that the differences in the city rankings resulting from the seven studies that can be explained by different operations are often smaller than the differences that can be explained by the type of infrastructure network analyzed. In other words, the differences in the accessibility rankings of cities depends more on the choice of the network (air, rail, road, or a combination of those types) than on the operation of the accessibility concept.

2 Accessibility concepts: a survey

2.1 Alternative definitions of accessibility

A general definition of accessibility is that it is the potential of opportunities for interaction (see Hansen, 1959; Martellato et al, 1998). In other, related, definitions terms such as "ease of spatial interaction", "potentiality of contacts with activities or

45

supplies", or more precisely, "attractiveness of a node in a network taking into account the mass of other nodes and the costs to reach those nodes via the network", are employed. However, these descriptions are still rather vague. In practice a large number of possible operationalizations are used. We list a number of these possibilities in table 1.

When we compare these definitions of accessibility, it appears that for most of them the only information we require is concerned with spatial data such as the location of nodes, the length of links, and data on transport costs (travel time, fares, etc). However, for the remainder we need additional information about the mass of nodes. For acc7, acc8, and acc10, we need data on spatial interaction patterns, or parameters of models describing these spatial interactions.

Table 1. Alternative operationalizations of accessibility.

	Definition	Assumptions and remarks	Example
acc1	A node has access to a network if a link exists between the node and the network.	Accessibility actually means access or connectivity; accessibility is a binary variable: 1 or 0.	The city of Bonn is connected to the German autobahn network.
acc2	The accessibility of a node with respect to a network is the distance one has to travel to the nearest node on the network (negative).	If accessibility defined according to acc1 equals 1, acc2 attains its most favourable outcome (acc1 = 1 implies acc2 = 0).	The distance of village A to the nearest point of entry of the national express way system is 16 km. The distance of the city Gent to Brussels airport is 60 km.
acc3	The accessibility of a node in a network is the total number of direct connections with other nodes.		From Rotterdam airport one can fly to 12 destinations without changing plane.
acc4	The accessibility of a node in a network is the total number of links connected to this node.		From Hannover the railway lines go in 4 directions.
acc5	The accessibility of a node to another node is measured as the travel cost between these nodes (negative).	This definition considers accessibility in a strictly bilateral way without summation across destinations.	It takes 2.5 hours to fly from London to Lisbon; the costs of a return trip are US $460.
acc6	The accessibility of a node in a network is the weighted average travel cost between the particular node and all nodes in the network (negative).	Weights may relate to the masses of the nodes; or to the total number of trips made to the nodes.	The average distance of Vienna to all major cities in Europe weighted by population size is 880 km; when weighted by the shares in the total number of trips it is 350 km.
acc7	The accessibility of a node in a network is the expected value of the maximum utility of a visit to any node.	Utility of a visit to a certain node is assumed to depend on: the mass of the node, the travel costs of a trip to the node, a stochastic term.	The accessibility of Milan for road transport in Europe is 56 compared with Frankfurt 100 (index).

46

Table 1 (continued)

	Definition	Assumptions and remarks	Example
acc8	The accessibility of a node in a network is (proportional to) the spatial interaction between the node and all other nodes.	The spatial interaction between nodes may be directly measured, or computed by means of a spatial interaction model.	See acc7.
acc9	The accessibility of a node in a network is the total number of people one can reach from the node within a certain transport cost limit.	The transport cost limit can be formulated in any dimension: distance, travel time, etc.	From Copenhagen one can reach 80 million people within 4 hours.
acc10	The accessibility of a node is the inverse of the balancing factor in a singly or doubly constrained spatial interaction model.	This interpretation has been given by several authors (for example, Hamerslag, 1980; Wilson, 1982).	See acc7.
acc11	Accessibility is measured by means of expert judgment.	No formal definition is given.	The five European cities with the best accessibility are, say, A, B, C, D, and E.

Note: accessibility is defined as a positive concept; the higher the value attained the better. Only in three cases (acc2, acc5, acc6) is the definition in negative terms so that an inverse transformation is needed.

In the case of acc8 a possible formulation would be: the accessibility of a city is measured as the weighted sum of the population in all cities where weights are equal to the 'travel time decay' (compare Keeble et al, 1982):

$$\text{acc}_i = \sum \text{pop}_j \Big/ (\text{travel time}_{ij})^a .$$

According to this measure the location of a city at one hour travelling distance contributes more to the accessibility than a city located four hours away. If the travel-time parameter a is set equal to 1 (this is the parameter value used most often in empirical studies), the ratio of the weights is 4:1.

In the case of acc7, accessibility is given a basis in utility theory by using a utility function as a starting point (see, for example, Bröcker, 1989):

$$u_{ij} = v_j - bc_{ij} + e ,$$

where u_{ij} denotes the net utility of a visit from i to j, v_j denotes the utility without transportation costs c_{ij}. The parameter b represents utility per unit transport costs, and e is a stochastic component. Suppose that residents of location i choose the destination of their trip by maximizing the expected net utility of the trip with i as the origin (denoted as A_i). Then, when e is Weibull distributed, stochastic utility theory leads to the following result for A_i

$$A_i = \ln \sum_j \exp(v_j - bc_{ij}) = \ln \sum_j \exp v_j \exp(-bc_{ij}) .$$

Clearly, the definition of A_i is very close to the one given for acc8 when v is the log of population size. In the case of acc9 one would need a standard limit for transport costs (maximum one hour travel time for commuting trips; maximum thirty minutes travel time for shopping trips, etc).

47

2.2 Further variations in the accessibility concept

In fact, many more definitions can be given than the ones presented here. Variations may relate to a number of factors, some of which are listed below.

The way the mass of a node is measured. In most applications the mass of a node is represented by its population size. However, various other mass indicators can be used, such as employment or GDP (gross domestic product). When one studies accessibility for specific production activities, the masses may also be related to more specific variables, such as the volumes of sales in cities, or the amounts of inputs received from certain input nodes.

The use of a unimodal versus a multimodal approach. Many studies are unimodal. However, in certain cases a second mode is required; for example, when a mode has incomplete coverage of space, in which case one usually adds a supporting mode with a spiderweb structure (all points in space being connected to the nearest mode in the network considered). A more drastic step is to introduce a truly multimodal network with transshipment points. By the use of a log-sum approach accessibility indicators for the multimodal system as a whole can be computed (see Vickerman et al, 1998). A further step would be to allow for intermodal transport chains.

The way the transport costs are measured. The usual proxies of transport costs are distance and travel time. If a generalized transport-cost approach were to be used one would add up distance-dependent costs (fares, or the variable costs of vehicle use) and time-dependent costs (travel time multiplied by the value of time). Also waiting times would have to be taken into account, as well as any inconvenience costs incurred when certain transport mode activities have to be rescheduled because of low user frequency. An important implication of this line of thought is that, because values of time differ among different groups of people, accessibility would also have to be specified for different groups. A final cost component which is usually neglected in accessibility studies concerns the costs of uncertainty in unreliable networks. As an aside it is interesting to note that in certain discussions about transport policies 'accessibility' is interpreted as a 'lack of congestion'.

The choice of a particular trip purpose. Accessibility is often studied in view of a certain type of activity. This not only has an implication for the way masses are defined (see above), but also for the spatial interaction function used in acc8. Thus, the spatial interaction formula should be trip-purpose specific: for example, business trips tend to be more distance-dependent than shopping trips.

The choice of the point in time. When networks are congested, the choice of the point in time is important. This is especially true for national and regional accessibility studies.

The choice of the spatial interaction function. As already mentioned above, different specifications can be used for the spatial interaction function. Two commonly used forms are the power function (acc8) and the exponential function (acc7). The shapes are similar, but differ in the fact that the power function may achieve very high values for short distances. Fotheringham and O'Kelly (1989) note that the exponential function tends to be more suitable for analysis of short distances and the power function tends to be more appropriate for longer distance spatial interactions.

2.3 Problems in the measurement of accessibility

We list below some problems that are important in the measurement of accessibility. They relate to:

(1) dimension of measurement of accessibility;
(2) choice or demarcation of the nodes;
(3) demarcation of total area; and
(4) treatment of internal accessibility.

48

(1) *Dimension of measurement of accessibility.* Most of the accessibility concepts presented have a clear dimension and are easy to interpret. However, there are some exceptions: acc7, acc8, and acc10 need the inclusion of an index value [for example, by comparison of different nodes (Paris = 100) or different years (1990 = 100)] in order to provide the user with an appropriate frame of reference.

(2) *Choice or demarcation of the nodes.* Three different approaches can be distinguished in the demarcation of the nodes.

First, the analysis can be confined to a set of nodes which does not completely cover the whole area. For example, as is often done, the nodes represent the major cities in a country. Because administrative boundaries are not useful here, one faces the problem of how to demarcate the cities.

A second approach would be to use nodes as point representations of regions (surfaces) so that the total area is covered. Here again we have the problem of demarcation. In the case of the European Union (EU) one has the advantage that a commonly accepted regionalization in terms of NUTS [Nomenclature of Territorial Units for Statistics (Eurostat, 1997)] regions can be used.

A third approach, which has become possible by the emergence of GIS (geographical information systems), is the use of grids. These grids have the big advantage that demarcation problems can be avoided because the spatial units are exogenously given. However, when one wants to formulate conclusions about the accessibility of cities such as Paris or London one has to decide on which grids this should be based and how the grid scores should be aggregated.

(3) *Demarcation of total area.* The total area taken into account in an accessibility study is obviously an important choice. Of course, the demarcation used depends on the purpose of the accessibility study. The lower the sensitivity to transport costs, the larger the study area should be. In many studies the spatial demarcation coincides with the borders of a country. This tends to lead to low accessibilities of locations near borders.

When accessibility is studied at the European level, the question is how to demarcate 'Europe'. Some studies take into account only the EU members. Indeed, the choice of the EU has advantages because of the availability of a standardized data set, and because the economic and policy importance of the EU justify special treatment for the EU. Nevertheless, even if one wants to focus on accessibility of EU members, it would be strange to neglect their accessibility to non-EU countries. For the accessibility of Greece, for example, it is much more important to include its neighbouring countries than countries such as Ireland and Denmark.

(4) *Treatment of internal accessibility.* The internal accessibility of a spatial unit may have a substantial impact on the final outcome in the case of accessibility concepts acc7, acc8, and acc10 (see also Frost and Spence, 1995). The reason is that the functional forms used lead to high weights for internal accessibility. The problem is that the data for the local transport network are usually weak. For example, we would like to know whether the average travel time between all origins and destinations in a metropolitan area is 30 minutes or 75 minutes. This uncertainty has far-reaching consequences for the accessibility scores of cities, especially the larger ones.

It would be tempting to avoid this problem by ignoring the internal accessibility of a city. But this would lead to counterintuitive outcomes with high scores for smaller cities which are near to large cities and low scores for the large cities themselves. The use of small areas, as in the case of a grid system, clearly leads to less of a dependence on the internal accessibility and, therefore, provides a good way to avoid this problem.

49

2.4 Comparison of acc6, acc7 or acc8, and acc9

An obvious advantage of the average-distance-based indicator (acc6) is that it is easy to interpret. However, accessibility measured as the (inverse function of) average distance has the unattractive property in that it becomes rather sensitive to the demarcation of the area of research. 'Too narrow' a demarcation means that relevant nodes are missing, whereas 'too broad' a demarcation means the outcomes of the accessibility indicator are strongly influenced by irrelevant nodes.

A possible way to solve this problem is to apply a weighting by means of the shares in the total number of trips. This has the attractive property that, when areas are added which are irrelevant in the sense that no trips are made to those areas, the accessibility indicator is not affected. However, this weighting scheme also has an unattractive feature: it may lead to high outcomes for isolated cities where the large majority of the trips is made in the immediate vicinity. This would, for example, imply a high accessibility for an isolated city such as Tromsö in Northern Norway.

The gravity-based and utility-based definitions of accessibility (acc7 and acc8) do not suffer from such a strong dependence on the demarcation of the area of research because the addition of an irrelevant destination does not affect the accessibility values of the other nodes, and hence is harmless. At the same time the gravity-based or utility-based approach does not give rise to the problems of isolated cities receiving good scores. To stick to the example given above, Tromsö will receive a low accessibility value (according to definitions acc7 and acc8) because its large distance from major European cities prevents it benefiting from the large masses present there. There is, however, another problem with acc7 and acc8 which deserves our attention: they may depend strongly on the way their own mass is treated, a subject already discussed above.

Thus we can conclude that there is an interesting trade-off between the average-distance-based indicators (acc6) and the interaction-based indicators (acc7 and acc8). The average-distance-based indicators are sensitive to the demarcation at the outer side of the area of study, whereas the interaction-based indicators depend more strongly on the way the internal distance problem is handled.

A difference between the approaches of acc8—which indicates *potential* accessibility—and acc9—which indicates the *daily* accessibility—concerns the treatment of travel-time decay. In acc8 there is a gradual decay: a halving of travel time leads to a doubling of the weight for the particular city pair. Very remote cities do receive a positive weight, although it may be very small. The contribution of a city to its own accessibility may be considerable for large cities, which partly explains the relatively high rankings of cities such as Istanbul and Athens, but also of Paris and London.

In acc9, on the other hand, travel-time decay does not occur until the travel time exceeds a critical level (about six hours), so that it is no longer possible to spend four hours at the visit location. No further differentiation is used within these ranges of travel times. For example, according to acc9, a major improvement in the link between two cities so that travel time is reduced from five hours to two hours does not lead to an improvement in the accessibility between the two.

2.5 Effects of network improvement

Improvement of infrastructure will in general lead to an improvement of accessibility of locations. There are some exceptions, however.

First, in congested road systems an improvement of a link, or the addition of a new link, may lead to higher average transport costs because of the possible discrepancy between the user equilibrium and system optimum (the so-called Braes paradox, see, for example, Sheffi, 1985). This paradox may be relevant in congested urban road networks. A second exception may be relevant in congested urban road networks:

improvements in an infrastructure network usually imply disadvantages for particular points in space. For example, the upgrading of a highway will lead to a reduction in the number of highway access points, so that for some locations the highway system may become less accessible.

An inspection of the various definitions of accessibility in table 1 reveals that most of them will be able to capture changes in the network, although the level of refinement varies. For example, distance-based measures will not be able to capture speed improvements. In addition, frequency improvements are only captured when waiting times and scheduling inconveniences are taken into account.

When we take a closer look at the locations where a network improvement takes place, we can see that accessibility indicators acc1 – acc4 have a rather local effect. An improvement on a link between A and B is only important for A and B, not for other nodes. With the other accessibility concepts there is a rather wider effect. For example, the construction of the Channel Tunnel not only affects regions immediately connected, such as South East England and Northern France, but also other regions. However, the particular ways in which this happens may be rather different. For example, with an average travel-time index (acc6), the absolute improvement in travel time between Paris and London is equally large compared with that between Madrid and London. In the case of accessibility concepts acc7 and acc8, Paris would benefit much more than Madrid, because the weight of London will be higher for Paris compared with that for Madrid in the accessibility formula.

Another property of accessibility measures concerns their *symmetry*. Suppose a link connecting a large city and a small city is improved. To what extent does this lead to symmetric improvements of accessibilities of both cities? Symmetry holds for measures acc3 – acc5 but not for measures acc6 – acc10. For this second group of measures we find that an improvement in travel costs of the link between a large node and a small node will lead to a larger increase in accessibility for the small node than for the large node. The transport-cost improvement is the same for both nodes (assuming symmetry in transport costs), but the weights applied are different, leading to a larger increase in accessibility for the small city compared with the large city. This lack of symmetry seems to be greater for the average travel costs function compared with the other two functions. The lack of symmetry occurs both in absolute and in relative terms. In relative terms the discrepancy is even larger.

This result has important implications for the use of accessibility indicators in research: economic theory suggests that, when infrastructure improves, in the first stage the core regions will benefit most (Krugman, 1991). Only in a later stage will peripheral regions start to benefit. However, such a pattern does not follow from the definition of accessibility itself, which indicates that in all phases an improvement of infrastructure will lead to accessibility improvements which are higher for the peripheral region compared with the core region. Thus, models dealing with the relationship between accessibility and economic performance should incorporate the possibility that certain types of regions benefit from a relative increase in accessibility, and others are hurt by it (see Rietveld, 1989). Another feedback effect which is important in this respect concerns the impact of changes in transport costs on travel demand, which will lead to changes in congestion levels (Martellato et al, 1998).

3 A comparison of accessibility measures

In the above section it was shown that the accessibility of cities can be measured in various ways. But what are the consequences of these different approaches for the ranking of cities on accessibility characteristics within a European context? Does it result in completely different rankings of cities, or are the differences in rankings rather small, independent of the measure used? In the present section we will discuss and compare the results of seven studies. The seven studies, given in chronological order, are DATAR (1989), Cattan (1992), Erlandsson and Lindell (1993), Bruinsma and Rietveld (1993), Healey and Baker (1994), Spiekermann and Wegener (1996), and Gutiérrez et al (1996).

In section 3.1 the different measures used in these studies are described and their consequences for the ranking of the cities from a methodological viewpoint are analyzed. In section 3.2 the impacts of the approaches are analyzed in line with the discussion of section 2. In section 3.3—in which the results are compared—our focus of attention will shift to the rankings for each modality. After a qualitative comparison of the rankings achieved by the different studies for, for instance, the accessibility by railway infrastructure, we give an analysis of correlations.

3.1 Methodological aspects of the seven studies

An overview of the main characteristics of the approaches of the seven studies is given in table 2.

Erlandsson and Lindell (EL) distinguish inbound and outbound contact potentials (acc9) for ninety-seven cities. We will use the term 'accessibility' in this context. Inbound accessibility of a city is measured as the total number of people living in urban areas who can travel to that city, stay there for at least four hours, and travel back on the same day. Outbound accessibility of a city is defined, in a similar way, as the total number of people living in urban areas who can be paid a visit by someone in that city, again with the restriction that the duration of the stay is at least four hours and that the return trip takes place on the same day. This is a relevant concept for business travel, as generalized costs of communication increase considerably when one has to stay overnight. A disadvantage of the definition is that 'population' is not always a relevant measure of the economic importance of a city. It is preferable to use the number of workers in particular economic sectors. The EL measure is based on a joint analysis of all relevant transport modes. Differences in departure and arrival times of trains and airplanes cause the differences between inbound and outbound accessibility of cities. If accessibility was dependent only on the road system, inbound and outbound accessibility would be identical.

Table 2. Overview of the main characteristics.

	Erlandsson and Lindell	Bruinsma and Rietveld	Spiekermann and Wegener
Type of indicator	acc9	acc8	acc9 and acc8
Demarcation	whole of Europe	Europe, except former USSR	Europe except eastern part of former USSR
Spatial unit	cities >100000 inhabitants	urban areas >1 million inhabitants	grids (raster cells 10 km square)
Modalities	fastest travel mode	fastest travel mode, car, train, airplane	train
Orientation	passengers	passengers	passengers
Mass indicator	population	population	population
Transport cost indicator	travel time	travel time	travel time

52

Bruinsma and Rietveld (BR) define accessibility in the context of a gravity-type model (acc8). For forty-two agglomerations with over one million inhabitants this measure has been computed by BR for various transport modes: airlines, railways, road transport, as well as combinations of these. For rail and air, total travel times also depend on waiting times, which are related to frequencies. For air, two indicators are computed: one which includes only direct flights and the other which also includes transfer flights. The BR approach shares the disadvantage with the EL approach in that the importance of cities is measured in terms of population rather than a more relevant economic variable.

Spiekermann and Wegener (SW) measure the accessibility of cities only via the rail network. They compute the accessibility measure acc9 (daily accessibility) as well as measure acc8 (potential accessibility). SW try to incorporate the fact that accessibility is continuous in space. To achieve this SW disaggregated the European territory into some 70 000 10 km square raster cells. For each country the population of large cities was first allocated to cells and then the remaining population of the country was distributed equally across the rest of the country. The total travel time consists of the access time, the travel time on the network, and the terminal time to the destination cell.

In line with the continuous-space approach of SW, Gutiérrez et al (GU) develop a—potential—accessibility indicator via the rail network. Unlike SW, who covered Europe with a raster grid, GU defined 4000 nodes and 7000 arcs linking these nodes. However, GU used a model in which the indicator is specified as a weighted (by GDP) average of travel times (acc6). So, in this approach there is no distance decay as there was in the gravity-type models.

Cattan (CA) used acc6 to compute the accessibility indicator for a sample of ninety cities each with over 200 000 inhabitants and an airport. In this study accessibility measures are computed for rail and air traffic. The air traffic indicator—by direct links—includes flight time and the time needed to travel from the city centre to the airport. The rail accessibility is calculated by the travel time between stations. Weighting was determined by the number of planes (trains) leaving to certain destinations.

Table 2 (continued)

Gutiérrez et al	Cattan	DATAR	Healey and Baker
acc6	acc6	acc1 or acc2	acc11
European Union	European Union, Austria and Switzerland	European Union, Austria, and Switzerland	Europe
4000 nodes	cities >200 000 inhabitants and airport	cities >200 000 inhabitants	major cities and possible newcomers as location for multinationals
train	train, airplane	airport, port, telecommunication	all modes
passengers	passengers	passengers, freight, information	passengers, freight
gross domestic product	number of planes, trains leaving to destination		attractiveness as location
travel time	travel time		

The problem of using the number of trains or planes to weight the interaction is that the number of trains and planes is not perfectly correlated with the size of the traffic flows: the numbers of seats varies among different types of airplanes; most international trains are block trains of which the blocks consist of different numbers of coaches having different destinations, and the composition of the block may change several times during the journey. CA had tested for this problem by computing the air attractivity of the cities defined by the number of passengers instead of the number of planes. The results show about the same hierarchy of cities (correlation coefficient 0.9).

In the last two studies we discuss—DATAR (DA) and Healey and Baker (HB)—the accessibility of European cities is measured in a more or less qualitative manner, instead of quantitatively as in the approaches described above.

In the DA study the socioeconomic performance of 165 European cities, each with a population of more than 200 000 inhabitants, is given. The performance of 'functional urban regions' is measured by means of sixteen indicators of which three are infrastructure indicators: airports, ports, and telecommunications. This can be conceived of as a variant of acc1 or acc2. The cities have been rated on a scale from 0 (most attractive) to 5 (least attractive). The data set has been checked by experts from different European countries.

An alternative approach is followed by HB, who measure perceptions of accessibility rather than accessibility itself (acc11). They study the attractiveness of a European city as a location for large companies. A stated-preference approach is followed by interviewing 500 senior managers of large companies in industry, trade, and services from nine European countries. The respondents are asked to rate the three cities which are the best locations in terms of various location factors. The two accessibility variables are: "easy access to markets, customers, or clients" and "transport links with other cities and internationally". Thus the responses relate to perceptions of the attractiveness. Although this is an interesting approach, two shortcomings should be mentioned. First, respondents had to mention only three cities, which has the effect that the dominant positions of London and Paris as attractive locations for company headquarters in Europe tend to be overrated when average scores are computed (see section 3.3.1). Second, a problem that is inherent to stated preference is that there is no guarantee that it is followed by actual location behaviour. Nevertheless, the perceptions observed in this way are a relevant piece of information, because they play a role in company location decisions.

3.2 A comparison of approaches

The seven studies are different in various respects, so that it is not surprising to find that they yield different results. One source of difference concerns the demarcation of the research area and the choice of the set of cities (see table 2). The boundaries of the area under research are rather arbitrary; EL include cities in the former USSR, which are excluded in BR, the area under study of SW is somewhere in between. GU restrict the area to the EU; CA and DA include Austria and Switzerland. HB confine themselves to a rather small set of major cities and possible newcomers. From a methodological point of view the spatial demarcation issue is especially important in acc6-type of models where the impact of distance decay is not included: the studies of GU and CA. In the other models the impact of the cities outside the research area becomes less important as their distance from the research area increases. Nevertheless, the scores of cities on the fringe of the chosen study area will be influenced negatively by the exclusion of cities nearby, but which are located on the 'wrong' side of the demarcation line.

Not only is the set of cities involved arbitrary but the way in which cities are delimitated and their total population size measured is arbitrary. There is no standard

54

database for this purpose. EL, BR, CA, and DA all use their own definition of urban areas. An extra complication is created by the delimitation of urban areas in large city regions such as the German Ruhr area, the Dutch Randstad, and the English Midlands. GU are confronted with the same difficulties when computing the GDP of the 4000 nodes. Even more detailed is the distribution of population in a 70 000-cell raster as used by SW.

In the HB study the problem of delimitation is avoided, but the disadvantage is of course that one does not know exactly to what spatial unit the answers of the experts relate: to the core of the city, or to the larger metropolitan area.

Another problem worth mentioning is the handling of the cities' own mass in computing the accessibility indicator. The economic strength of a city does not depend only on its external relations but also on its internal relations. If interaction is supposed to depend on the size of the agglomerations with which an agglomeration interacts, then not only the external interaction with other cities but also the internal interaction within the city need to be included. This holds particularly for the gravity-type models in which interaction over short distances is relatively strong.

A difference between the EL and BR studies is that in the EL study attention is paid to asymmetries in rail and air connections, which are not taken into account in the BR study; indeed it makes a difference whether the first flight from Copenhagen to Vienna leaves Copenhagen at 7.30 AM or leaves at 10.00 AM. Another reason why the measures may differ is that the transport modes considered are different. EL consider all transport modes jointly; but, in principle, it would not be a problem if their approach was repeated for each travel mode separately, as is done by BR.

3.3 Comparison of the rankings of each transport mode

In this section we will analyze the results achieved with the approaches used in the seven studies. In order to make the results comparable the rankings of cities in those studies are converted into indices in which the best accessible city receives the value 100 (see table 3, over). The comparisons will be presented for each modality, starting with the studies which give rankings for multimodal approaches (section 3.3.1) followed by the air mode (section 3.3.2), the rail mode (section 3.3.3), and the rail mode after the completion of high-speed rail links (section 3.3.4). First, a qualitative description of the differences in results is given, followed by a quantitative analysis. In the qualitative description the best accessible area—as a summation of the ten best accessible cities of each ranking—is given and we investigate to what extent the differences in outcomes are related to differences in the methodologies used.(1) In the quantitative analysis the rankings of the studies are compared using correlation analysis (see table 4) and the equity in accessibility is compared using the coefficient of variation (see table 3). We shall conclude this section with a short comparison of the results between the modes.

3.3.1 *Multimodal*

Four out of the seven studies give a ranking for cities of the accessibility by multimodal means. EL give a ranking for inbound and outbound accessibility and HB for access to markets, clients, and customers, and access by external transport links. This brings the total number of rankings to six (see table 3, columns A, G, H, I, S, and T).

The best accessible area in Europe—a summation of the ten best accessible cities of each ranking—is an almost circular area containing London, the Benelux cities, the Ruhr area, and Paris (see figure 1, page 513). There is one rather large spur, containing Munich, Switzerland, Milan, Marseille, and Spain and two small spurs; one towards the Midlands (United Kingdom) and the second into the direction of Berlin, Hamburg, and Copenhagen.

(1) The least accessible cities cannot be discussed because those cities are not included in all studies.

Table 3. Accessibility indices.

City	A	B	C	D	E	F	G	H	I	J
Vienna	68	61	70	51	60	46	61	58	27	60
Brussels	78	70	74	71	70	82	93	92	33	80
Sofia	49	43	51	35	45	29	1	1	–	–
Geneva	–	–	–	–	–	–	61	74	33	60
Zurich	73	73	76	54	63	59	83	84	30	80
Zagreb	50	36	51	42	54	35	1	4	–	–
Prague	57	48	59	45	58	38	26	43	–	–
Berlin	73	69	75	62	74	55	86	53	38	80
Cologne	87	42	60	85	75	84	74	49	38	40
Düsseldorf	100	60	69	90	78	83	77	67	38	80
Essen	89	18	60	81	77	74	–	–	25	0
Frankfurt	77	75	77	64	70	71	92	100	60	100
Hamburg	70	60	71	61	66	56	73	58	50	60
Munich	68	65	70	54	63	54	73	63	38	80
Copenhagen	67	64	70	44	52	42	58	58	50	80
Barcelona	64	60	67	46	54	49	53	39	43	80
Madrid	70	67	73	53	58	50	57	50	38	80
Lyon	67	48	65	63	62	68	49	47	30	40
Marseille	59	39	61	51	56	56	31	5	50	60
Paris	96	100	100	100	100	100	100	94	60	100
Birmingham	76	48	62	76	70	69	63	52	27	40
Glasgow	–	–	–	–	–	–	51	38	38	60
Leeds	87	31	56	77	74	69	49	32	23	0
Liverpool	86	21	54	71	68	63	57	57	27	20
London	98	99	99	96	94	90	93	85	100	100
Manchester	91	51	63	77	71	68	62	60	43	80
Newcastle	67	32	55	55	60	50	47	42	27	20
Athens	61	57	64	46	52	37	23	4	43	80
Budapest	61	55	63	51	61	43	14	24	–	–
Genoa	56	28	54	49	59	47	17	13	30	0
Milan	73	69	72	57	65	62	60	71	43	80
Naples	53	33	54	42	49	44	22	15	33	40
Rome	70	66	73	57	63	52	60	50	38	80
Turin	62	35	60	52	61	54	49	40	27	40
Dublin	63	50	66	39	43	33	54	46	27	40
Amsterdam	81	70	73	66	67	67	96	84	50	80
Rotterdam	74	32	66	67	69	68	85	64	60	60
Lisbon	57	49	59	42	48	36	34	24	38	60
Lodz	49	17	49	39	49	32	4	1	–	–
Warsaw	57	52	58	44	51	37	12	18	–	–
Bucharest	54	48	56	42	50	34	3	2	–	–
Moscow	–	–	–	–	–	–	24	35	–	–
Stockholm	58	50	60	40	45	34	58	30	–	–
Belgrade	53	47	55	42	52	35	2	8	–	–
Istanbul	67	65	70	58	67	47	9	6	–	–
Cov	0.195	0.353	0.165	0.281	0.193	0.319	0.584	0.628	0.366	0.464

Bruinsma and Rietveld (1993): A fastest travel mode; B air traffic, transfer flights excluded; C air traffic, transfer flights included; D rail traffic; E road traffic; F rail traffic, future high speed train network included.
Erlandsson and Lindell (1993): G inbound accessibility; H outbound accessibility.
DATAR (1989): I airports, sea/inland ports and telecommunication; J airports.
Cov, coefficient of variation.

Table 3 (continued)

City	K	L	M	N	O	P	Q	R	S	T
Vienna	25	15	64	69	27	33	–	–	9	3
Brussels	33	30	87	90	100	100	90	95	50	33
Sofia	–	–	42	51	14	25	–	–	–	–
Geneva	17	25	47	44	19	12	–	–	14	11
Zurich	36	34	71	71	36	51	–	–	11	20
Zagreb	–	–	47	53	8	19	–	–	–	–
Prague	–	–	60	67	24	38	–	–	5	2
Berlin	7	17	78	78	40	46	54	64	19	6
Cologne	65	16	92	89	90	92	82	92	–	–
Düsseldorf	47	27	92	84	74	60	81	89	30	13
Essen	–	–	93	83	63	49	79	89	–	–
Frankfurt	39	53	71	76	69	74	79	90	78	80
Hamburg	39	21	76	72	48	43	67	69	15	8
Munich	48	33	73	74	39	39	71	72	16	9
Copenhagen	5	17	39	48	5	21	46	40	3	4
Barcelona	9	18	47	56	10	21	57	60	15	6
Madrid	11	27	57	59	20	21	41	45	15	5
Lyon	29	13	76	79	56	67	91	88	10	8
Marseille	32	11	50	57	15	32	74	66	–	–
Paris	65	71	100	100	73	99	100	100	86	79
Birmingham	47	12	67	58	47	30	55	65	–	–
Glasgow	8	12	47	46	18	13	45	52	3	3
Leeds	25	4	67	61	44	32	54	61	–	–
Liverpool	–	–	58	55	44	32	51	61	–	–
London	100	100	83	86	52	76	62	82	100	100
Manchester	33	17	63	63	62	40	51	61	10	6
Newcastle	22	4	51	43	22	14	52	58	–	–
Athens	2	9	42	42	11	7	19	12	–	–
Budapest	–	–	62	67	25	30	–	–	7	–
Genoa	20	2	46	44	21	14	70	66	–	–
Milan	48	28	68	74	45	56	70	71	29	10
Naples	29	5	54	55	32	26	49	46	–	–
Rome	51	25	71	69	39	32	55	51	5	3
Turin	13	4	62	72	32	55	68	72	4	2
Dublin	1	12	44	38	10	6	24	27	–	–
Amsterdam	41	37	79	79	61	76	77	76	26	35
Rotterdam	31	5	71	66	40	32	81	82	–	–
Lisbon	3	8	42	47	13	14	29	32	3	–
Lodz	–	–	47	44	22	14	–	–	–	–
Warsaw	–	–	60	63	24	30	–	–	8	–
Bucharest	–	–	49	51	17	15	–	–	–	–
Moscow	–	–	51	39	23	15	–	–	3	–
Stockholm	–	–	41	45	7	7	–	–	4	1
Belgrade	–	–	51	59	16	26	–	–	–	–
Istanbul	–	–	52	53	34	25	–	–	–	–
Cov	0.702	0.909	0.258	0.245	0.640	0.662	0.311	0.315	1.211	1.417

Cattan (1992): K rail traffic; L air traffic.
Spiekermann and Wegener (1996): M rail traffic, potential accessibility 1993; N rail traffic, potential accessibility 2010; O rail traffic, daily accessibility 1993; P rail traffic, daily accessibility 2010.
Gutiérrez et al (1996): Q rail traffic 1993; R rail traffic 2010.
Healey and Baker: S access to markets; T accessibility by external transport links.

Table 4. Overview of correlation coefficients (intramodal correlation coefficients are printed bold).

	A	B	C	D	E	F	G	H	I
A	–	0.377	0.603	0.946	–	**0.785**	**0.758**	**0.326**	0.179
B	$n = 42$	–	**0.899**	0.322	–	0.576	0.630	0.618	**0.843**
C	$n = 42$	$n = 42$	–	0.570	–	0.738	0.749	0.713	**0.767**
D	$n = 42$	$n = 42$	$n = 42$	–	**0.955**	0.693	0.656	0.354	0.089
E	–	–	–	$n = 42$	–	–	–	–	–
F	$n = 41$	$n = 41$	$n = 41$	$n = 41$	–	–	**0.926**	**0.459**	0.584
G	$n = 41$	$n = 41$	$n = 41$	$n = 41$	–	$n = 44$	–	**0.378**	0.560
H	$n = 32$	$n = 32$	$n = 32$	$n = 32$	–	$n = 33$	$n = 33$	–	0.638
I	$n = 32$	$n = 32$	$n = 32$	$n = 32$	–	$n = 33$	$n = 33$	$n = 34$	–
J	$n = 30$	$n = 30$	$n = 30$	$n = 30$	–	$n = 32$	$n = 32$	$n = 32$	$n = 32$
K	$n = 30$	$n = 30$	$n = 30$	$n = 30$	–	$n = 32$	$n = 32$	$n = 32$	$n = 32$
L	$n = 42$	$n = 42$	$n = 42$	$n = 42$	–	$n = 44$	$n = 44$	$n = 34$	$n = 34$
M	–	–	–	–	$n = 42$	–	–	–	–
N	$n = 42$	$n = 42$	$n = 42$	$n = 42$	–	$n = 44$	$n = 44$	$n = 34$	$n = 34$
O	–	–	–	–	$n = 42$	–	–	–	–
P	$n = 30$	$n = 30$	$n = 30$	$n = 30$	–	$n = 30$	$n = 30$	$n = 31$	$n = 31$
Q	–	–	–	–	$n = 30$	–	–	–	–
R	$n = 24$	$n = 24$	$n = 24$	$n = 24$	–	$n = 27$	$n = 27$	$n = 22$	$n = 22$
S	$n = 21$	$n = 21$	$n = 21$	$n = 21$	–	$n = 23$	$n = 23$	$n = 21$	$n = 21$

	J	K	L	M	N	O	P	Q	R	S
A	0.678	0.619	0.784	–	0.773	–	0.428	–	**0.706**	**0.640**
B	0.467	**0.880**	0.381	–	0.277	–	0.158	–	0.829	0.806
C	0.563	**0.920**	0.581	–	0.437	–	0.319	–	0.851	0.840
D	**0.765**	0.586	**0.845**	–	**0.826**	–	**0.580**	–	0.773	0.700
E	–	–	–	**0.812**	–	**0.840**	–	**0.867**	–	–
F	0.549	0.680	0.710	–	0.655	–	0.551	–	**0.671**	**0.722**
G	0.512	0.709	0.686	–	0.566	–	0.541	–	**0.737**	**0.767**
H	0.569	0.764	0.228	–	0.148	–	0.195	–	**0.781**	**0.813**
I	0.298	**0.686**	0.184	–	0.130	–	0.084	–	0.702	0.665
J	–	0.720	**0.747**	–	**0.657**	–	**0.584**	–	0.733	0.718
K	$n = 32$	–	0.542	–	0.417	–	0.352	–	0.915	0.933
L	$n = 32$	$n = 32$	–	**0.941**	**0.894**	–	**0.766**	–	0.640	0.544
M	–	–	$n = 45$	–	–	**0.929**	–	**0.851**	–	–
N	$n = 32$	$n = 32$	$n = 45$	–	–	**0.886**	**0.729**	–	0.636	0.531
O	–	–	–	$n = 45$	$n = 45$	–	–	**0.840**	–	–
P	$n = 29$	$n = 29$	$n = 31$	–	$n = 31$	–	–	**0.953**	0.530	0.546
Q	–	–	–	$n = 31$	–	$n = 31$	$n = 31$	–	–	–
R	$n = 22$	$n = 22$	$n = 27$	–	$n = 27$	–	$n = 19$	–	–	**0.966**
S	$n = 21$	$n = 21$	$n = 23$	–	$n = 27$	–	$n = 18$	–	$n = 23$	–

Bruinsma and Rietveld (1993): A fastest travel mode; B air traffic, transfer flights excluded; C air traffic, transfer flights included; D rail traffic; E rail traffic, future high speed train network included; 1992 data.
Erlandsson and Lindell (1993): F inbound accessibility; G outbound accessibility; 1992 data.
DATAR (1989): H airports, sea/inland ports and telecommunication; I airports; 1989 data.
Cattan (1992): J rail traffic; K air traffic; 1991 data.
Spiekermann and Wegener (1993): L rail traffic, potential accessibility 1993; M rail traffic, potential accessibility 2010; N rail traffic, daily accessibility 1993; O rail traffic, daily accessibility 2010.
Gutiérrez et al (1996): P rail traffic 1993; Q rail traffic 2010.
Healey and Baker (1994): R access to markets; S accessibility by external transport links.

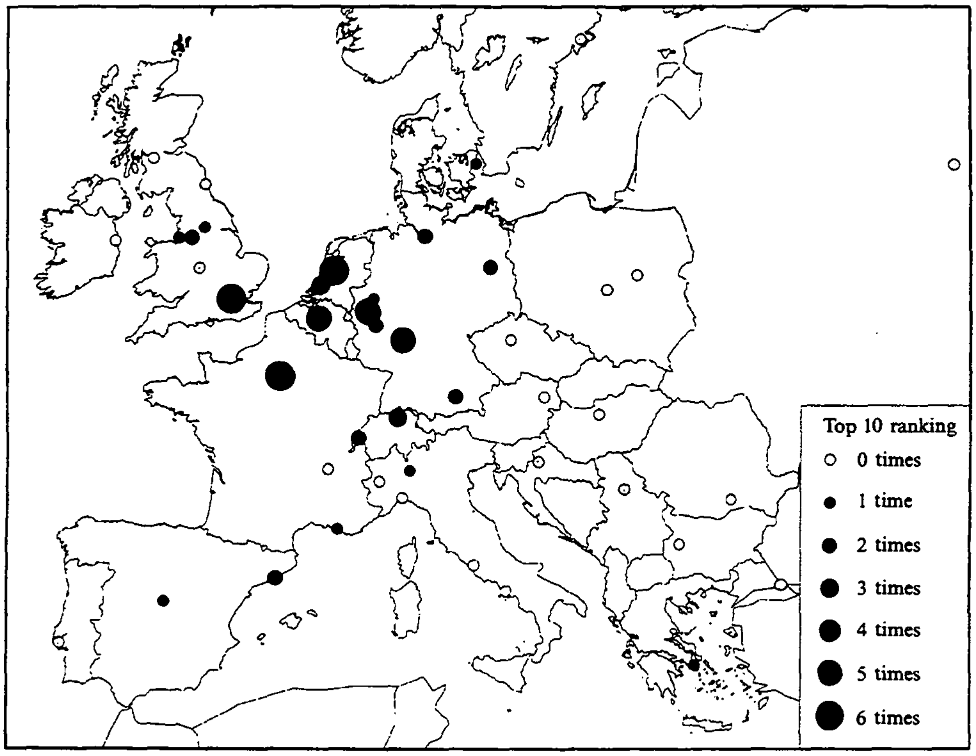


Figure 1. The best accessible area by the fastest travel mode (as a summation of the ten best accessible cities of each ranking).

It is remarkable that London scores best in the nonmodel approaches, in which accessibility is measured in subjective terms. In the case of the HB study this might partly be explained by a British bias. The fact that Paris scores best in the inbound accessibility measure but not in the outbound accessibility measure might be explained by the asymmetries in rail and air connections. In general, each morning Paris is fed by the other cities *before* the departures towards other European cities take place (this also holds true for London and, to a lesser extent, for Frankfurt). The high scores of Brussels, Amsterdam, and Düsseldorf—all in model approaches—can be explained by their central position between the densely populated areas of Paris, London, and the Ruhr area. The high score of Rotterdam in the ranking of DA is explained by the rather different criteria of this study on which the accessibility measure is based (airports, ports, and telecommunications). The fact that Rotterdam is the world's largest harbour seems decisive here.

The different operationalization of accessibility by DA also becomes clear when we compare the rankings by means of Pearson correlation coefficients (see table 5, over). The correlations with the quantitative approaches (BR and EL) are low. However, the correlations with the more qualitative rankings of HB are quite good. Most closely correlated are the rankings based on the same approach. The mutual correlations between the results of the quantitative approaches seem to be higher than the correlations between the results of the qualitative and quantitative approaches.

The last comparison concerns the equity in accessibility as given by the coefficient of variation (see table 5, last column). The lower this coefficient the more evenly accessible are the cities within the European infrastructure network. The approach of BR results in the most even distribution of accessibility over Europe. The range of

53

Table 5. Correlation coefficients for multimodal accessibility indices.

	Study						Cov
	BR	EL[a]	EL[b]	DATAR	HB[c]	HB[d]	
BR		0.785	0.758	0.326	0.706	0.640	0.195
EL[a]	$n = 41$		0.926	0.459	0.671	0.722	0.584
EL[b]	$n = 41$	$n = 44$		0.378	0.737	0.767	0.628
DATAR	$n = 32$	$n = 33$	$n = 33$		0.781	0.813	0.366
HB[c]	$n = 24$	$n = 27$	$n = 27$	$n = 22$		0.966	1.211
HB[d]	$n = 21$	$n = 23$	$n = 23$	$n = 21$	$n = 23$		1.417

Note: BR, Bruinsma and Rietveld; EL, Erlandsson and Lindell; HB, Healey and Baker; Cov, coefficient of variation.
[a] Inbound accessibility. [b] Outbound accessibility. [c] Access to markets. [d] Access by external links.

outcomes in this study is relatively low (from 100 to approximately 50). This low range can partly be explained by the impact of the travel-time decay as discussed in section 2.4. The worst equity in accessibility is found in the HB measures. In this study the gap between the top three cities—London, Paris, and Frankfurt—and the rest of the sample is very big. A possible explanation is that the respondents had the opportunity to rank only the three most accessible destinations. A city with a reasonable degree of perceived accessibility will not easily enter the top three of respondents and therefore will receive a very low score.(2)

3.3.2 *Air traffic*

The scores of the cities by air traffic in the various studies are given in table 3, columns B, C, J, and L. The best accessible area is more wide-ranging for this transport mode, containing nearly all major international airports (see figure 2). In the DA ranking, which is based on expert opinion, more cities receive a high ranking. However, the experts had only a limited range (a 6-point scale) to rank the cities.

At first sight there seems to be a strong similarity in results achieved by these rather different approaches. However, it is of great importance to consider if transfer flights are included in the measuring procedure or left out. The difference is measured in the BR study. Cities without an airport, or with only a very small one, score very low when only direct flights are included (in the manner of acc8: the scores of, for instance, Essen and Lodz which have no airport are explained by their own mass). In cities where transfer flights are allowed or passengers are allowed to travel via nearby airports, a sharp increase is shown in accessibility.

Table 6. Correlation coefficients for air traffic accessibility indices.

	Study				Cov
	BR[a]	BR[b]	DATAR	Cattan	
BR[a]		0.899	0.843	0.880	0.353
BR[b]	$n = 42$		0.767	0.920	0.165
DATAR	$n = 32$	$n = 32$		0.686	0.464
Cattan	$n = 30$	$n = 30$	$n = 32$		0.909

Note: BR, Bruinsma and Rietveld; Cov, coefficient of variation.
[a] Transfer flights excluded. [b] Transfer flights included.

(2) This might be an indication of the sensitivity of the equity measure (as measured by the coefficient of variation) for the set of cities selected and the operationalization of accessibility.

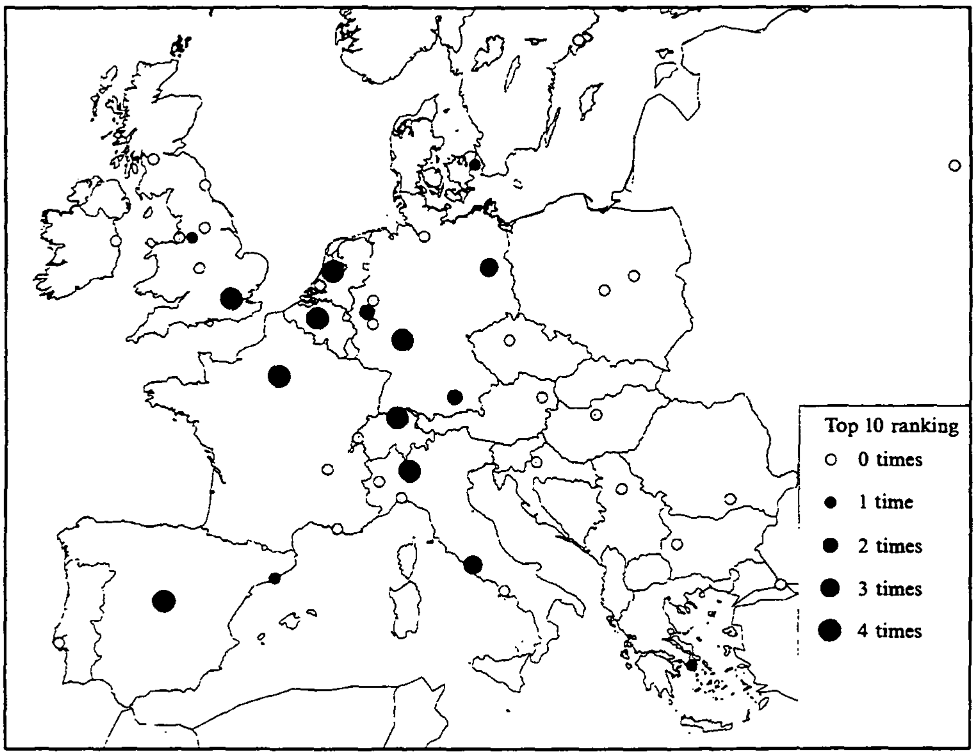


Figure 2. The best accessible area via the air network (as a summation of the ten best accessible cities of each ranking).

When we analyze the correlations between the rankings (table 6), then it is again clear the rankings show strong similarities. Even the rather crude ranking of DA (based on a 6-point scale) correlates closely to the other rankings.

The importance of transfer flights is again obvious if attention is paid to the equity in accessibility. The BR ranking without those flights is clearly less evenly distributed than the BR ranking with the transfer flights.

3.3.3 *Rail traffic*

Accessibility via rail traffic is interesting because it is undergoing a big improvement with the construction of high-speed rail lines. We will return to this in section 3.3.4. Here, however, we will concentrate on the existing network (including the high-speed rail link between Paris and Lyon which was already operational at the time of these studies).

The best accessible area by rail in Europe (see figure 3 and table 3, columns D, K, M, O, and Q) is to a large extent similar to that for the multimodal case. Only the spurs are slightly different. The spur towards Switzerland and Spain is missing, Lyon appears to be important, and also the spur into the Midlands is more strongly accentuated.

A closer look into the scores of the rankings by the different approaches shows that compared with the range of the potential accessibility rankings (BR and SW) the range of scores in the daily accessibility ranking is greater. The same holds true for the ranking of the CA study, in which the number of trains that leave for a destination is used as a weighting factor.

According to table 7 we can see that the rankings correlate rather well, only the correlations between GU, on the one hand, and BR and CA, on the other hand, are rather low. The broader range in scores of the daily accessibility rankings and of the

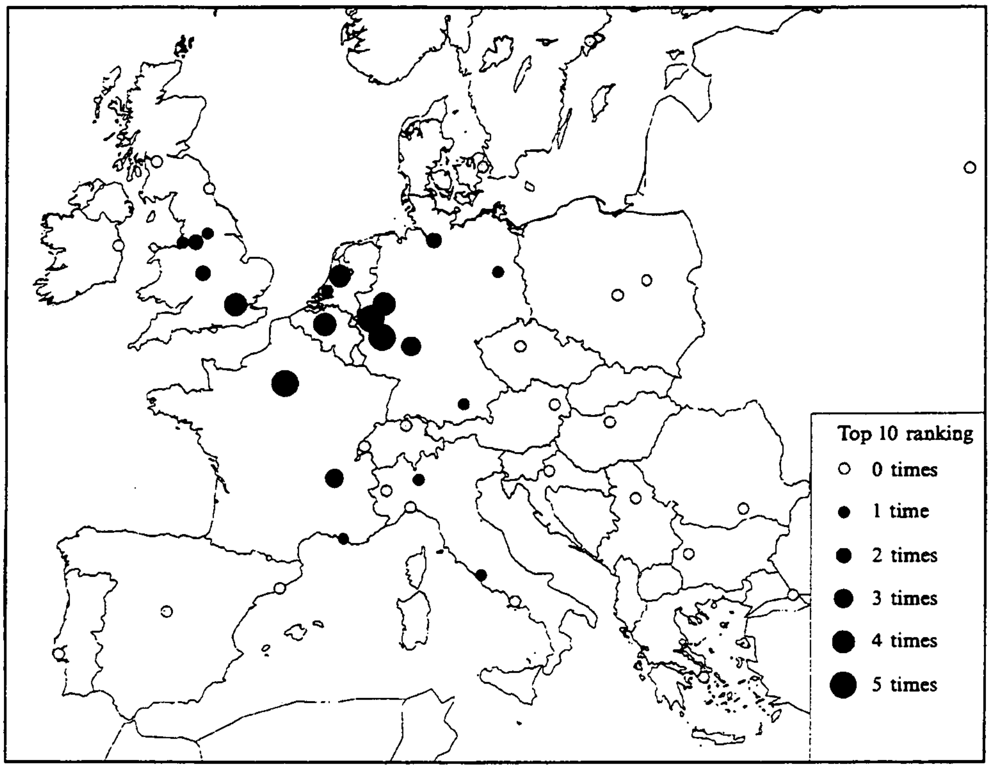


Figure 3. The best accessible area via the actual rail network (as a summation of the ten best accessible cities of each ranking).

Table 7. Correlation coefficients for rail traffic accessibility indices.

	Study					Cov
	BR	Cattan	SW[a]	SW[b]	GU	
BR		0.765	0.845	0.826	0.580	0.281
Cattan	$n = 30$		0.747	0.657	0.584	0.702
SW[a]	$n = 42$	$n = 32$		0.894	0.766	0.258
SW[b]	$n = 42$	$n = 32$	$n = 45$		0.729	0.640
GU	$n = 30$	$n = 29$	$n = 31$	$n = 31$		0.311

Note: BR, Bruinsma and Rietveld; SW, Spiekermann and Wegener; GU, Gutièrrez et al; Cov, coefficient of variation.
[a] Potential accessibility. [b] Daily accessibility.

CA ranking compared with the potential accessibility rankings are reflected in the coefficient of variation of the scores. The potential accessibility rankings result in a more equally distributed accessibility over Europe.

3.3.4 *High-speed train network*

The impact of the construction of the high-speed train (HST) network in northwestern Europe is an improvement of the accessibility of the cities which were already best accessible by the rail network (see table 3, columns F, N, P, and R). The best accessible area has narrowed to London, the Benelux cities, the Ruhr area, Frankfurt, Lyon, and Paris with only small spurs to Northern Italy and the Midlands (see figure 4).

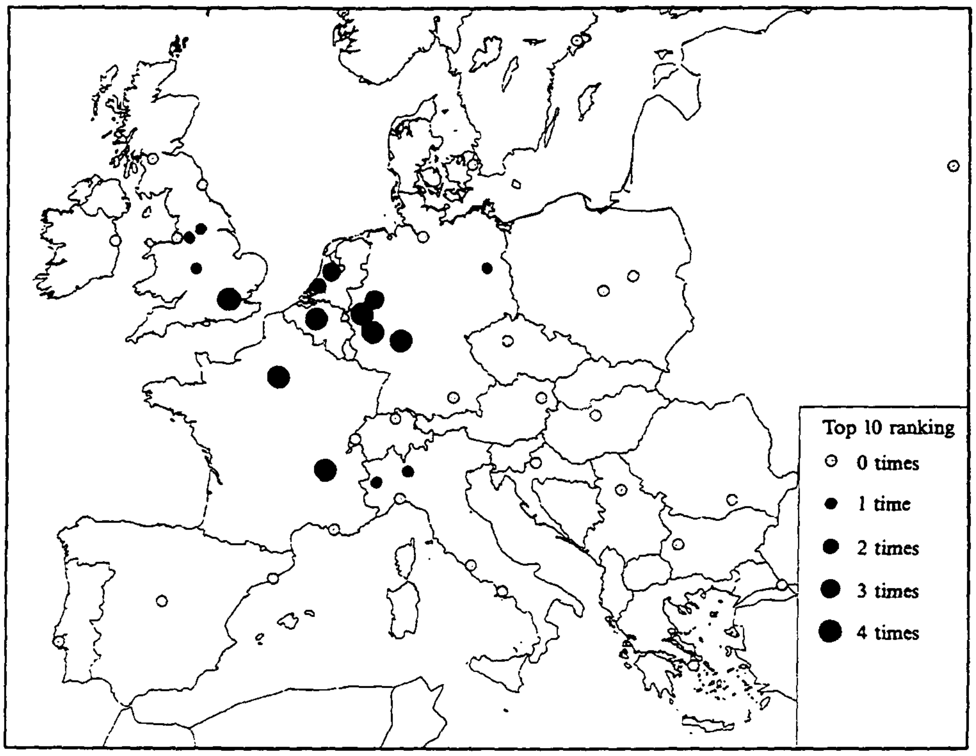


Figure 4. The best accessible area via the rail network after the construction of the high-speed lines (as a summation of the ten best accessible cities of each ranking).

Table 8. Correlation coefficients and coefficients of variation for rail traffic accessibility indices in 2010.

	Study				Cov	+/−	Cor.
	BR	SW[a]	SW[b]	GU			
BR		0.812	0.840	0.867	0.319	+0.038	0.955
SW[a]	$n = 42$		0.929	0.851	0.245	−0.013	0.941
SW[b]	$n = 42$	$n = 45$		0.840	0.662	+0.022	0.929
GU	$n = 30$	$n = 31$	$n = 31$		0.315	+0.004	0.953

Note: BR, Bruinsma and Rietveld; SW, Spiekermann and Wegener; GU, Gutiérrez et al; Cov, coefficient of variation 1993; +/−, change in cov 1993–2010; Cor., correlation index 1993–2010.
[a] Potential accessibility. [b] Daily accessibility.

The accessibility rankings for the future rail network are all closely correlated (see table 8). However, more important is the change in the dispersion of accessibility over Europe. As might be expected we can see the tendency for a decrease in equity as the accessibility of the already best accessible cities improves.[(3)]

The changes in the coefficient of variation are relatively low and the accessibility rankings of the existing network correlate highly with the future network. So, both from an equity point of view and from a competing accessibility viewpoint, the average

[(3)] Note that in section 2.5 we found that an improvement in a link between a large and a small city leads to an accessibility advantage for the small city. An important difference with the proposed HST network is that it often connects cities which *both* already have a high level of accessibility by rail.

consequences of the construction of the high-speed rail network in the northwestern part of Europe are limited.

Two points must be emphasized here. First, for individual cities the consequences may be considerable. Second, in the tables we present only relative positions. The absolute change in accessibility (and travel times) of European cities owing to high-speed lines is substantial. The average accessibility increases by 18.6% in the BR study; by 34.5% (potential) and 63.8% (daily) in the SW study; and—depending on how one measures the increase—by 53.2% (in travel time) or even 113.8% (in accessibility scores) in the GU study as a consequence of the construction of the high-speed network.

3.3.5 *Comparison between modes*

Until now the comparison of the accessibility indices concerned the same type of infrastructure. Before we compare the intermodal indices an hypothesis can be formulated. First, one might expect that air traffic indices (especially when transfer flights are excluded) will lead to low correlations with rail traffic indices, as there are relatively few short-distance air connections. On those short distances rail performance is high because of the fast heart-to-heart connections between cities. The same holds true for road infrastructure. The only study in which the accessibility of rail and road is measured (BR) shows a relatively high correlation between rail and road accessibility (0.953). This hypothesis is tested in table 9. Indeed the correlations between the air and the rail modes are low. With exception of the correlation between CA rail and CA air, all correlation coefficients are below the overall average of 0.635.

Table 9. Correlation coefficients of air mode indices with rail indices.

	Study				
	BR (rail)	CA (rail)	SW (potential)	SW (daily)	GU (rail)
BR[a]	0.320	0.467	0.381	0.277	0.158
BR[b]	0.570	0.563	0.581	0.437	0.319
DATAR[c]	0.089	0.298	0.184	0.130	0.084
Cattan[c]	0.586	0.720	0.542	0.417	0.352

Note: BR, Bruinsma and Rietveld; CA, Cattan; GU, Gutiérrez et al.
[a] Transfer flights excluded. [b] Transfer flights included. [c] Air traffic.

Following the above line of thought, we can determine that the fastest travel mode will contain train or car modes for short-distance connections and the air mode for the longer distances. For instance, in the fastest travel mode index of the BR study airplane is the fastest travel mode for 93% of all connections, car for 5%, and train for 2%. The impact of those 7% nonairplane connections is shown in table 4. The correlation between the fastest travel model index and both air traffic indices is relatively low (0.377 transfer flights excluded, 0.603 transfer flights included) compared with the correlation with the index of rail traffic (0.946). This strong impact of only 7% of the connections by car and train is to a great extent the effect of the distance-decay factor which is incorporated in the BR gravity model. Short-distance connections receive heavy weights. Without such a distance-decay factor the impact of modes for the short-distance connections might be quite different. In table 10 the correlations are given of the fastest travel mode indices with, on the one hand, the air traffic indices and, on the other, the rail traffic indices.

In this table it is clearly shown that there are higher correlations between all the fastest travel mode indices with the BR index in which transfer flights are included than with the BR index without transfer flights. A similar conclusion can be drawn

64

Table 10. Correlation coefficients of fastest travel mode indices with air and rail indices.

Fastest travel mode	Air traffic indices				Rail traffic indices				
	BR[a]	BR[b]	DA	CA	BR	CA	SW[c]	SW[d]	GU
BR	0.377	0.603	0.179	0.619	0.946	0.678	0.784	0.706	0.640
EL (inbound)	0.576	0.738	0.584	0.549	0.693	0.549	0.710	0.655	0.551
EL (outbound)	0.630	0.749	0.560	0.512	0.656	0.512	0.686	0.566	0.541
DA	0.618	0.713	0.638	0.569	0.354	0.569	0.228	0.148	0.195
HB (markets)	0.829	0.851	0.702	0.915	0.773	0.733	0.640	0.636	0.530
HB (links)	0.806	0.840	0.665	0.933	0.700	0.718	0.544	0.531	0.546

Note: BR, Bruinsma and Rietveld; EL, Erlandsson and Lindell; DA, DATAR; CA, Cattan; HB, Healey and Baker; SW, Spiekermann and Wegener; GU, Gutiérrez et al.
[a] Transfer flights excluded. [b] Transfer flights included. [c] Potential. [d] Daily.

with regard to the higher correlations between the fastest travel model indices and the SW potential accessibility rail index compared with the SW daily accessibility rail index.

Most apparent in this table is that in the studies in which the fastest travel mode indices are measured by quantitative approaches (BR and both EL indices) the correlations tend to be higher with rail traffic indices. However, in studies in which the fastest travel mode is measured in a more qualitative manner (DA and both HB indices) the correlations with the air traffic indices tend to be higher. It may be concluded that the models show the objective impact of rail transport on the short and medium distance connections. However, in the perception of experts and senior executives of companies the accessibility of European cities can to a large extent be explained by air traffic. The impact of rail traffic on short and medium distance connections seems to be neglected.

A last step is to compare the intermodal correlations with the intramodal correlations. In table 4 the correlations between indices of the same type of infrastructure (intramodal) are printed bold. It appears that in general the intramodal correlations are higher than the intermodal correlations. The average of the intramodal correlations is 0.773 compared with the intermodal average of 0.558 (the overall average is 0.635).

In table 11 it is shown that all the average correlations of the intramodal comparisons are above the overall average. Only one intermodal average correlation is above this overall average.

Table 11. The average correlation of intramodal and intermodal comparisons.

Intramodal	0.773	*Intermodal*	0.558
Fastest travel mode	0.696	Rail – air	0.374
Air travel	0.833	Rail – fastest mode	0.656
Rail travel	0.739	Air – fastest mode	0.591
Rail travel 2010	0.857		
Rail – rail 2010 travel	0.945	Overall average	0.635

A last comparison concerns the equity aspect of accessibility measured by the coefficient of variation. All the equity measures given the type of infrastructure and the operationalization concept are shown in table 12. Not much can be said with regard to the type of infrastructure; one finds relatively high inequality indicators as well as low inequality indicators within the same type of infrastructure.

However, the type of operationalization seems to be important. 'Simple' types of operationalization tend to lead to high inequality indicators. For instance, the daily accessibility concept (acc9) leads to higher inequality in accessibility than the potential accessibility concept (acc8). Another factor which might lead to low equity

65

Table 12. Coefficient of variation for various types of infrastructure and operationalization concepts.

	acc1/acc2	acc6		acc8		acc9		acc11
	DA	GU	CA	BR[a]	SW	SW	EL[a]	HB[a]
Fastest travel	0.366			0.195			0.584; 0.628	1.211; 1.417
Air	0.464		0.702	0.353; 0.165				
Rail		0.311	0.909	0.281	0.258	0.640		
High-speed trains		0.315		0.319	0.245	0.662		

[a] The column contains two figures because two different results were available.

indicators is the fine tuning within an operationalization concept. For instance, the inequality indicator of GU, who used in their concept 4000 nodes and 7000 arcs linking these nodes, is lower compared with the indicator of CA, who used a sample of ninety cities. A similar impact might be expected if HB had asked the managers to mention more than the three best accessible cities. If they had been asked to mention five cities one might expect that the coefficient of variation would decrease. The difference in equity between GU and CA might not only be explained by the fine tuning in the choice of cities and links, but also by different weighting procedures. GU weight by GDP, whereas CA weights by the number of trains departing for each destination.

4 Conclusion

In this paper we give a brief overview of different approaches used to measure the accessibility of cities. In practice, a broad range of approaches (qualitative and quantitative) is used.

Four choices are of major importance in the measurement of accessibility:
(a) the demarcation of the area under research;
(b) the selection of cities;
(c) the operationalization concept; and
(d) the choice of the type of infrastructure.

Considering the operationalization of accessibility, additional choices have to be made about weighting procedures (mass of cities, travel time and/or costs), the frequencies of flights and trains and the parameter in the spatial interaction models (for example, the hour tolerance in case of the daily accessibility concept).

In this paper the results of seven studies on the accessibility of cities within Europe are compared. The comparison is focused on two aspects. The comparison of the rankings of the cities as a result of the different conceptualizations and the type of infrastructure involved; and the equity in accessibility given the conceptualization and the type of infrastructure. By correlation analysis the similarity of rankings can be addressed. It appears that, although different conceptualizations indeed lead to differences in rankings of cities, a clear tendency can be observed that given a certain mode the correlations are rather high (see table 11 for the average intramodal versus intermodal correlation coefficients). When one is interested in a *ranking* of cities in terms of accessibility the choice of the accessibility concept tends to be less important than the choice of the type(s) of infrastructure to be considered. An interesting result is that in the perception of managers and experts the accessibility by air appears to be the most important element in the overall accessibility of cities, whereas quantitative approaches emphasize short-distance connections in which rail infrastructure and road infrastructure are the most important modes.

If one is interested in *inequalities* in accessibility among cities, the operationalization appears to have a much larger impact compared with the case when one studies orders in rankings per se (see, for instance, table 12). Thus when issues of 'cohesion' in Europe are studied by means of accessibility indicators, analysts must be aware that their results depend to a considerable extent on the specific concepts used.

Acknowledgements. The authors wish to thank Nadine Cattan, DATAR, Ulf Erlandsson, Klaus Spiekermann, and Michael Wegener for making data available. Without their cooperation the analytical part of this study would not have been possible.

References

Bröcker J, 1989, "How to eliminate certain defects of the potential formula" *Environment and Planning A* **21** 817 – 830

Bruinsma F R, Rietveld P, 1993, "Urban agglomerations in European infrastructure networks" *Urban Studies* **30** 919 – 934

Cattan N, 1992, "Air and rail accessibilities and attractivities of European metropolis", in *Selected Proceedings of the 6th World Conference on Transport Research* Ed. A Bonnafous, LET Université Lumière Lyon, Lyon, pp 43 – 54

DATAR, 1989 *Les Villes "Européennes"* (RECLUS, Montpellier)

Erlandsson U, Lindell C, 1993 *Svenska Regioners Kontakt- och Resemöj-Ligheter i Europa 1992* Rapporter och Notiser 119, Institutionen för kultur-geografi och ekonomisk geografi vid Lunds Universitet, Lund.

Eurostat, 1997 *Regions Statistical Yearbook 1996* (Eurostat, Luxembourg)

Fotheringham A S, O'Kelly M E, 1989 *Spatial Interaction Models* (Kluwer, Dordrecht)

Frost M E, Spence N A, 1995, "The rediscovery of accessibility and economic potential: the critical issue of self-potential" *Environment and Planning A* **27** 1833 – 1848

Gutiérrez J, Conzález R, Gómez G, 1996, "The European high-speed train network: predicted effects on accessibility patterns" *Journal of Transport Geography* **4** 227 – 238

Hamerslag R, 1980, "Spatial development, developments in traffic and transportation and changes in the transportation system", in *Changes in the Field of Transportation Studies: Essays on the Progress of Theory in Relation to Policymaking. In Honour of Professor J P B Tissot van Patot* Eds J B Polak, J B van der Kemp (Martinus Nijhoff, Dordrecht) pp 61 – 79

Hansen W G, 1959, "How accessibility shapes land-use" *Journal of the American Institute of Planners* **25** 73 – 76

Healey and Baker, 1994 *European Real Estate Monitor; Executive Summary* Healey and Baker, 29 St George Street, London W1R 9RE

Keeble D, Owens P L, Thompson C, 1982, "Regional accessibility and economic potential in the European Community" *Regional Studies* **16** 419 – 432

Krugman P, 1991 *Geography and Trade* (MIT Press, Cambridge, MA)

Martellato D, Nijkamp P, Reggiani A, 1998, "Measurement and measures of network accessibility: economic perspectives", in *European Network Developments and Policies* Eds K Button, P Nijkamp, H Priemus (Edward Elgar, Cheltenham) forthcoming

Rietveld P, 1989, "Infrastructure and regional development" *The Annals of Regional Science* **23** 255 – 274

Spiekermann K, Wegener M, 1996, "Trans-European networks and unequal accessibility in Europe" *European Journal of Regional Development* **4** 35 – 42

Sheffi Y, 1985 *Urban Transportation Networks* (Prentice-Hall, London)

Vickerman R, Spiekermann K, Wegener M, 1998, "Accessibility and economic development in Europe" *Regional Studies* **32** forthcoming

Wilson A G, 1982 *Transport Location and Spatial Systems* School of Geography, University of Leeds, Leeds

67