Cybergeo

Systèmes, Modélisation, Géostatistiques

Colette CAUVIN

A systemic approach to transport accessibility. A methodology developed in Strasbourg: 1982-2002

Une approche systémique de l'accessibilité. Une méthodologie développée à Strasbourg 1982-2002

article 311

ABSTRACT/RÉSUMÉ

In this article, the author presents a new methodology to study the concept of accessibility. The approach was created by the "Image et Ville" laboratory in Strasbourg between 1982 and 2002 and led to the development of specific softwares. Two definitions of accessibility —one theoretical, the other operational —, are given, but the main emphasis of the article is laid on methodology. First, the author explains the basic principles and rules underlying the construction of a database designed for the capture of information on travel times and stay times, for any given means of transport. Next, the different processing procedures, which always associate statistics, modelling and visualisation, are described. Three methods to study system accessibility, based on a global data, are suggested: marginal indices and isopleth or piezopleth maps for potential accessibility, correspondence analysis and point symbol maps with envelopes in order to determine a hierarchy of locations, in terms of accessibility, multidimensional scaling and bidimensional regression in order to "reveal" multipolar functional spaces. Subsystems accessibility studies the accessibility of specific places either through classical procedures such as unipolar isopleth maps or thanks to new methods such as isodistance maps or the construction of unipolar functional spaces. The purpose of this article, illustrated with images of Luxembourg, is purely methodological and no commented geographical examples are given. Nonetheless, this approach (summed up in a general diagram) has been applied to areas ranging from Europe to the city of Strasbourg — giving rise to numerous publications demonstrating its validity on a wide range of scales.

Cet article présente une nouvelle approche méthodologique du concept d'accessibilité, élaborée au laboratoire Image et Ville de Strasbourg entre 1982 et 2002, qui a conduit à développer des logiciels spécifiques. Après avoir privilégié deux définitions de l'accessibilité, l'une théorique et l'autre opérationnelle, l'accent est mis sur les méthodes utilisées. Dans un premier temps, sont explicités les principes et règles fondamentaux pour constituer une base de données adaptée à la collecte des temps de parcours et des temps de séjour quel que soit le mode de locomotion. Dans une seconde étape, les traitements sont exposés, avec comme particularité, de toujours associer statistiques, modélisation et visualisation. L'accessibilité de système est abordée en proposant trois ensembles de méthodes appréhendant les données dans leur globalité : indices marginaux et cartes isoplèthes ou piézoplèthes pour l'accessibilité potentielle, analyse factorielle des correspondances et représentation ponctuelle avec enveloppes pour dégager une hiérarchie des lieux en termes d'accès, analyse multidimensionnelle des proximités et régression bidimensionnelle pour "révéler" les espaces fonctionnels multipolaires. Quant à l'accessibilité de sous-système, elle permet d'appréhender celle de lieux caractéristiques soit par des procédures classiques comme les cartes isoplèthes unipolaires, soit par des méthodes plus originales comme les cartes d'iso-distances ou la construction d'espaces fonctionnels unipolaires. Cet exposé, illustré par des images du Luxembourg, est purement "méthodologique "; aucun exemple géographique commenté ne l'accompagne, mais la démarche, concrétisée par un schéma général, a été appliquée au cours du temps à de nombreux espaces allant de l'ensemble de l'Europe à la ville de Strasbourg, qui ont fait l'objet de nombreuses publications, montrant sa validité à des échelles très diverses.

PLAN

TEXTE

1 A great deal of research on accessibility has been conducted in Strasbourg **1** since the early 1980s. Though these studies were initially based on the research of A. Pred and G. Tornqvist (1973, 1974), their number and the diversity of scales on which they were performed has led researchers to develop an original methodology, whose statistical and cartographic results are both stable and comparable on all levels: international (Western Europe, Eastern Europe, etc.), national (France, South Korea, etc.), regional (e.g Upper Rhine Graben), or on the city level (e.g. Strasbourg, Luxembourg). After a reminder of basic definitions, we will briefly present the different stages of our research, as well as the methods and software we used in our approach **2**.

2 We refer to the two following definitions of accessibility, which we justified in a report sent to DATAR **3** in 1992 **4**, and in a book published in 1998 (Reymond H. *et al*.):

3 *Theoretical and processual definition :*

4 *Accessibility is a permanent construction effort aimed at establishing regular and easy communication (one can also speak of "degree of facility") between places of supply or wealth, socially recognized as such created and maintained by societies aware of their necessity and of the fact that they are not symmetrically distributed in space.*

5 *Operational and structural definition :*

6 *Accessibility is the measurable quantity of spatial distance between the place where one wishes to go and the place where one is, depending on the chosen means of transport. It is the minimal time distance necessary to link together two places thanks to a means of transport, via a given itinerary, and taking into account the notion of comfort.*

7 These definitions consider places — cities, crossroads, etc.— as the nodes of a network, and as such they must take into account not the administrative divisions, but the functional partitions of the territories in which these places are located. The first definition is essential from a conceptual angle, while the second enables us to conceive and develop databases adapted to a given means of transport. Part 1 presents the underlying principles of the databases; parts 2 and 3 describe the local and global approaches; in the conclusion, we will provide a diagram summing up our approach.

Creating the datbase

8 The notion of accessibility implies a circumscribed area which includes places considered as points in this space; it is measured in terms of space-time **5**, that is time intervals between any two places. In order to obtain comparable and spatialized data, it is necessary to have a set of geographic references (a map) and thematic references (reference distances, in this case orthodromes).

Reference database

9 This base includes spatial and thematic references.

Spatial base

10 This is the main map with its georeferenced anchor points; it must include at least an outline, an envelope of the considered area, and the points representing the selected places. Additional illustrations can be added as well: main roads, wooded areas, built-up areas, etc. (see figure 1). This map as a closed shape must be digitalized in vector mode.

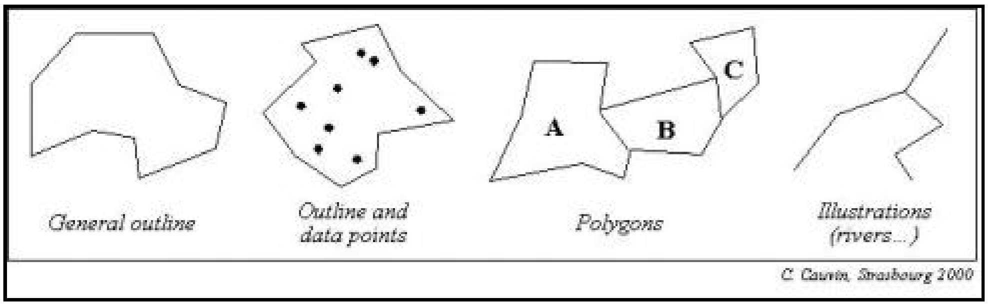

Figure 1. Geographical base and digitalisation
The shape and the statistical analysis of the spatial distribution of the points can be verified with the software Geocart.

Thematic base : reference distances

11 The more commonly used distance reference is orthodromes **6**, the shortest distances between two points on a geoïd's surface, i.e. considering the curvature of the surface of the earth. To measure this distance, one must first determine the geographic coordinates of each of the places, that is their longitudes and latitudes. Then these coordinates must be entered into a file, as a table containing n rows (=places) and 2 columns, one for latitudes, the other for longitudes; this presentation is shown in figure 2.

Latitude	Longitude
44.12	0.27
43.56	2.09
43.54	2.18
47.28	-0.33
45.39	0.09
45.54	6.07
44.56	2.27
47.40	3.24
43.57	4.49
47.15	6.02
F	

C. Cauvin Strasbourg 2000

Figure 2. Table of orthodromes

12 Based on this table, one can compute orthodromes thanks to specifically adapted software, such as "Orthodromie".

13 The reference distances are computed with the software Orthodromie

14 The various distance-time measurements obtained for each means of transport will be compared to these reference distances.

Accessibility databases

15 When building accessibility databases, the capture of information in connection with the underlying hypotheses must follow very strict rules. However, schedules can lead to considerable variations; for this reason, we established a distinction between the construction of databases corresponding to

movements governed by time-tables and those corresponding to free movement.

Basic principles

16 The general principle is the following: "Given all possible ways of linking point A to point B, the best access time is the time taken to cover the shortest journey". However, this principle is not sufficient if accessibility is considered within a larger context, that is including the duration of stay **7**. In that case, other terms must be defined, as shown in figure 3.

- ***Transit time, Ttdr****,* is the total time spent by a person outside of his/her home between the time of departure from residence (or any other place considered as a point of departure) and time of return:
  Ttdr = time of return—time of departure
- **Access-time : At** is the time taken to go somewhere added to the time taken to return. It corresponds to the time needed to travel from one's place of departure to one's destination, and from the destination point back to the departure point. Thus it corresponds to the time spent travelling, excluding the time spent in the place of destination. Access time includes time spent getting to airports, train stations, bus stations **8**, etc. in both directions, checking in (if necessary), waiting for transfers, and includes nights if the trip includes spending the night in a place other than one's destination.
  At = At there+ At back
  or
  At = Att+ Atb
- ***Travel-time : Tt*** is the time spent actively travelling, that is the time during which the chosen means of transport is actually moving. It corresponds to access time minus all forms of waiting time.
  Tt = Tt there + Tt back = Ttt + Ttb
  or
  Tt = At — (all waiting times)

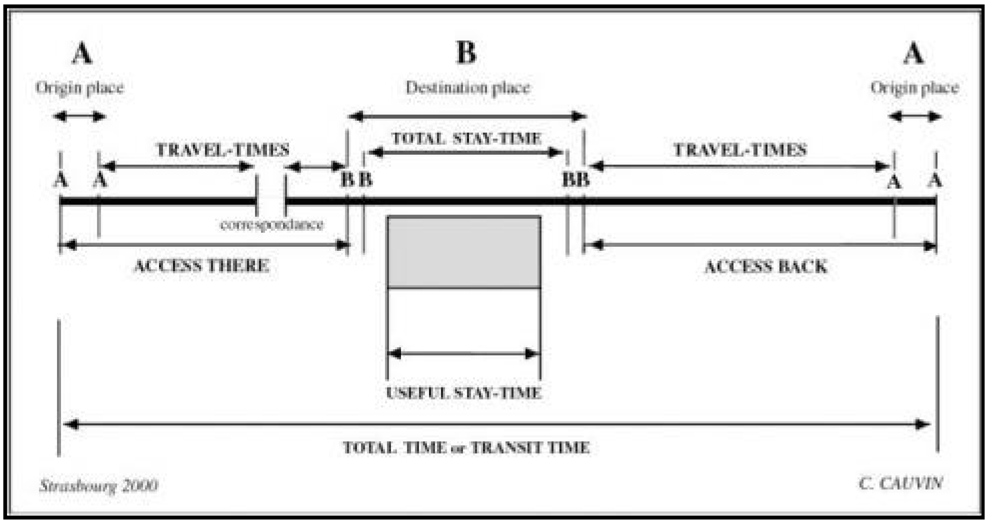

Figure 3. Accessibility components

- ***Stay-time (duration of stay)*** This time is more complex, and must be divided into total time of stay and useful stay time.
  - ***Total stay-time : TST*** is the amount of time actually spent by a person in his/her place of destination B. It is obtained by calculating the difference between the time of departure from B and the time of arrival in B. But depending on when these times occur during the day, the time of stay can be considered useful or not; for this reason a second notion was defined, that of "useful time of stay".
    TST = Tt — At

- ***The useful stay-time, UST,*** is the amount of time during which a person is actually involved in various activities and exchanges. Depending on arrival time, part of the time spent in one's destination can be considered to be not useful in the context of one's scheduled activities. The parameters are defined according to the hypotheses of the study, and the time slots considered useful or not useful can vary.

- **The time slots, TS**, are the exact times during which the useful duration of stay can be determined. For example, a useful duration of stay lasting one hour between 9 and 10 AM will not be considered in the same way as a the same duration of one hour situated between 1 and 2 PM.

17 The number of rules for elaborating databases has thus increased; these can be stated as follows:

- minimize total transit time, Ttdr
- minimize access time there and back, Att, Atb
- consequently reduce the difference between access time and travel time, At, Tt
- maximize the useful stay time,UST
- minimize the difference between total stay time, TST, and useful time UST.

18 These rules make it possible to establish priorities when computing the time needed to link each pair of points, but the construction of each database depends on the means of transport and on whether or not it is governed by a schedule.

Databases without schedules

19 In the case of trips made in vehicles which are not tied to schedules (private car, bicycle, etc.), each trip is divided into a sequence of sections (see figure 4), each of them corresponding to a given distance in kilometres and an average speed, weighted according to the type of landscape, crossroads, cities crossed, etc.

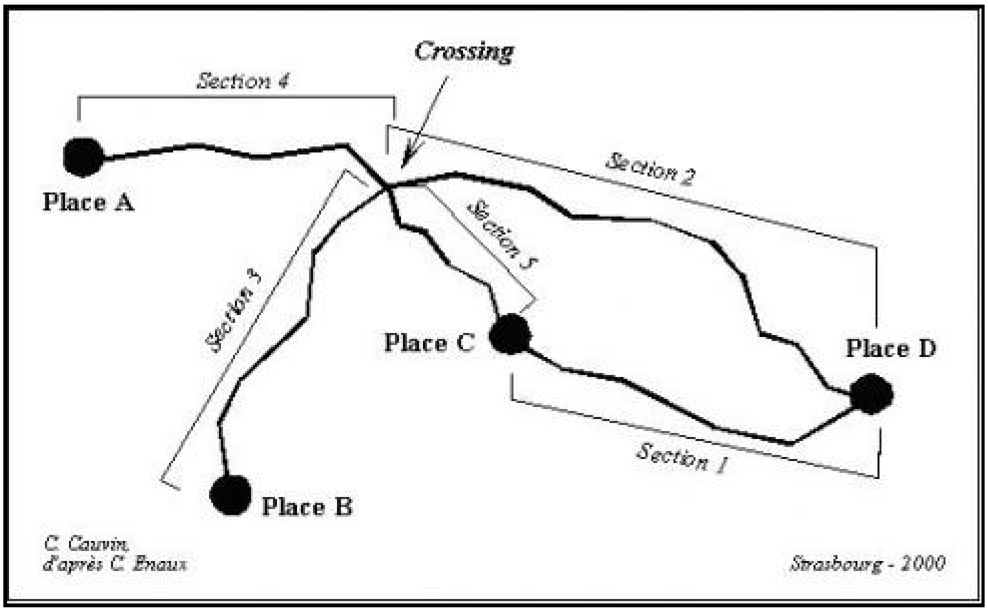

Figure 4. Notion of road section

20 This information is entered into a table, each row corresponding to a link, and each column corresponding to a section. The access time is the sum of the distances in kilometres weighted by the corresponding speeds. Some softwares provide additional information, but they are often insufficient or incomplete, depending on the level of precision sought or on the hypotheses. The collecting of data can be facilitated by using a GPS.

Database with schedules

21 These databases are more difficult to establish. Usually, a choice is made concerning the time of departure and arrival. Whether the person is travelling by train, by bus or by airplane, one must determine the shortest possible trip while taking into account constraints linked to departure and arrival times and avoiding too many transfers when there is no direct connection. The database is thus made up of a sequence of times indicating the changes in the "actions". For the time base, different countries have developed various types of software, but a great deal of personal input on the part of the person building the base is still necessary.

22 Once these databases have been elaborated, it is necessary to transform the information into accessibility matrices.

From database to accessibility matrices

23 The software Acced is perfectly adapted to this purpose: it instantly converts information into access time from one location to another, the rows and columns of the matrix corresponding to the chosen locations. It can also calculate, depending on need, other times and other matrices: waiting times, transfers, trips etc.

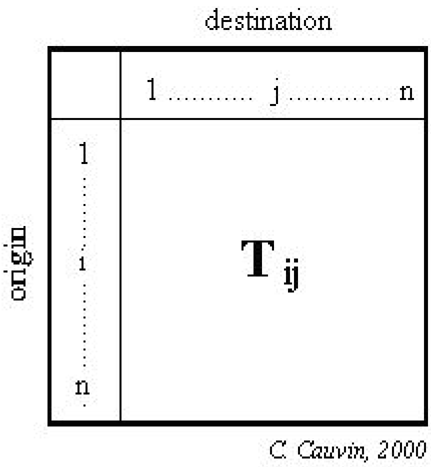

Figure 5. Access-time matrix

24 To be usable, the tables of the bases must be built according to the precise instructions for use provided with the software.

25 *To establish time matrices, use the software Acced.*

26 The accessibility matrices can be symmetrical or not, depending on the chosen means of transport; for instance, for trains and planes, they are usually assymetrical. "Intercity" roads can be considered symmetrical, but within cities, roadways are rarely symmetrical: the itineraries from A to B or B to A in a city are rarely symmetrical, due to one-way streets or traffic circles. In some cases it may be necessary to work with a symmetrical matrix. In order to do this, one must first verify the strength of the asymmetry by calculating, for example, an asymmetry index (Tij/Tji) and studying the statistical variation of this index. If the variation is weak, then the matrix can be made symmetrical by calculating the half-sum of this matrix and of its transpose. These computations can be done with *Calmat* software.

27 *To obtain asymmetry indices or symmetrize a matrix, use Calmat.*

28 Once the matrix has been obtained, it is possible to analyse the data, in other words study the accessibility of the space under consideration. There are many ways of processing the data: they are classified here according to two large categories, depending on whether they concern the entire matrix or only one row or column of the matrix. In the first case, we may speak of system accessibility or global accessibility (total matrix), and in the second case of sub-system accessibility or local accessibility (a row or column of the matrix), as shown in figure 6.

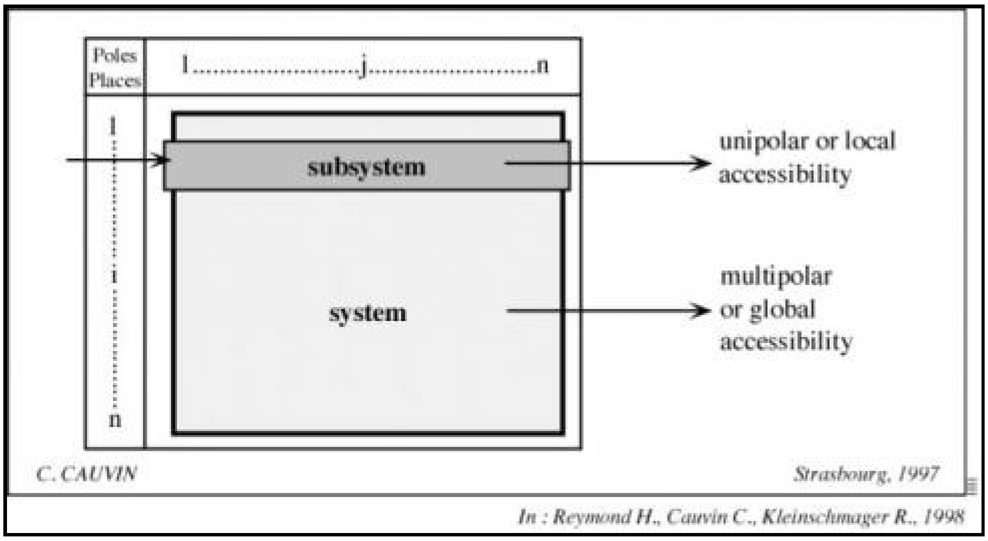

Figure 6. System and subsystem accessibility

29 Both types of processing have been considered. We will first present the system accessibility-type of processing.

System or global accessibility

30 Three groups of methods can be considered depending on the elements included in the accessibility matrix. We can summarize the information, transform the available times into frequencies or process the entire matrix (see figure 7); each method brings new, additional information which completes the rest.

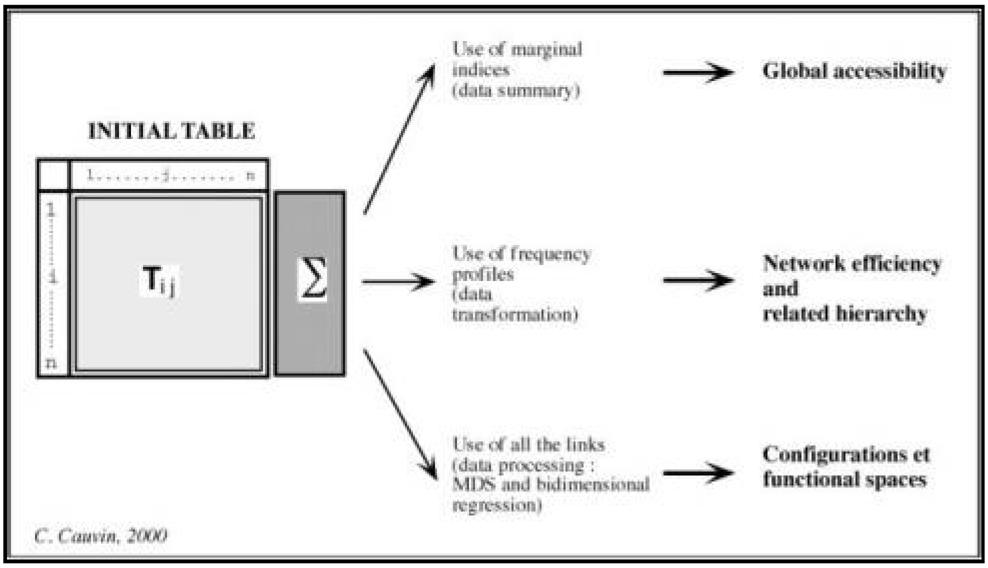

Figure 7. System accessibility methods

Global accessibility

31 On the basis of the accessibility matrix, one calculates indices summing up all the information; one thus obtains three indices, often used in the field of transport (see figure 8):

32 - the potential accessibility index, which is the sum of times in rows or columns, a typical transport index (Lowe, Moryadas, 1975)

33 - the centrality index, the sum of the times in rows or columns, weighted by the double sum of the matrix; this a-dimensional index is included between 0 and 1.

34 - the dispersion index, double sum of the matrix weighted by the sums of times in rows or columns.

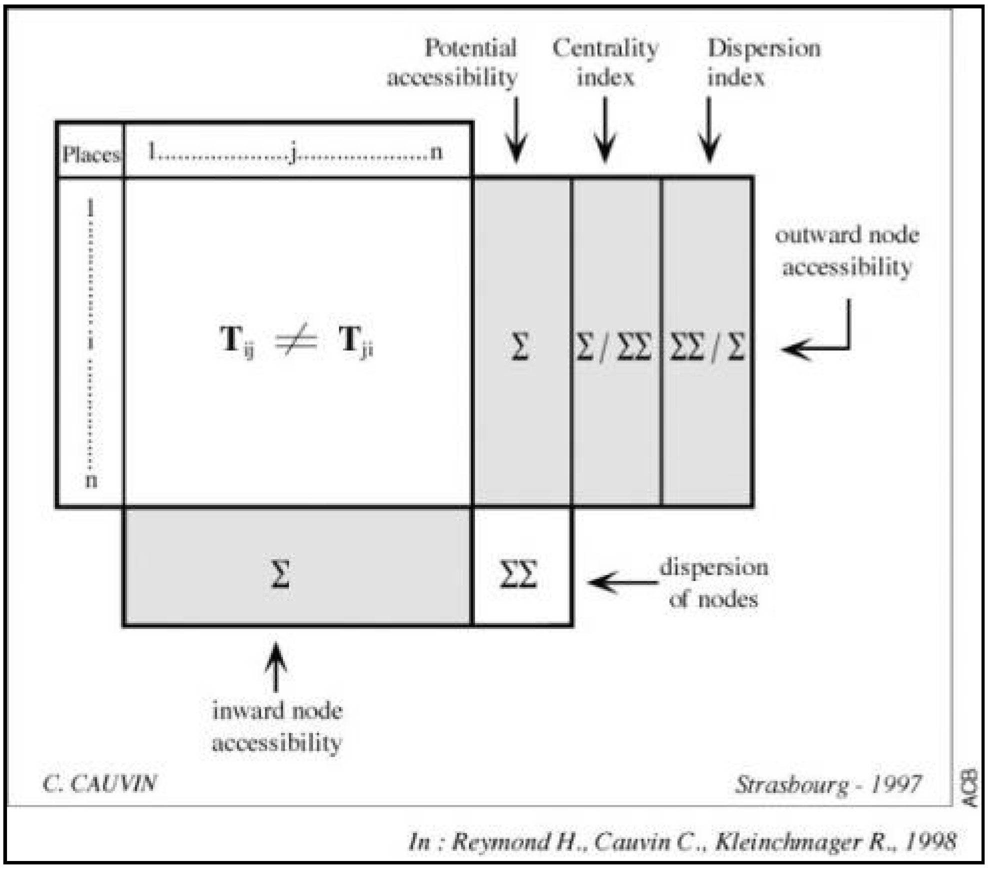

Figure 8. Commonly used accessibility indices

35 *These indices can be computed with Calmat.*

36 After the statistical analysis, these indices can then be mapped as isolines (isopleth map) thanks to cartography software or a geographical information system with an interpolation function. The results are easy to understand and provide an initial image of network accessibility.

37 However, another mapping system can also be used to visualize potential accessibility: the piezopleth map. In this method, developed by C. Schneider (Cauvin, Schneider, 1989), the different thematic values are not represented through distinct grey areas; the variable is considered as having an impact on the geographic surface in the same way as a force will alter a given material. This material, and consequently the geographic surface, expands or contracts under the impact of this force; thus the surface variations of the map's elementary units express the impact of the phenomenon (see figure 9). This method, which is seldom used, was developed in Strasbourg, along with the programme that goes along with it, called *STRUCT*; its present version is called *Anaplaste.*

38 In order to obtain a piezopleth map, use the software Anaplaste.

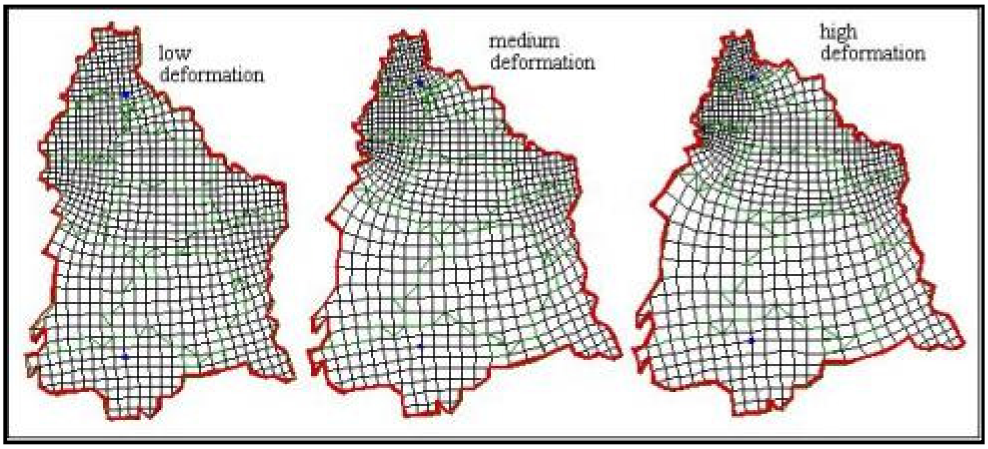

Figure 9. Potential accessibility and piezopleth map

C. Cauvin, 2000

Accessibility profiles and hierarchy of places

39 The second approach reveals a hierarchy of places, in terms of accessibility. The focus is no longer exact time but significant time — or accessibility — spans The times included in the matrix are converted into frequencies; to do this, one first defines a time span, for example every ten minutes or every hour, depending on the type of transport and the area under consideration. Then the number of places accessible from each place, for each time span, is determined. In the new table, the rows indicate places, the columns indicate time spans and the cells show the frequencies (see figure 10). This operation can be performed with *Calmat*.

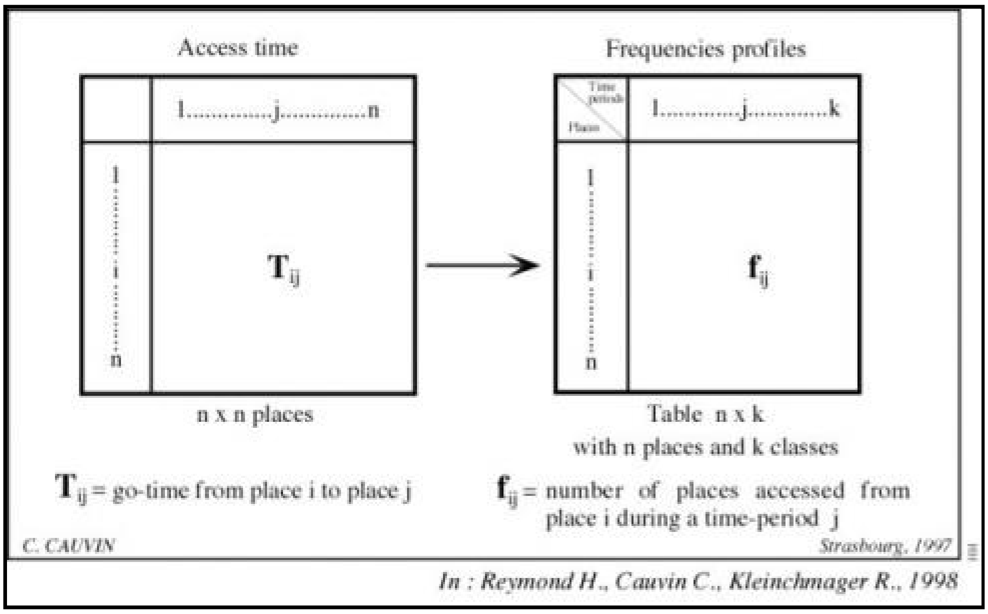

Figure 10. Table of accessibility frequency profiles

40 *To obtain frequency profiles, use Calmat.*

41 With this table, one can build frequency profiles with the time spans on the abscissa and the frequencies on the ordinate. For the comparison of profiles and the construction of typologies, correspondence analysis is a perfectly adapted tool. This can be done thanks to different data analysis software such as *XLSTAT, BMDP, SPSS, ADDAD*, or *SPAD*. The new map — with point symbols— will then reveal the hierarchy. Simple cartography software is sufficient, there is no need for GIS software.

From the time matrix to functional space

42 A last category of methods, which uses all the information contained in the accessibility matrix, takes us still further, enabling us to obtain a functional space linked to a given transport matrix — in other words the space through which we move, and within which the points can be considered either nearby or far away, depending on how fast the distance is covered, compared to their location in the space of reference. Two main steps are necessary to construct this functional space (see figure 11).

43 First, one must determine the relative position of the locations in terms of time, that is their functional configuration; next, one must compare this configuration to the space of reference, in order to obtain through adjustment and interpolation the corresponding functional, and comparable, space.

From matrix to configuration

44 In order to determine the relative positions of points on the basis of time-distance, one can use methods belonging to the family of multidimensional scaling, or elastic mapping (Müller, 1982), or still trilateration (Tobler, 1977). The basic principles and the general approaches of most of these methods are similar or almost similar (see figure 12).

45 Let us consider a matrix of time-distances *Δij*. First, we choose [or calculate or randomly select] an

initial configuration with 2 dimensions, *X* and *Y*, and *n* rows (*n* places). Next, we also choose a distance function which will express the underlying structure of the studied space. Thanks to this function, we calculate the distances, *dij,* between the n places of the initial configuration; these are then compared to the distances observed either directly or after regularization of the observed distance matrix *Δij* thanks to an fit function. We then calculate an index of fit (goodness-of-fit function or loss function), called Stress (according to the **KYST** method ; it is like a similarity index) which varies from 0 to 1. The closer it is to 0, the better the fit, the greater the similarity. If this index is lower then the chosen threshold, the configuration is selected; if it is higher, then the configuration must be improved and the procedure is repeated. The algorithm can be stopped once the index has reached the fixed threshold or when the function has reached its minimum. This configuration can be obtained with various software such as *KYST, SSA, SPSS*; the software used here is *AMDP*, which is similar to *KYST*, developed by Kruskal et al. (1968).

46 *For the multidimensional scaling analysis, use AMDP*

47 This configuration only indicates relative positions which are not comparable to geographical positions; for this reason, the configuration must be transformed in order to become comparable.

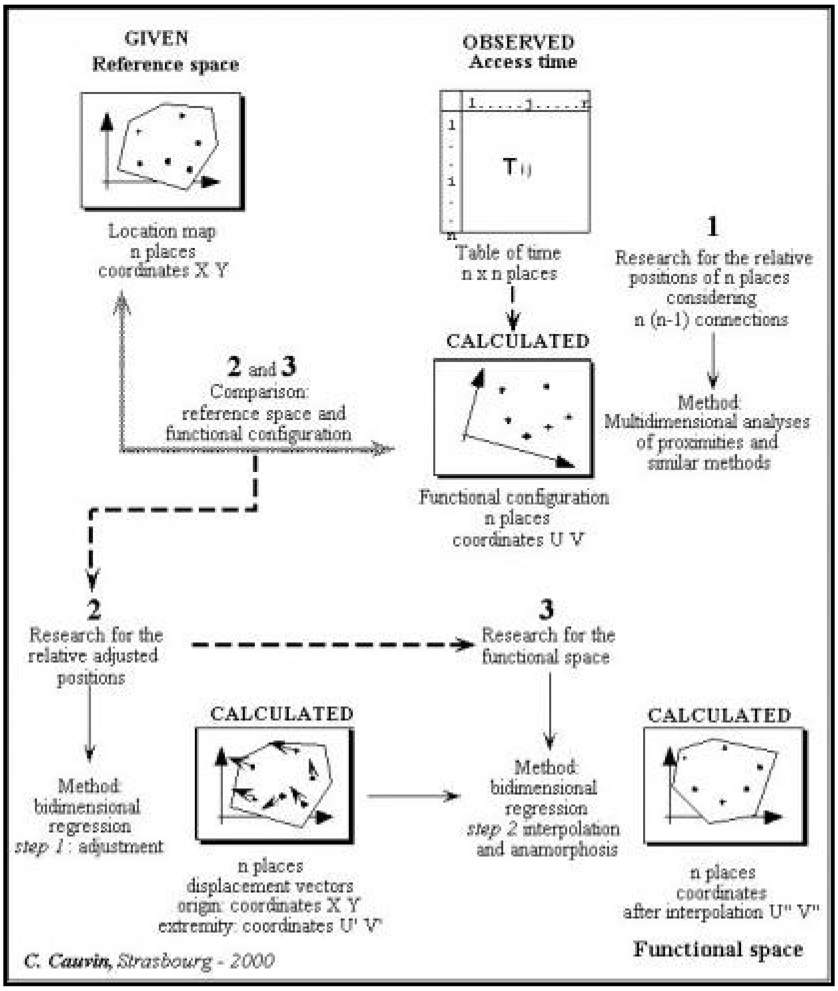

Figure 11. From time matrix to functional space : main steps

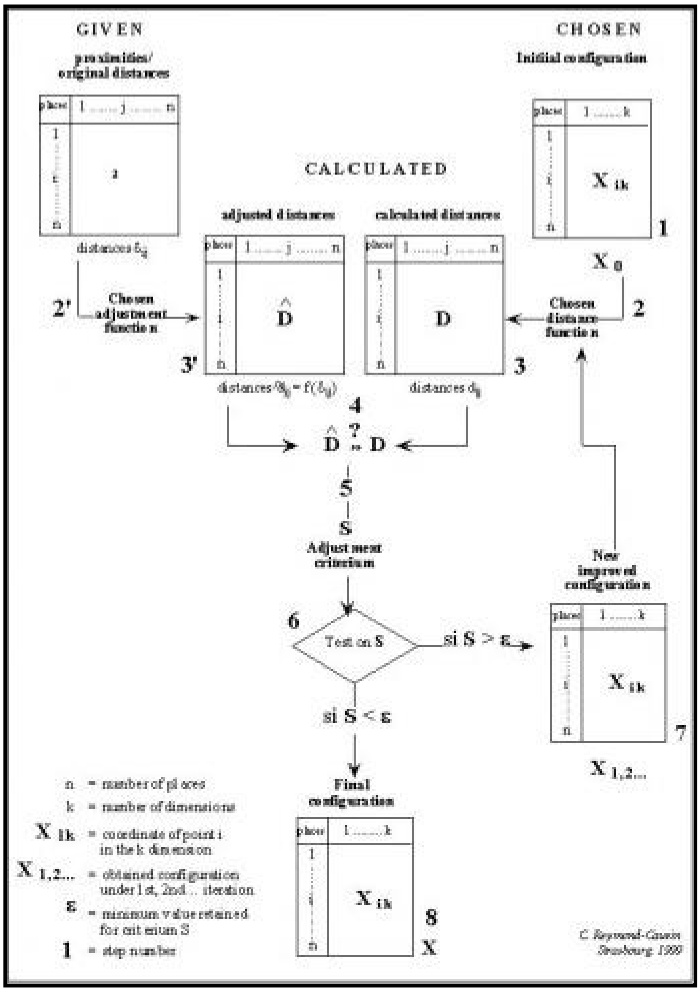

Figure 12. Approach of multidimensional scaling analyses (the KYST method)

48 *From configuration to functional space*

49 The functional configuration (W) differs from the reference map (Z) as concerns origin, orientation and the scale of the coordinates, independently of the differences due to the characteristics of the chosen means of transport. To ensure the comparability of the two spaces, it is necessary to apply bidimensional regression as suggested by W. Tobler (1977). There are two steps to this method: first, one adjusts the configuration to the geographic map and next, one performs an interpolation in order to generalize results (see figure 13).

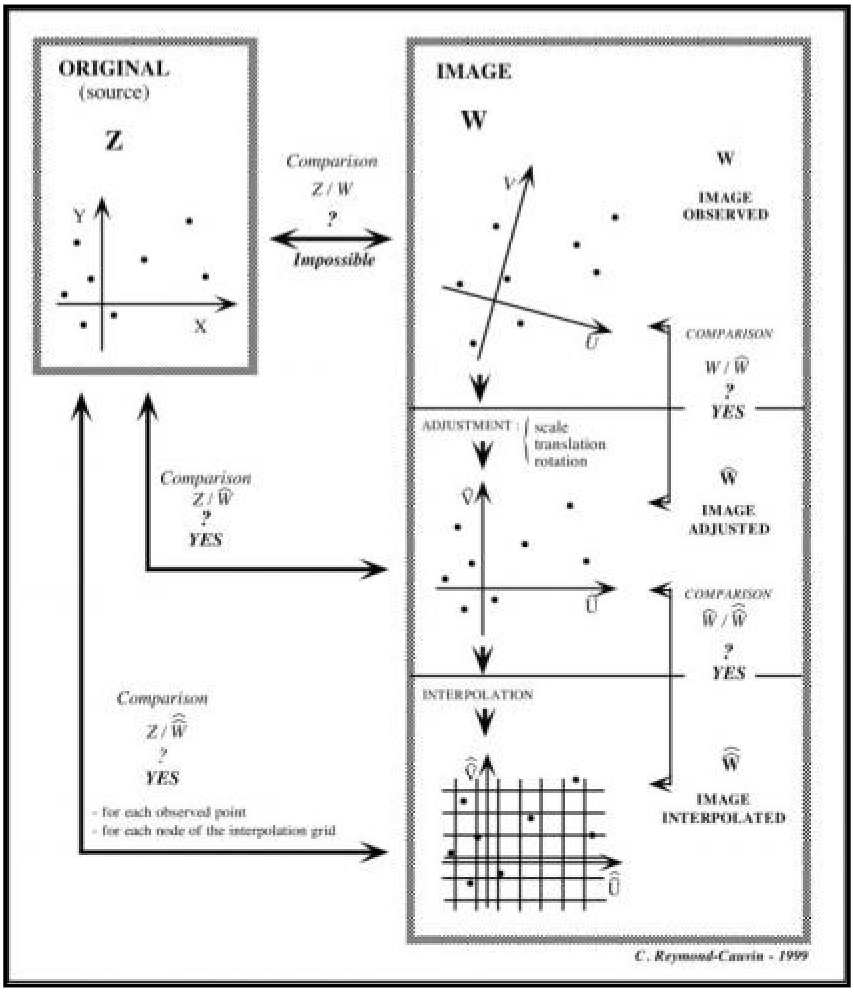

Figure 13. Simplified bidimensional regression

50 Fitting makes it possible to obtain an adjusted functional configuration W'; the vectors attached to the studied points originate in the positions located in the space of reference and terminate in their homologous points located in the configuration; the norm of this vector is equal to the movement of the point depending on the type of transport considered.

51 The interpolation is generally based on a squared grid. It is alternately performed along the rows and columns, making it possible to violate the monotonicity and subsequently the topology if necessary; an image of the associated functional space of transportation, W'', can then be obtained (see figure 14).

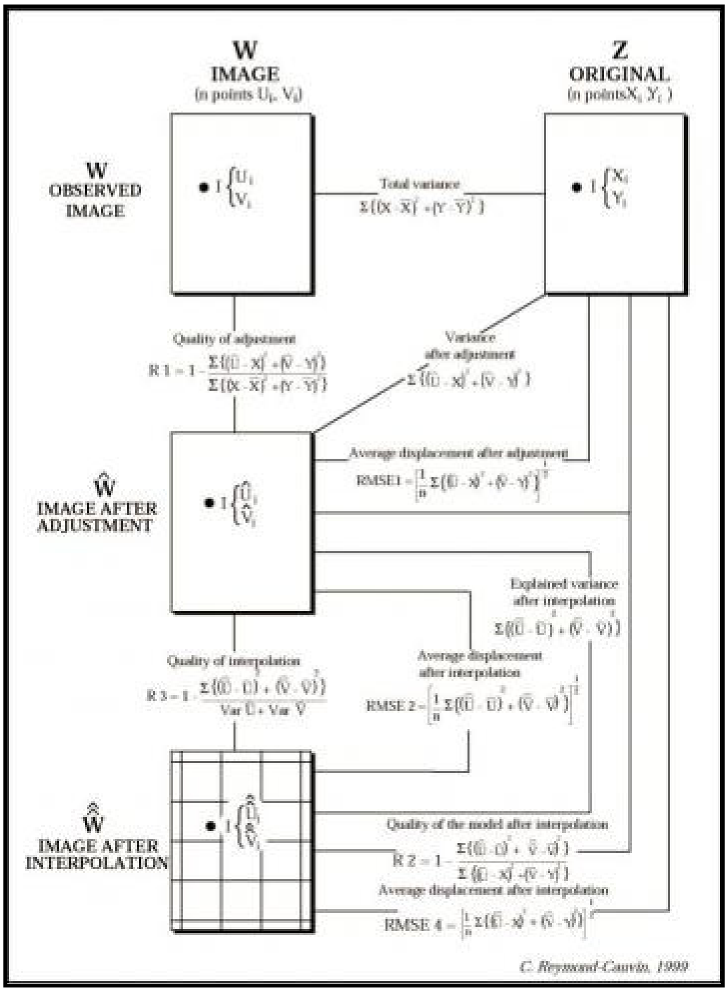

Figure 14. Complete bidimensional regression

52 A great many maps can thus be generated, providing numerous results either as concerns the homologous points, or the grid nodes (figures 15 and 16); all can be interpreted in terms of transport.

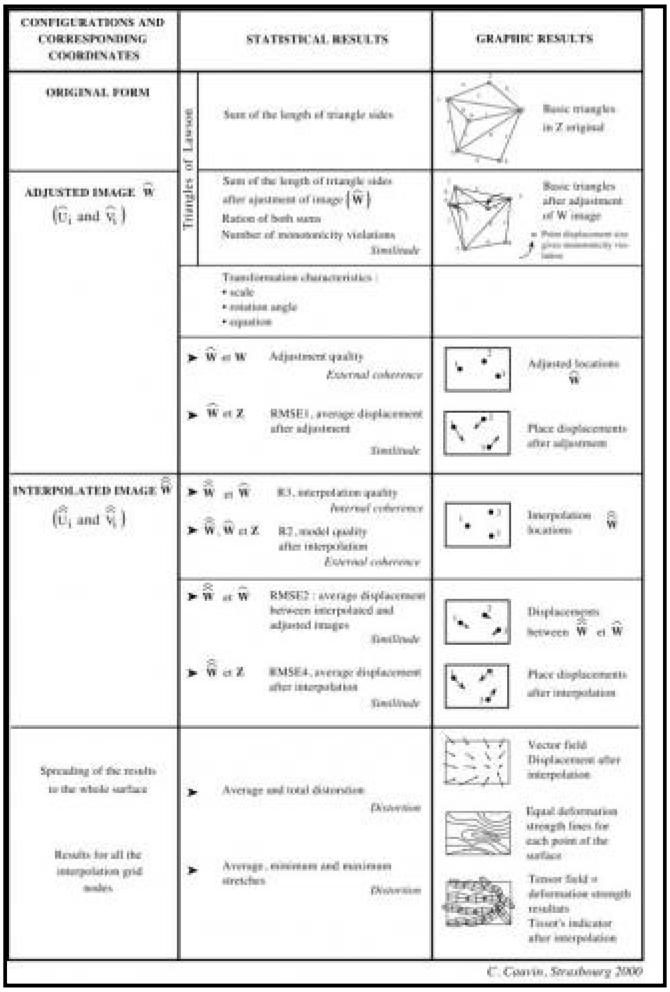

Figure 15. Results tied to the bidimensional regression

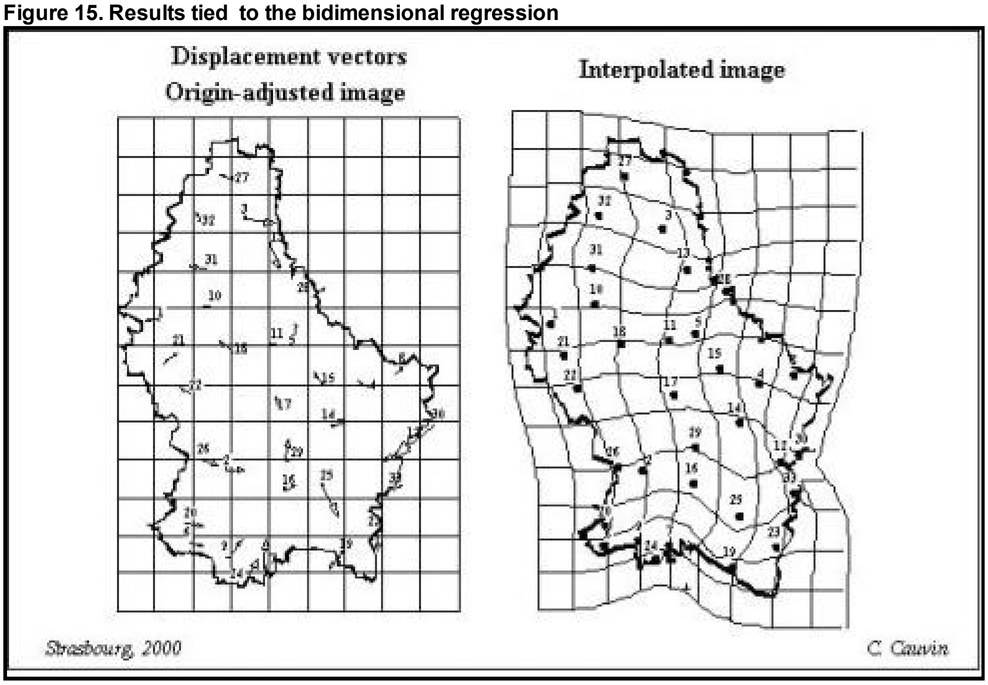

Figure 16. Maps of Luxembourg

53 Bidimensional regression, developed by W. Tobler on the basis of W. d'Arcy Thompson's research, can be applied thanks to the Darcy programme, first developed by W. Tobler between 1963 and 1978, then adapted by different persons in Canada and in Strasbourg. The programme used here was entirely rewritten by B. Guérin.

54 *To apply the bidimensional regression, use the Darcy programme.*

55 Once these three stages completed, we have at our disposal many results which complement each other, providing a great deal of material for interpretation; local examples provide illustrations for the

different sets thus identified.

Local or subsystem accessibility

56 Until now our use of the accessibility matrix was based on all the rows and all the columns; on the basis of these global results, we will now look separately at one or the other of these rows or columns. This is a local analysis, in other words a sub-system analysis. Several approaches are possible; three will be retained in this presentation. The first takes into account the raw values of access time, the second underscores the movement of the points and the third highlights the spatial distortion caused by these movements.

Local accessibility and isopleth map

57 The row or the column corresponding to the studied place is considered as a vector representing the location's accessibility from all other locations of the network. These vectors can be statistically analysed and cartographically represented thanks to lines of equal accessibility (see figure 17). Any cartography or GIS programme that includes isopleth maps can provide this type of easily read map.

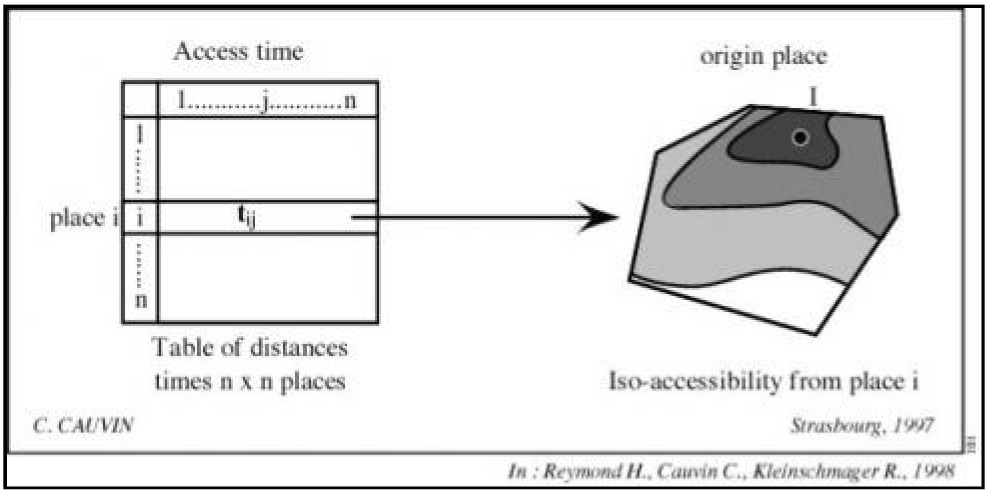

Figure 17. Unipolar iso-accessibility

Accessibility and iso-distances

58 Another representation aims to emphasize the relative closeness or distance from the original location according to the chosen mode of transport. On one hand, we have the time matrix W, on the other the reference distance matrix Z and the basic map. The double sum of each of the two distance matrices is calculated, and the matrices are made comparable by multiplying the time matrix by the ratio of the double sums, a ratio which in fact expresses the average speed necessary to cover the reference space using any given means of transport:

$$V = \sum\sum Z / \sum\sum W$$

59 *To obtain the matrix of weighted times, use Calmat.*

60 We thus obtain the weighted time matrix, W'. The matrices W' and Z, expressed in metric units, are now comparable. We are aware of the geographic position of the different locations in relationship to the original location thanks to the reference map. In order to determine where these locations are in terms of time, we must draw all the half-lines linking the original location to all the other locations within the area under consideration. The displacement vectors starting from the geographical positions are located on these half-lines. In order to find the magnitude of the displacement vectors, we must calculate the difference between the matrices W' and Z; the time locations, which are the extreme points of the vectors, are located on the half-lines, either in the direction of the original location (moving closer) or in

the other direction (moving further), depending on whether the sign of the magnitude is + or — (figure 18).

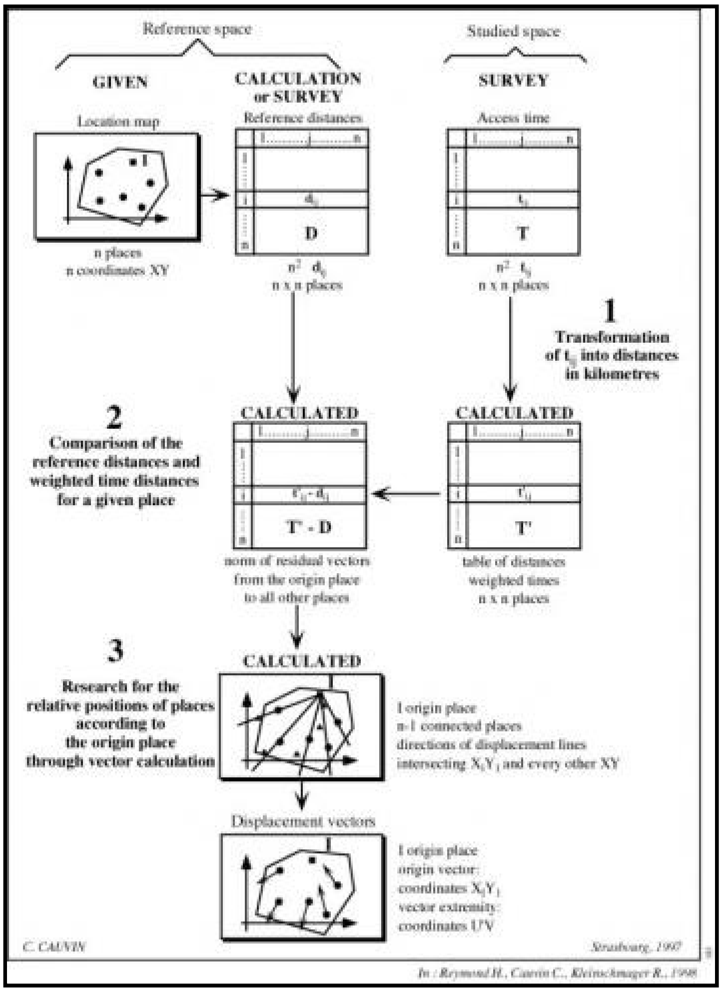

Figure 18. Iso-distance maps

61 Many representations can now be based on these new positions, as shown in figures 19 and 20. These can be obtained thanks to the software Isodist.

62 *To obtain isodistances, use Isodist software.*

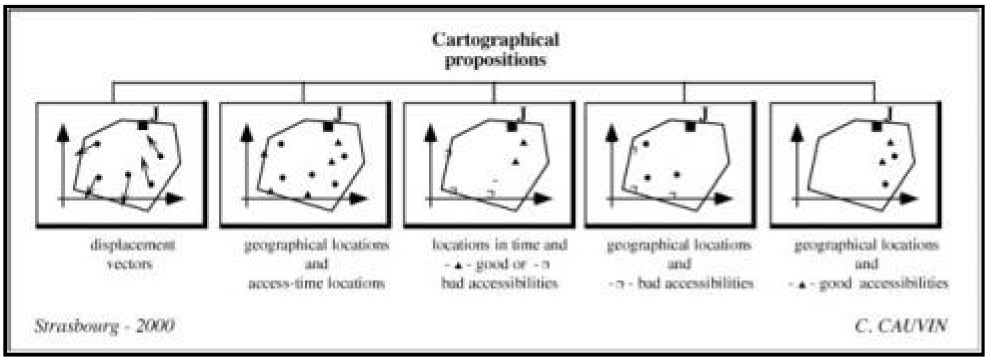

Figure 19. Isodistances representations

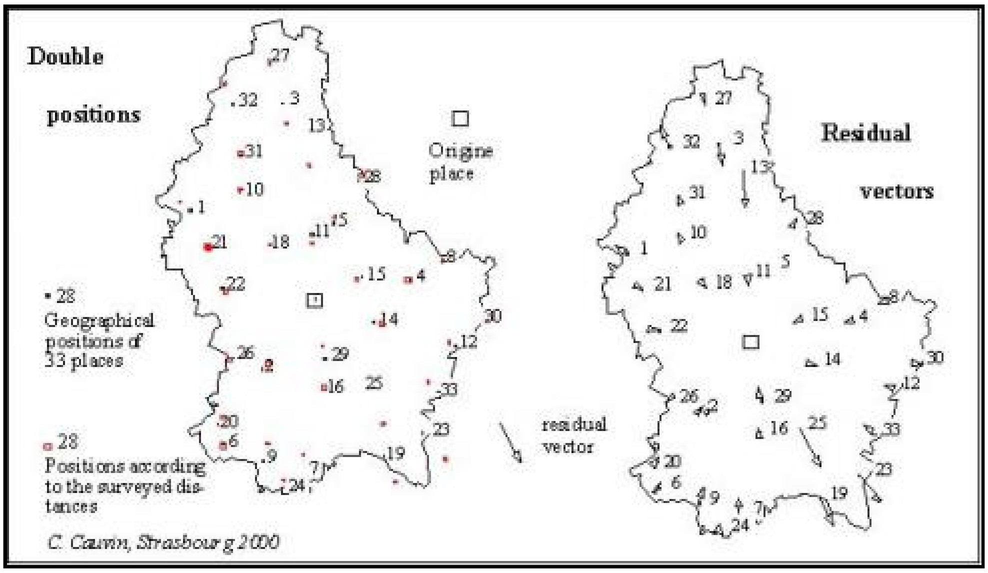

Figure 20a. Examples with Luxembourg

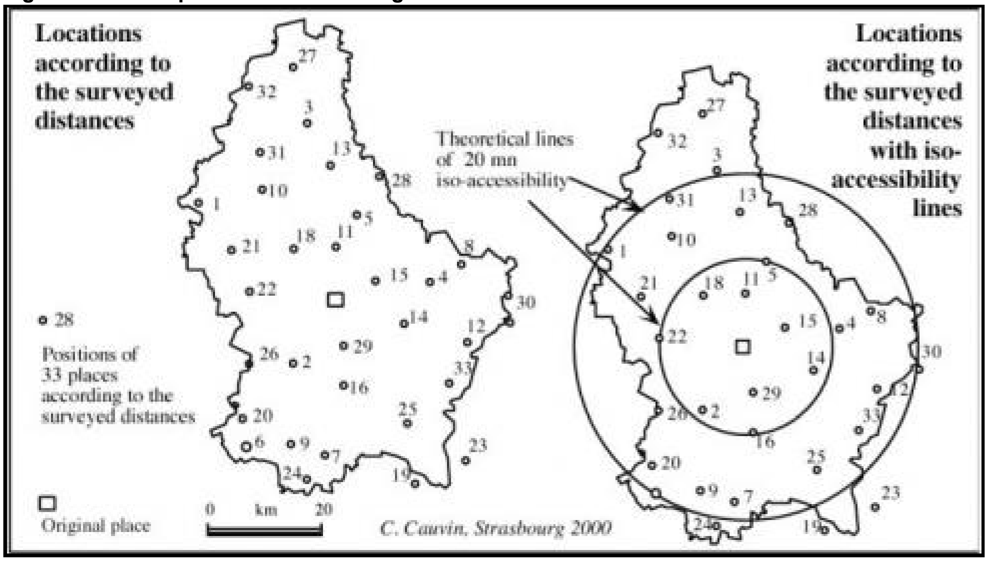

Figure 20b. Examples with Luxembourg

63 However, only the modifications of the positions of the points were taken into account; there is no global distortion of the space.

Unipolar functional space

64 We will now only take into account the positions of the points obtained through Isodist and those of the homologous points in the reference area. They are directly comparable and the locations corresponding to the travel time can be generalized by interpolation thanks to bidimensional regression, applied only during the second phase. We then obtain an image of the unipolar functional space (figure 21).

65 *In order to obtain the unipolar functional space, use Darcy.*

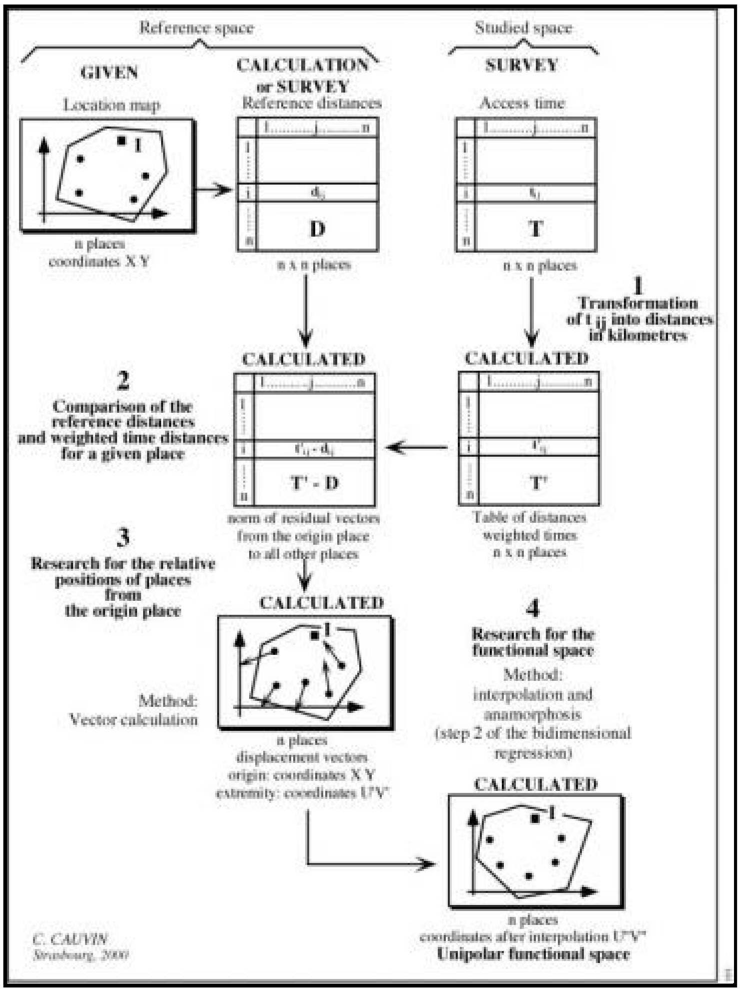

Figure 21. Obtaining unipolar spaces

66 These methods make it possible to illustrate the characteristics of certain places depending on their role in the global typologies.

Conclusion

67 The method described in this article makes it possible to determine the accessibility of a given location with any given means of transport; it explains how to obtain access time data (Acced software), how to obtain a global view of accessibility or an illustration of the specific characteristics of a given place. As announced in the introduction, a general diagram enabling the user to follow all or only some of the different steps of this approach, depending on the aim of the study, is provided below (see figure 22).

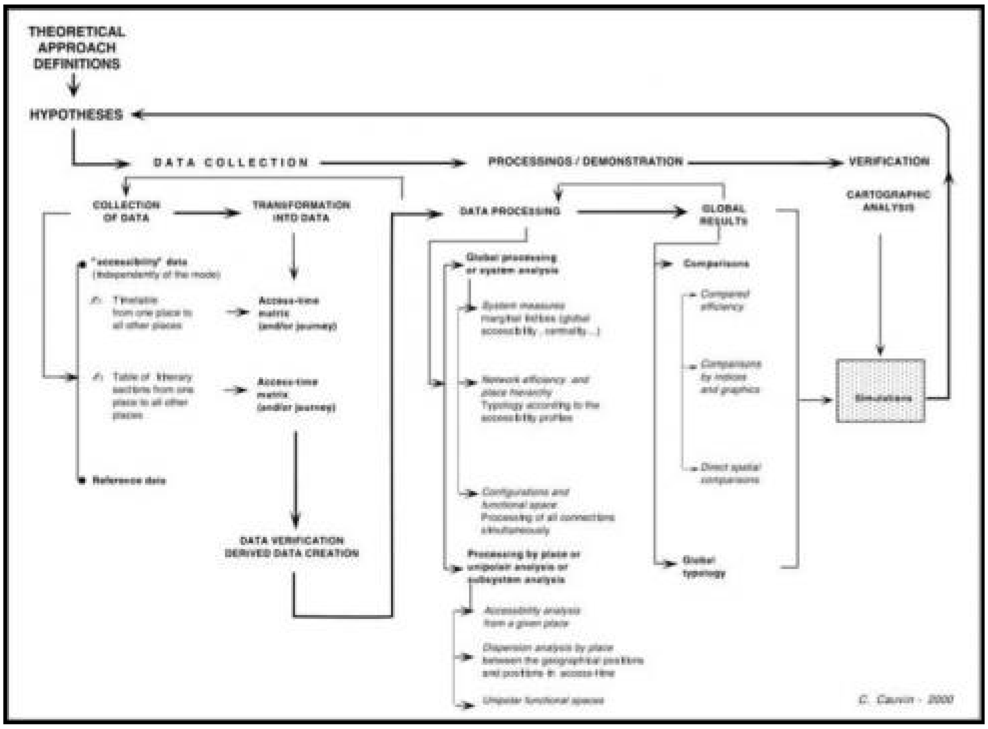

Figure 22. General diagram

68

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ANNEXES

Available software

The softwares mentioned below were developed or adapted (Darcy) at the "Image et Ville" laboratory (image.et.ville@lorraine.u-strasbourg.fr) between 1988 and 2000. They are available on demand in this laboratory after training provided in the laboratory. They were developed in the context of the accessibility approach set up in Strasbourg: indeed, in the 1980s and 90s, this type of software for micro-computers did not yet exist in France. Today, part of the processing can be done with a GIS or statistics software.

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NOTES

1 *Image et Ville* Laboratory, URA 902, CNRS, currently UMR 7011 CNRS.

2 This study does not refer to the Graph theory, which is very important in the field of transport (as shown by I.C. Jung's Ph.D thesis), though we have done so in other studies.

3 *Direction à l'Aménagement du Territoire et à l'Action Régionale* – Bureau of Physical Planning and Regional Action.

4 Cauvin C., Reymond H., Enaux C., *et al.*

5 For this presentation, we took into consideration only the time measurements; however, our laboratory has already experimented with other measures of accessibility, such as cost-distance, also very interesting.

6 The orthodromic distance between two points is equal to the length of the arc of the great circle linking these two points.

7 The definition and relevance of the stay time are based on the research conducted by the two authors mentioned in the introduction (Pred, Tornqvist).

8 For the sake of simplicity, we decided to call all points of departure or arrival of a given type of transport "station". In some cases (a trip by car, for example), the point of departure of the trip (home) is the same as the point of departure of the chosen means of transport.

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