

Silva, Mateus Araújo E; Kawamoto, Eiji

Conference Paper

An overview of accessibility measures

50th Congress of the European Regional Science Association: "Sustainable Regional Growth and Development in the Creative Knowledge Economy", 19-23 August 2010, Jönköping, Sweden

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: Silva, Mateus Araújo E; Kawamoto, Eiji (2010) : An overview of accessibility measures, 50th Congress of the European Regional Science Association: "Sustainable Regional Growth and Development in the Creative Knowledge Economy", 19-23 August 2010, Jönköping, Sweden, European Regional Science Association (ERSA), Louvain-la-Neuve

This Version is available at:

<https://hdl.handle.net/10419/118975>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

An overview of accessibility measures

Mateus Araújo e Silva*, Eiji Kawamoto

Universidade de São Paulo, Escola de Engenharia de São Carlos, Departamento de Transportes

São Carlos, Brazil

This paper presents a review of accessibility measures in transportation studies by addressing its conceptual framework, data requirements, and applications. Depending on the theoretical basis, the accessibility measures are classified in infrastructure, location, gravity, space-time and utility-based measure. A system approach is applied to identify the relations among the interacting variables: land-use, transportation, temporal and individual ones. The criteria, including theoretical basis, interpretability, and data requirements are used to evaluate these measures. Recent progress in accessibility studies point towards the inclusion of more individual's spatial-temporal accessibility measure (using the space-time prism concept) but the data requirements, and interpretability of this measure remain as a problem. Furthermore, most of the measures fail for not considering the competition for opportunities (e.g. jobs on the employment market), and it seems to be the main issue for the development of more realistic accessibility measures.

Keywords: Accessibility; Land-use; Transportation; Competition

* Corresponding author. Tel.: + 55 16 3373-9613; fax: + 55 16 3373-9602

E-mail address: masilva@sc.usp.br (Mateus Araújo e Silva)

1. Introduction

Accessibility has been used in a larger number of scientific fields with important meaning in urban planning. It is often used as a policy tool by planners and decision makers to tackle some of the urban problems. However, it is often misunderstood, not properly defined and it presents a lack of developing theory and measure building, thus the potential of accessibility in planning practice is far less developed (Geurs & Van Wee, 2004; Straatemeier, 2008).

To take these factors into consideration, specific in urban studies, the last decades witnessed the effort of researchers to develop accessibility measures to achieve the urban issues and several authors have reported the advances in accessibility research and their implication for future studies on this topic, such as Kwan, et al. (2003) and Geurs and Van Wee (2004).

Following this perspective, this paper proposes a method framed to present necessary and sufficient conditions for the validity of accessibility measuring and evaluate the representation-theoretic aspects of the distinguishing approaches of accessibility studies by addressing the criteria applied to review on this topic in the literature.

The aims of this paper are: (1) to contribute to the understanding of accessibility, (2) to propose a different approach to represent and interpret the relationships among accessibility components: land-use (made by the intensity and distribution of the demand and supply for activities); transport (transport system features); temporal (durations and available times of activities and time budget for activity participation) and individual (needs, abilities, and opportunities of individuals), and (3) to serve as foundation for accurate measuring and modeling accessibility.

Following this line, the method is presented on the next section. An overview of the accessibilities including the application of the criteria to evaluate the measures is presented in Section 3. The paper summarized by some implications and recommendations for further research.

2. Method

This section describes the analytical approach developed for the understanding of accessibility. In order to develop this method, an appropriate working hypothesis for the concept of accessibility is proposed and a set of relevant criteria including theoretical basis, data requirements and interpretability are introduced to evaluate the different accessibility measures.

The aforementioned set of criteria is based on an extensive literature review and partially follows the perspective approach presented by Geurs and Van Wee (2004). However, the method applied for the analysis of the theoretical basis of accessibility measures differs from the existing reviews in the following ways. Firstly, the relevant criteria of theoretical basis are considered as general as possible. Thus, it implies an inclusive analysis. Secondly, for the context of systems to represent and interpret the relationships among elements and accessibility, and relationships among the elements themselves, it achieves a new perspective for the accessibility framework and thus for theory building and measurement form.

The presentation of the method is informal and the emphasis is more conceptual rather than technical. Moreover, the analytical structure is framed to present the necessary and sufficient conditions for the validity of accessibility measuring and it evaluates the representation-theoretic aspects of the distinguishing approaches of accessibility studies. For this purpose, it seems appropriate to explore the method in four aspects: accessibility concept, theoretical basis, data requirements and interpretability.

2.1 Accessibility concept

Accessibility has been used in a broader number of scientific fields (especially in geography, transportation and urban planning) with important meaning for decision makers. However, it is often misunderstood, not properly defined and it presents a lack of developing theory and measure building (Geurs & Van Wee, 2004; Straatemeier, 2008).

According to the scientific field and application, accessibility can take a variety of meanings. In this work, accessibility is defined as a measure that denotes the ease with which any land-use activity can be reached from a location using a particular transportation system.

This concept, firstly introduced by Burns and Golob (1976), suggests that the service provided by transportation is indeed an accessibility measure.

Although some accessibility studies often neglects this concept of accessibility (classified as location-based measure), this measure highlights the important role that transport system plays on the context of individuals and their decisions for traveling to a particular destination. What matters for households (and firms) is the fact that transport systems provide access to spatially and temporally dispersed opportunities (Straatemeier, 2008), and this concept of accessibility is capable to reflect this perspective.

Another advantage of using a simpler concept is the fact that planners and policy makers are able to understand and interpret distance or travel time, first approximations to a more complex evaluation of spatial separation under constraints in relative space, and it gives them the opportunity to access the effect changes in accessibility conditions in an urban context (social and economic impacts analysis). Thus, accessibility can be used as a policy design tool.

These various aspects lead to the conclusion that accessibility, as defined above, has the potential to address the expected functionality, a tool to help researchers and policy makers as a planning framework to tackle some of the problems of urban transportation planning. Based on this concept, a set of requirements is proposed for accessibility theory building.

2.2 Theoretical basis

The theoretical basis is the line of what accessibility studies should strive for: a theory building to appropriately deduce a mathematical form for the measure. It begins with the formulation of requirements expressing desirable properties for accessibility measures and followed by the representational framework for the accessibility elements (land-use, transportation, temporal and individual).

Since the measurement of accessibility is of relevance in many fields of investigation relating to spatial aspects of human behavior, it was considered desirable to keep the theoretical basis as general as possible.

The requirements expressing desirable properties are useful to evaluate the contribution of accessibility studies and serve as a basis for theory building. It addresses the relevant criteria applied in the literature of accessibility studies and potential needs of urban planning. However, it should not be regarded as exhaustive and more aspects can be achieved. One may bear in the construction of accessibility properties that the more inclusive the properties are, the more feasible the measure will be. By this approach, the developed desirable properties are:

1. The method on which accessibility measure arises should present a representational framework for the relations among the accessibility elements: land-use, transport, temporal and individual.
2. The accessibility measure is always positive, null only if the individual (or groups of individuals) has insufficient abilities or capabilities to use any mode of transport system or participate in that activity.
3. If the service level (i.e., improvement of travel time, reduction of costs and effort) of any transport mode in an area increases (decreases), accessibility should increase (decrease) to/from any activity in that area, or point within that area (Geurs & Van Wee, 2004).
4. Improvement in one transport mode should not alter the accessibility to any individual (or groups of individuals) with insufficient abilities or capabilities to use that mode or participate in that activity (adapted from Geurs & Van Wee, 2004).
5. Spatial scale of accessibility is relevant: personal accessibility (point-based spatial) offers individual level analysis in contrast to place accessibility (zone-based spatial scale) that provides global analysis (average in population).
6. Accessibility should reflect the role of supply-demand aspect (competition effect).
7. Accessibility should identify constraints which surround actors (reflect the space-temporal limits of activities).

It should be noted, as described by Geurs and Van Wee (2004), that the application of criteria on accessibility studies would imply a level of complexity and detail that can prove to be difficult, since the study of accessibility is conducted in a larger number of scientific fields, therefore it takes different purposes and structures.

However, it is important to strike the need of clarification and validity of different types of accessibility. Implications of violating one or more of above-mentioned theoretical criteria should be recognized and described.

Yet, even if a desirable number of properties are defined and achieved, there is a need to go into the ramification of the representational framework for the relationships among land-use, transport, temporal and individual variables. To trace the dynamics of interaction among these parts and to develop a clear picture of it is crucial to help researchers and policy makers to tackle some of the problems of urban transportation planning.

To deal with this complexity there are long-established studies for conceptualizing the organization and functioning of each variable on accessibility in the context of systems, since an appropriate working hypothesis is that theories are about understanding systems (Von Bertalanffy, 1968).

System is defined as the collection of elements in their entirety and the relations between them. On this approach two basic components are considered: elements and relations. Elements are the variables and relations are the interactions that explain the phenomena among the variables. Further details about systems are presented by Von Bertalanffy (1968).

Understanding the nature of transactions among land-use, transport, temporal and individual variables and accessibility is central to understand the accessibility in the context of system.

There is also another aspect of the methodological tool kit needed for theory building based on understanding systems which needs to take into account. Even though the general system approach states that the dynamic of interactions among elements is a transformation mechanism (e.g., variable “x” plus variable “y”, yield “z”) and essentially the accessibility studies state in this way, it seems appropriate to explore beyond of this scope.

It may be possible to clarify this crucial part of the discussion by considering the concept of problem-solving in systems in more depth. Urban phenomena are complex and they require a number of simplifying assumptions, otherwise the level of problem-solving shift from simple problems, described by a limited number of variables, to problems of organized complexity, which involve dealing simultaneously with sizeable number of factors which are

interrelated into an organic whole, or problems of disorganized complexity, which the number of variables is very large, and one in which of the many variables has an individually erratic behavior and may be totally unknown. Further details about simple, organized and disorganized problems in the context of system are presented by Weaver (1961).

The restriction to mechanism transformation, applied to the dynamics of interaction among elements, keeps the system less inclusive and places some limitations under the organization and functioning of each element on accessibility. There are some substantial problems to translate this mechanism into the numerical measurement of accessibility, or as described in Weibull (1980, p.53) “there appears to be a gap between the general and somewhat vague verbal definitions of the concept and the very specific numerical indicators in current use”. Therefore, it seems appropriate to explore an appropriate alternative approach for the interaction flows among the variables to bear in the study of accessibility.

When hypotheses (or theories) are built, it is often necessary to include terms which are difficult to interpret in any direct way. Thus, it is necessary to begin by defining and specifying the system of interest. A system from this frame of reference is composed of two types of relationships: transformation mechanism and associative.

On the transformation mechanism, the emphasis is on the effect produced by the combination of the variables and directly translated into the numerical measurement of accessibility. By this approach all the variables (land-use, transport, temporal and individual) must be included in the mathematical formulation of the accessibility measure, and as mentioned before there are some substantial problems to translate this mechanism into the numerical measurement of accessibility.

The associative interaction also concerns the effect produced on the combination of the variables (land-use, transportation, temporal and individual), but this effect is not directly related to the numerical measurement of accessibility, thus it is not formalized in mathematic terms.

Although some studies have argued the use of indirect and direct effects to represent the interaction flow among variables and accessibility and variables themselves, it was never achieved in the context of systems.

It can then be argued that it is more effective to work with this concept of system characterized by two approaches to explain interaction flows rather than the general system approach. Even though mathematics exists in principle, in the case of transformation process, either not enough is known substantially about the system to make mathematical analysis feasible, or there are too many aspects to be considered in the analysis. On the other hand, dealing with simplifying assumptions, the case of associative process, place some limitations on the interpretation results.

Before proceeding with the data requirements and interpretability aspects, it may be possible to clarify this part of the method. This approach may be viewed as the problem of an accessibility measure study to represent two variables on the numerical measurement of accessibility (e.g., individual and transport) and also analyzing the effect of the others (e.g., land-use and temporal).

For this purpose, the planner/researcher can take an individual perspective of average travel times by available modes to potential destinations, considering the supply-demand aspect and space-temporal limits of activities, as the accessibility measure.

Such example is certainly basic to provide insights about the possibilities of developing the proposed approach of different types of relationships (transformation and associative) among element on accessibility system.

In this examples the relationship among the mix individual/transport variables and the accessibility is classified as a transformation process, while the relationships among the mix land-use/temporal variables and the accessibility is classified as associative. All the elements are considered in the analysis.

The mathematical aspects of the measure are not presented on this material. The emphasis is based on conceptual rather than technical concepts. However, the numerical measurement of accessibility should strive for a framework that provides a rigorous guideline for developing measures that are internally consistent and with respect to the behavioral situation analyzed.

Axiomatic frameworks for formulating accessibility measures are given by Weibull (1976, 1980) and should be considered to build an appropriate accessibility measure.

2.3 Data requirements

The more complex is the measure, the more detailed information is requested on the numerical of accessibility. For theory and measure accessibility building, it is necessary to find the balance that works equally well with the theoretical basis and data availability.

According to the aforementioned theoretical basis, measures are estimated using information from four data set groups (the accessibility elements): land-use, transport, temporal and individual. The type and detail of information from each group is based on the analysis scope of the accessibility studies.

2.4 Interpretability

Accessibility measures should present information in a comprehensible and useful form, and researchers, planners and policy makers should be able to understand and interpret the measure. Otherwise, the measure is unlikely to address the expected functionality, a tool to help researchers and policy makers as planning framework to tackle some of the problems of urban planning.

3. An Overview of Accessibility Measures

This section describes the overviews of accessibility measures. Based on similarities in theoretical basis the measures are classified in four distinguishing clusters: in infrastructure, location, gravity, space-time and utility-based measure. The analysis begins with a description of the four clusters and it proceeds with the application of the criteria (designed in previous section) made by theoretical basis, interpretability, and data requirements to evaluate the different proposed approaches for the measures.

Striving for clarity of the differences among the accessibility clusters is the emphasis of this analysis and to be clearly the presentation of this material is more conceptual rather than numerical and real-world applications aspect of the measures, since the method was designed on this frame.

Moreover, it is not the aim of this section to describe each accessibility study. The analysis focuses on the four accessibility clusters, since the emphasis is to trace the theoretical

approach of the studies on this topic. However, this places some limitations on the analysis and it may be noted that this approach provides substantial insights about the differences among the clusters.

3.1 Accessibility clusters

Based on similarities in theoretical basis, the measures are classified in four distinguishing clusters: in infrastructure, location, gravity, space-time and utility-based measure.

3.1.1 Infrastructure-based accessibility measure

This cluster relates the measures that express accessibility as the performance or service provided by transport infrastructure. Several indicators are used to describe the functioning of the transport system, such as journey times, congestion and operating speed on the road network, number of seats available in transit systems, number of transit lines by area, etc.

3.1.2 Location-based accessibility measure

Accessibility measures in this cluster describe the spatial separation from locations of supply to the locations of demand. Based on the way in which the spatial separations and the activities are considered this cluster is grouped into three different types of location measures: spatial separation measure, contour measure and potential measure:

Spatial separation measure

Simple spatial distances measures such as straight line distances or travel time on network are only primary approximations to a more complex evaluation of spatial separation under constraints in relative space. Based on the concept of accessibility “as the inherent characteristic (or advantage) of a place with respect to overcoming some of spatially operating source of friction (for example, time and/or distance), Ingram (1971) introduced two subsidiary forms for spatial separations measures: relative accessibility (the degree to which two places – or points – on the surface are connected), equation (1), and integral accessibility (the degree of interconnection with all other points on the same spatial limits), equation (2).

$$A_{ij}^{Relative} = c_{ij} \quad (1)$$

$$A_i^{Integral} = \frac{\sum_{j=1}^n c_{ij}}{n} \quad (2)$$

where $A_{ij}^{Relative}$ is the relative accessibility, $A_i^{Integral}$ is the integral accessibility, $f(c_{ij})$ is the distance or travel time from the origin i to destination j .

Contour measure

It expresses accessibility in terms of number of activities that can be reached within a given distance, travel time, or generalized cost as shown by equation (3):

$$A_i = \sum_j W_j \cdot f(c_{ij}) \quad (3)$$

where W_j , represents the number of activities (number of job vacancies, number of shops etc) in zone j and $f(c_{ij})$ is a measure of impedance from i to j . $f(c_{ij})=1$ if $c_{ij} \leq C$ e $f(c_{ij})=0$ if $c_{ij} > C$, and C is the boundary of the contour measure.

Potential measure

It was first introduced by Hansen (1959) and represents the “potential opportunities for interaction” (the interaction between activity and the effort to reach it) expressed by equation (4):

$$A_i = \sum_j W_j \cdot d_{ij}^\alpha \quad (4)$$

where W_j , represents the number of activities (number of job vacancies, number of shops etc) in zone j , d_{ij} is the distance from i to j and α is an exponent describing the effect of the distance between zones.

A general approach for the Hansen`s formulation is proposed by equation (5), conceiving the generalized cost between zones:

$$A_i = \sum_j W_j \cdot f(c_{ij}) \quad (5)$$

where $f(c_{ij})$ is the generalized cost. Several forms of impedance function are used in accessibility studies: a negative power function, a negative exponential function, a modified version of the normal or Gaussian function and a modified (log)logistic function.

Progress in location measure

Advances in locations measures (potential measures) tries to achieve the situation when equilibrium of supply and demand has been overtaken by reality (e.g. employees have to compete for jobs, firms have to compete for employees), such examples of this effort are the Weibull (1976) and Van Wee, et al. (2001) approaches.

Weibull (1976) proposed an accessibility measure, equation (6), achieving the competition in the job market as a ratio between supply and demand (which can be reached within a given distance, or travel time), equation (7):

$$A_i = \sum_{j=1}^n f(d_{ij}) \cdot \frac{W_j}{e_j} \quad (6)$$

$$e_j = \sum_{k=1}^n f'(d_{kj}) \cdot h_k \quad (7)$$

where A_i is the accessibility of zone i , $f(d_{ij})$ is the distance or travel time between i and j , W_j represents the number of activity (number of job vacancies, number of shops etc) in zone j , e_j is the demand potential for activity in j , $f'(d_{kj})$ is the distance or travel time between k and j and h_k is the number of workers in zone k (zones that can be reached within a given distance, travel time, or generalized cost).

Another approach is the one developed by Van Wee, et al. (2001). The measure is described as a product between a volume component (a contour measure) and a competition factor:

$$A_{i(t \leq t_{max})} = A_{i(t \leq t_{max})}^0 \cdot e_{i(t \leq t_{max})} \quad (8)$$

$$A_{i(t \leq t_{max})}^0 = \sum_{j=1}^n \frac{W_j}{t_{ij}^\alpha} \quad (9)$$

$$e_{i(t \leq t_{max})} = \frac{\sum_{k=1}^n \left(\frac{W_k \times L_{fk}}{t_{jk}^\alpha} \right)}{\sum_{k=1}^n \left(\frac{L_{fk}}{t_{jk}^\alpha} \right)} \quad (10)$$

$$A_{Jobs_i(T \leq T_{max})} = \sum_{j=1}^{j=n} \left(\frac{W_j}{t_{ij}^\alpha} \times \frac{\sum_{k=1}^{k=n} \left(\frac{W_k \times L_{fk}}{L_{jk}^\alpha} \right)}{\sum_{k=1}^{k=n} \left(\frac{L_{fk}}{t_{jk}^\alpha} \right)} \right) \quad (11)$$

where $A_{Jobs_i(T \leq T_{max})}$ is the accessibility of jobs within a certain time (t), within the limit of maximum travel time (t_{max}) including competition; $A_i^0(t \leq t_{max})$ is the accessibility for a given time (t), within the limit of maximum travel time (t_{max}) without competition; $e_{i(t \leq t_{max})}$ is the competition factor for a given time (t) within the limit of maximum travel time (t_{max}), i is the origin zone, j are the destination zones that can be reached from i given the travel time (t) within the limit of maximum travel time (t_{max}), k are the zones of demand that can be reached from j within the limit of maximum travel time, W_j e W_k are the number of activity in zone j and k , L_{fk} is the size of the employment market in zone k and α is the deterrent factor of the travel time between zones .

3.1.3 Gravity-based accessibility measure

The measures related in this cluster is based on the balancing factor of the single and doubly constrained gravity model. Wilson (1967), in a doubly constrained gravity model, equation (12), called the denominator of balancing factor for the total trip origins in zone i as a measure of accessibility, equation (15):

$$T_{ij} = A'_i \cdot O_i \cdot B_j \cdot D_j \cdot e^{-\beta \cdot c_{ij}} \quad (12)$$

$$A'_i = \left(\sum_j B_j \cdot D_j \cdot e^{-\beta \cdot c_{ij}} \right)^{-1} \quad (13)$$

$$B_j = \left(\sum_i A'_i \cdot O_i \cdot e^{-\beta \cdot c_{ij}} \right)^{-1} \quad (14)$$

$$A = \frac{1}{A'_i} = \sum_j B_j \cdot D_j \cdot e^{-\beta \cdot c_{ij}} \quad (15)$$

where T_{ij} is the number of trips between zones i and j , O_i is the total of trip origins in i , D_j the total of trip destinations in j , c_{ij} is the impedance between i and j , A'_i is the balancing factor for trip origins in i , B_j is the balancing factor for trip destinations in j , β is the deterrent factor of the impedance between i and j and A is the accessibility of everyone to opportunities at j . Thomas (1977) states that the accessibility to j can be represented by B_j , equation (14).

Fortheringham (1983) addresses the situation of competing destinations in a spatial structure (competition among destinations) and in this approach, accessibility is described by the potential measure of destination j to all other destinations available to origin i as perceived by the residents of origin i .

The underlying assumption is a two step decision process: the decision maker firstly chooses a broader region and secondly an alternative within that region. Therefore, the utility of each alternative is affected by the number of alternatives in the same region. With an increasing number of alternatives within the same region the probability for each alternative to be recognized, and thus to be chosen, decreases.

The single constrained Fortheringham's model:

$$T_{ij} = Z_i O_i W_j A_{ij}^{\delta_i} d_{ij}^{\beta_i} \quad (16)$$

$$Z_i = \left(\sum_{j=1}^n W_j A_{ij}^{\delta_i} d_{ij}^{\beta_i} \right)^{-1} \quad (17)$$

$$A_{ij} = \sum_{\substack{k=1 \\ (k \neq i, k \neq j)}}^n W_k d_{jk}^{\sigma_i} \quad (18)$$

The doubly constrained Fortheringham's model:

$$T_{ij} = Z_i O_i B_j D_j A_{ij}^{\delta_i} d_{ij}^{\beta_i} \quad (19)$$

$$Z_i = \left(\sum_{j=1}^w B_j D_j A_{ij}^{\delta_i} d_{ij}^{\beta_i} \right)^{-1} \quad (20)$$

$$B_j = \left(\sum_{i=1}^m Z_i O_i A_{ij}^{\delta_i} d_{ij}^{\beta_i} \right)^{-1} \quad (21)$$

$$A_{ij} = \sum_{\substack{k=1 \\ (k \neq i, k \neq j)}}^l W_k d_{jk}^{\sigma_i} \quad (22)$$

where T_{ij} is the number of trips between zones i and j , O_i is the total of trip origins in i , D_j the total of trip destinations in j , A_{ij} is the accessibility of destination j to all other destination available to origin i as perceived by the residents of origin i , d_{ij} and d_{jk} are the impedance for the trip between i and j and k and j , Z_i is the balancing factor for trip origins in i , B_j is the balancing factor for trip destinations in j , W_j and W_k are the number of activities in zones j and k , σ_i reflects the importance of distance on accessibility, β_i is the deterrent factor of the

impedance between i and j and δ_i reflects the importance of accessibility on the spatial interaction.

Fortheringham (1983) states that if each center in the spatial system under investigation is both an origin and a destination and the set of such center is a good approximation of the total set, then an approximation to the definition of A_{ij} given by equation (23) is:

$$A_{ij} \approx \sum_{\substack{k=1 \\ (k=1, k \neq j)}}^m W_k d_{kj}^{\sigma_i} \quad (23)$$

A further approximation can be made if σ_i is assumed to be equal to all origins i :

$$A_{ij} \approx A_j = \sum_{\substack{k=1 \\ (k=1, k \neq j)}}^m W_k d_{kj}^{\sigma} \quad (24)$$

3.1.4 Space-time-based accessibility measure

Space-time-based accessibility concerns physical and temporal constraints on individual behavior and are founded in space-time theory of Hägerstrand (1970). The underlying assumption on this approach is the space-time prism, that is, the set of locations in space-time that are accessible to an individual given the locations and durations of fixed (mandatory) activities, a time budget for flexible (discretionary) activity participation and the travel speed allowed by the transportation system (Hägerstrand, 1970). It identifies the feasible activity space for an individual with a particular set of space-time constraints. These space-time prisms can be regarded as accessibility measures.

Miller (1999) proposed three complementary approaches by deriving space-time accessibility and benefit accessibility measures: a transform-additive (A_1), an additive (A_2) and maxitive (A_3) accessibility measure:

$$A_1 = \frac{1}{\mu} \cdot \ln \sum_{j=1}^m e^{W_j^\alpha \cdot T_j^\beta \cdot e^{-\mu \cdot t_j}} \quad (25)$$

$$A_2 = \sum_{j=1}^m b_k \quad (26)$$

$$b_k = \begin{cases} 0 & \text{se } a_k=0 \text{ ou } T_k \leq 0 \\ e^{\left[\mu \cdot \left(\frac{\alpha}{\mu} \ln a_k + \frac{\beta}{\mu} \ln T_k - t_k \right) \right]} & \end{cases} \quad (27)$$

$$A_3 = \max_k [b_k] \quad (28)$$

where μ is the deterrent of the travel time between i and j , W_j is the level of activity in j , α is the calibration parameter for the level of activity in j , T_j is the time available for activity participation (time budget), β is the calibration parameter for the time available for activity participation, t_j is the travel time between i and j and m are the supply location within the space-time prism.

Moreover, following the perspective of Miller (1999), Ettema and Timmermans (2007) proposed the developing of space-time accessibility under conditions of uncertain travel times.

3.1.5 Utility-based accessibility measure

Utility-based accessibility measures are based on random utility theory and interpret the measure as the outcome of an operation on a set of travel alternatives (destination, or mode-destination) in which the individual maximizes its choice (Ben-Akiva & Lerman, 1979). In this aspect, accessibility is directly related to individual's travel-decision processes and it represents the expected value of a set of travel alternatives (Dong, et al., 2006).

By this approach, the study of choice behavior is described by the objects and sets of alternatives available to decision-makers, the observed attributes of decision-makers, and the model of individual choice and behavior and distribution behavior patterns in the population (McFadden, 1973). The choice process is considered to be a result of individual's trade-off between a vector of attributes evaluated by the individual and the benefits perceived to be associated with each alternative decision.

In light of the above-mentioned theoretical basis Ben-Akiva and Lerman (1979) developed the utility-based accessibility measure. For Multinomial Logit Models (e.g., destination choice), an individual's expected maximum utility achieved from a set of alternatives can be expressed as:

$$A_n = E_{i \in C_n} (\max U_{in}) = \frac{1}{\mu} \cdot \ln \sum_{i \in C_n} e^{\mu \cdot V_{in}} \quad (29)$$

where V_{in} is the systematic component of the utility U_{in} for individual n choosing alternative i from the choice set C_n . For the more general nested logit model the expected maximum utility

is also the logsum, but it is calculated for the root, or the highest level of the model, which includes in it the logsums from the lower levels (Dong, et al., 2006).

This measure can also be related to microeconomic theory of consumer surplus, but first the measure must be normalized, ensuring that both scales and level conditions are satisfied, before comparisons can be made across individuals.

Recent advances in utility-based accessibility studies pointed towards the inclusion of the space-time and activity-based trip theory. The first was described in the previous section (the space-time measures explained accessibility phenomena within the analytical structure of utility functions) and the second is described in Dong, et al. (2006).

The aspect of activity-based accessibility measure is that it measures accessibility to all activities in which an individual engages, incorporating constraints, such as scheduling, and travel characteristics such as trip chaining (Dong, et al., 2006)

3.2 Results of accessibility clusters evaluation

The accessibility clusters evaluation is based on the question of the theoretical basis, interpretability and data requirements being included or not in the measures and how the criteria is satisfied.

The evaluation starts with the presentation of Table 1 adapted from Geurs and Van Wee (2004) that provides an overview of the components for each accessibility cluster. Table 2 and 3 presents the analysis of the accessibility clusters by addressing the theoretical basis (Table 2), data requirements and interpretability (Table 3).

As mentioned in previous sections, this evaluation is more conceptual rather than numerical and real-world applications aspect of the measures, since the method was designed on this frame. The analysis of the results and conclusions are presented in the Discussion section.

Table 1. Perspective on accessibility and components

Accessibility Measures	Land-use	Transport	Temporal	Individual
Infrastructure	-	Travelling speed, vehicle hours lost in congestion	Peak-hour period; 24-hr period	
Location			Travel time may be sensitive to peak-hours period	-
Gravity	Distribution patterns of demand and supply	Distance, travel time, cost (generalized cost) between locations of activities	Temporal constraints of activities and time available for activities	
Space-Time			Travel time may be sensitive to peak-hours period (individual travel times)	Individual level analysis
Utility				

Table 2. Summary of review of accessibility measures: theoretical basis

Accessibility Measures	Desirable Properties ^a						Framework of Accessibility Elements ^b			
	(1)	(2)	(3)	(4)	(5)	(6)	Land-use	Transport	Temporal	Individual
Infrastructure	1	1	-1	-1	-1	-1	-1	0	0	-1
Location	Spatial Separation	1	1	-1	-1	-1	0	0	0	-1
	Contour	1	1	-1	-1	-1	0	0	0	-1
	Potential	1	1	-1	-1	0	0	0	0	-1
Gravity	1	1	-1	-1	0	-1	0	0	0	-1
Space-time	1	1	1	1	-1	1	1	1	1	1
Utility	1	1	1	1	-1	-1	1	1	1	1

Score: "1" means criterion satisfied, "0" criterion moderately satisfied, "-1" criterion not satisfied.

^a Desirable Properties: (1) The accessibility measure is always positive, null only if the individual (or groups of individuals) has insufficient abilities or capabilities to use any mode of transport system or participate in that activity. (2) If the service level (i.e., improvement of travel time, reduction of costs and effort) of any transport mode in an area increases (decreases), accessibility should increase (decrease) to/from any activity in that area, or point within that area. (3) Improvements in one transport mode should not alter the accessibility to any individual (or groups of individuals) with insufficient abilities or capabilities to use that mode or participate in that activity. (4) Personal accessibility (point-based spatial) offers individual level analysis. (5) Accessibility should reflect the role of supply-demand aspect (competition effect). (6) Accessibility should identify constraints which surrounds actors (reflect the space-temporal limits of activities).

^b Representational framework for the relations among the accessibility elements.

Table 3. Summary of review of accessibility measures: data requirements and interpretability

Accessibility Measures	Data requirements ^a				Interpretability ^b
	Land-use	Transport	Temporal	Individual	
Infrastructure	-1	1	-1	-1	1
	Spatial Separation	1	1	1	1
Location	Contour	1	1	1	1
	Potential	1	1	1	1
Gravity	1	1	1	-1	-1
Space-time	-1	0	-1	0	-1
Utility	1	0	0	0	-1

^a Score: "1" means easy availability, "0" moderately availability, "-1" scarce availability or criterion not applicable.

^b Score: "1" means easy to interpret, "0" moderately to interpret, "-1" difficult to interpret

4. Discussion

Accessibility must be structured according to a broad range of requirements made by theoretical basis (including representational framework for the accessibility components), data, application and interpretability for researchers and policy makers.

This paper proposed a method framed to present necessary and sufficient conditions for the validity for accessibility measuring and evaluate the representation-theoretic aspects of the distinguishing approaches of accessibilities studies by addressing criteria applied to review on this topic in the literature. The question that might arise is if the set of criteria has ever been fully explored, and it does appear that the research frontier will keep expanding on it.

However, it is clear that this work achieves the possibility of a different approach to represent and interpret the relationships among elements and accessibility, and relationships among the elements themselves and should serve as foundation for accurate measuring and modeling of accessibility and thus address the expected functionality, a tool to help researchers and policy makers as planning framework to tackle some of the problems of urban planning.

Infrastructure and location measures present shortcomings on the theoretical basis (desirable properties: inclusion of 2 among 6 properties; and representational framework on the accessibility components). These shortcomings can be viewed as limitations to tackle some of the problems of urban planning.

Gravity measures reflect more the calibration aspect of interaction models for trip distributions rather than interaction among accessibility components. The accessibility concept of Fortheringham (1983) addresses the spatial proximity among destination when it seems more appropriated to achieve the situation when equilibrium of supply and demand for activities has been overtaken by reality.

Recent progress in accessibility studies point towards the inclusion of more individual's spatial-temporal accessibility measure (using the space-time prism concept) but the data requirements, and interpretability of this measure remains as a problem.

Utility-based measure addresses the individual perspective and it has the advantage to compute the economic benefit of the destination attributes. However, this measure is not easily interpreted without a reference parameter (e.g., monetary terms) and it is relatively demanding on data.

Another aspect to take into account about utility-based measure is the assumption that the decision to engage in an activity only belong to an individual. In fact, in highly competition environment, as the labor market when the supply for jobs is insufficient for the demand, the individual is compelled to engage where the activity is available to him. Moreover, in others cases, related to the labor market, the decision of the employment belongs more to the employer rather than the individual.

Furthermore, most of the studies fail for not considering the competition for opportunities (e.g. jobs on the employment market), and it seems to be an issue for the development of more realistic accessibility measures.

Location measures are moderately not so demanding on data and easier to interpret for researchers and policy makers. However, simple spatial measures such as distances or travel time (primary approximations to a more complex evaluation of spatial separation under constraints in relative space) represent a linkage between accessibility and urban travel demand studies in spatial interaction models, thus an understanding of the behavioral responses to the spatial separation of locations of supply to the locations of demand.

Drawbacks of spatial measures, lack of individual perception, representational framework of components and competition for opportunities, can be overcome by taking the individual perspective with the capabilities offered by geographic information systems, different relationship structure among components and delimitation of the potential action space which opportunities are accessible to individual (space-time prism concepts and competition for opportunities).

There are many open research problems associated with the use of accessibility in the context of location models and it is expected to see more research on this topic in the future.

Acknowledgements

This research was given financial support by the National Council for Scientific and Technological Development (Brazil), through grants 141058/2006-4, the São Paulo Research Foundation (Brazil), through grants 06/57487-5 and the CAPES Foundation (Brazil), through grants BEX2188/07-4. The first author is greatly indebted to Mr. Bert Van Wee on his kind help to understand the knowledge behind the competition effect on his paper and Mr. Jorgen W. Weibull to able the access to his valuables papers.

References

- Ben-Akiva, M. & Lerman, S.R., 1979. Disaggregate travel and mobility choice models and measures of accessibility. In: D.A. Hensher, D.A. & P. R. Sopher, eds. 1979. *Behavioural travel modelling*. Andover, Hants: Croom Helm, pp. 654–679.
- Burns, L.D. & Golob, T.F., 1976. The role of accessibility in basic transportation choice behavior. *Transportation*, 5, pp. 175-198.
- Dong, X., Ben-Akiva, M.E., Bowman, J.L. & Walker, J., (2006) Moving from trip-based to activity-based measures of accessibility. *Transportation Research Part A*, 40 (2), pp.163 – 180.
- Ettema, D. & Timmermans, H., 2007. Space-time accessibility under conditions of uncertain travel times: theory and numerical simulations. *Geographical Analysis*, 39, pp.217-240.
- Fortheringham, A.S., 1983. A new set of spatial interaction models: the theory of competing destinations. *Environment and Planning A*, 15, pp.15-36.
- Geurs, K.T. & Van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*, 12, pp.127-140.
- Hägerstrand, T., 1970. What about people in regional science? *People of the Regional Science Association*, 24, pp.7–21.
- Hansen, W. G., 1959. How accessibility shapes land use. *Journal of American Institute of Planners*, 25 (1), pp.73–76.
- Ingram, D. R., 1971. The concept of accessibility: a search for an operational form. *Regional Studies*, 5, pp. 101–107.
- Kwan, M., et. al, 2003. Recent advances in accessibility research: representation, methodology and applications. *Journal of Geographical Systems*, 5, pp. 129-138
- McFadden, D., 1973. Conditional logit analysis of qualitative choice behavior. In: P. Zarembka, ed. 1973. *Frontiers in econometrics*. New York: Academic Press, pp. 105-142.
- Miller, H. J., 1999. Measuring space–time accessibility benefits within transportation networks: basic theory and computational procedures. *Geographical Analysis*, 31 (2), pp.187–212.
- Straatemeier, T., 2008. How to plan for regional accessibility? *Transport Policy*, 15, pp.127-137.

Thomas, R.S., 1977. An interpretation of the journey to work on Merseyside using entropy-maximizing methods. *Environment and Planning A*, 9, pp. 817-834.

Van Wee, B., Hagoort, M., Annema, J.A., 2004. Accessibility measures with competition. *Journal of Transport Geography*, 9, pp. 199-208.

Von Bertalanffy, L., 1968. *General systems theory: foundation, development and applications*. New York: George Braziller.

Weaver, W. (1961) A quarter century in the natural sciences. *Public Health Report*, 76 (1), pp. 57-66.

Weibull, J. W. 1976. An axiomatic approach to the measurement of accessibility. *Regional Science and Urban Economics*, 6, pp.357-379.

Weibull, J.W. 1980. On the numerical measurement of accessibility. *Environment and Planning A*, 30 (12), pp.53-67.

Wilson, A.G., 1967. A statistical theory of spatial distribution models. *Transportation Research*, 1, pp. 253-269.