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Evolving term “Accessibility” in spatial systems: Contextual Evaluation

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Abstract

Access terminology has been constantly evolving since its inception by Hansen in the year 1959. Accessibility is central to multiple disciplines such as geography, transportation, health, economics, social sciences etc. Developing indicators to measure access has been constant practice and has been evolving in interpretation as per application. Although, there has been extensive focus on examining nature of accessibility and develop its indicators, there isn't much work done on understanding how these indicators' focus has changed over time. The current work focuses on literature based contextual evolution of these indicators in measuring accessibility.

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Keywords: Accessibility; Evolution; Review; Measures; Indicator

1. Introduction

“Access” is derived from the Latin word ‘accedere’ which means “to come” or “to arrive”. Access refers to the possibility of reaching a place, goods, services etc. also known as opportunities, conveniently and comfortably. Accessibility is the potential for interaction and exchange (Hansen, 1959). As mentioned by (Dalvi and Martin, 1976), accessibility is how easily we can reach any activity using a certain transport system (Bocarejo S. and Oviedo H., 2012). It generally deals with estimating the availability of opportunities resulting from both transportation supply and land use characteristics (Halden *et al.*, 2000). The studies reviewed in this article help to understand how the focus on indicators of accessibility have evolved over time. The current work takes a perspective of reviewing the published

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articles and develop on the knowledge overlap for measuring accessibility, as specified in these studies. The review tries to develop a broader picture of understanding accessibility measures.

1.1. Search and Inclusion Criteria

The study is done by searching articles in Google scholar with keywords like ‘accessibility indicator review’, ‘accessibility measures’, ‘accessibility indicator’. The results were further sorted based on decadal pattern of publishing, starting from up to 1970 as first slot and increasing by ten years up to year 2000, thereafter each year was searched individually up to 2018 to find at least one article in each year, relevant to the given context. The search aimed at finding at least one review article in the domains of transportation systems, geographical systems and health systems with the word “accessibility” in either title or abstract in each year, 2000 onwards. As the main purpose of writing this article is to develop an understanding of how indicators have evolved and to highlight the concepts which repeat time and again in accessibility literature. The search started with skimming through articles, reading their titles and narrowing down to the ones deemed relevant. In the second stage of shortlisting, the abstracts of the articles were evaluated for their focus on accessibility study and if any indicator was used to evaluate it. This led to finalizing of about 40 articles, out of which about 15 were pertaining to health issues which were excluded during in depth review. These were then read through in detail to find the overlaps between the knowledge on accessibility indicator presented in them. The following sections of the current article is arranged as under: First the concept of accessibility as defined in geography, transportation and health are discussed. Second, timeline of evolution of accessibility studies is tabulated. Third, general approaches to measure accessibility is tabulated. Fourth section discusses theories behind accessibility measures. Fifth section brings forward the measurement problems with appropriate examples. Last, section integrates the core understanding of spatial, temporal and economic measures and related them for their direct and indirect use as measure of accessibility.

1.2. Accessibility in Geographical/Spatial systems

Travel time estimates function the best in estimating accessibility in geographical systems. Recent studies in health indicate its value in the form of impedance measures. Other major impedance measures in spatial systems being distance and speed. Latest developments in geographical information software has paved way for new possible dimensions to measure travel time. Accessibility studies have become more reliable as they are now capable of accounting impedance such as speed, which was not possible in prior studies. This signifies shift of accessibility measures from Euclidean distance and network distance to network travel time and now to further day-time based network travel time (Delamater *et al.*, 2012).

Space time framework has been consistently used for direct assessment of accessibility. Accessibility is basically measured in space-time prism, such that activities are accessible in a given time budget for flexible participation and travel velocities as per transportation system. Even though space-time tool emerges as a powerful option for measuring accessibility, a major constraint comes from the assumption of constant velocity and unreliable estimates of travel time and associated randomness. Velocities have a tendency to change even for the same location based on traffic variation, time of the day, weather etc. Travel time in addition to above factors depends on the incident related parameters. Delay caused due to road traffic congestion at incident site is unaccounted in most of the studies. Also, it is difficult to handle data in space-time frame. Being able to perform analysis on networks could thus form a realistic and practical technique for assessing accessibility which has been made possible by reliable travel time estimation methods available now. Besides GIS applications, Map based network application interfaces provide reliable estimates of travel time without knowledge of real time speeds (Miller, 1999; Wu, Liang and Liu, 2013; Basu, Aggarwal and Jana, 2017; Shaw *et al.*, 2017).

1.3. Accessibility in Transportation

Traditionally, accessibility in transportation has been established as the ease of reaching a destination from an origin, by utilizing the available travel mode options with inherent impeding properties of the route—generally time, distance and mode of transport (Niemeier, 1997). Accessibility can be measured as the total travel time saved by road

users and how many more destinations can be reached by the different road users in their travel time budget (Tiwari and Jain, 2012).

Accessibility and Mobility are generally confused terms in transportation planning. While mobility is the ease of moving people and goods, accessibility is the ease of reaching opportunities. Mobility is the subset of accessibility (Litman, 2003).

Table 1. Timeline for evolution of accessibility studies covered in the article

Year/Citation	Contribution	Definition
(Hansen, 1959)	Defined accessibility	The potential of opportunities for interaction
(Dalvi and Martin, 1976)	Defined transportation accessibility	The ease with which any land-use activity can be reached from a location using a particular transport system
(Pirie, 1979)	Attempted to construct measures of accessibility	Measures of access by examining the limitations, strengths, and conceptual basis of distance, topological, gravity, and cumulative opportunity measures of accessibility
(Handy and Niemeier, 1997)	Framework for implementation of measures	Defines accessibility as person's ease to visit destinations to meet their needs
(Geurs and van Wee, 2004)	Implementation of accessibility measures in transportation	Define accessibility as the extent to which land use and transport systems enable individuals to reach activities or destinations by means of transport mode
(Liu and Zhu, 2004)	Activity based definition of accessibility	Activity from one place to another via a particular traveling mode
(Handy, 2005; Vale, Saraiva and Pereira, 2015)	Opportunity and Activity based assessment	Defines accessibility as the ability to reach relevant activities, individuals or opportunities, which might require traveling to the place where those opportunities are located
(El-Geneidy and Levinson, 2006)	Attempted to portray access to destinations	Define accessibility as the measure of reaching valued destinations
(Geurs and van Wee, 2004; Medda, 2012)	Highlights scope of accessibility as a variable	Accessibility is but one of many variables determining location quality and value.
(Vasconcelos and Farias, 2012)	Accessibility in urban planning	Accessibility in an urban area is characterized by short trips.
(Martínez and Viegas, 2013)	Survey based measures of accessibility	Distance-decay or impedance function can be modelled in order to improve their representation of location attractiveness using empirical and stated preferences data obtained from an internet survey.
(Neutens, 2015)	Constructed in activity based concept of accessibility	Degree to which transport systems enable people to reach desired activity locations.
(Wang <i>et al.</i> , 2016)	Comfort as component of accessibility	Degree of convenience of travel from one location to another
(Liu <i>et al.</i> , 2018)	Individual centric measure of accessibility	The freedom of individuals to decide whether or not to participate in different activities

In table 1, we present the changing definitions of accessibility. In late seventies, accessibility was mostly based on gravity measures of location, distance and time, which developed to using infrastructure and transportation system enabled access in late 90's. Early 21st century experienced accessibility being defined more in terms of the perusal of activities. Activity oriented accessibility planning approaches came into planning domain. The accessibility is now quantified being much more than mere distance, time and cost. The focus shifted to making locations more accessible to activities which not only were independent of destinations, but also presented attribute of convenience and freedom of choice in accessing activities.

1.4. Accessibility in Emergency Health Care

Health services are said to be accessible if the combination of their location, type, expenses, acceptability is inline with patient's expectations. Bidgoli et al. made distinction between health access and health needs for road traffic injuries. Access is defined as physical availability of pre-hospital trauma care facilities and need was defined as number of injuries and deaths due to road traffic crashes in each province (Bidgoli, Bogg and Hasselberg, 2011).

(Noda et al., 2014), use distance between a crash site and the location of the life-saving emergency centre, (distance to EMC) instead of time as indicator of fatality rate from motor vehicle crashes. Their results showed that the distance had positive effect on fatality. For distances below 40 km, reduction in distance from Emergency Medical Centres (EMC), decreased rate of fatality. For hazard recognition, speeds less than 70 kmph and distance to emergency medical service (EMS) were significant secondary or tertiary variable. Longer distances from EMC's had adverse effects on fatalities. Even though the distance to EMS is said to be significant variable in their results, distance for ambulance to reach crash sites, their length of time and their impact on fatality has not been assessed. The true impact of ambulance services is not completely clear by this measure of access to emergency care.

It is noteworthy that mobility in transportation literature, defined as the ability to travel to destinations is also measured in terms of time (Arora and Tiwari, 2007), but mobility is said to be higher with higher time value, whereas in case of emergency services this may not be the correct measure, as higher time to transit for required care might have serious consequences.

1.5. General approaches to measure accessibility

The definition of accessibility has been broadly studied in relation to infrastructure, activity and mixed approach (Van Wee, Hagoort and Annema, 2001; Bocarejo S. and Oviedo H., 2012).

There are four major components of all the measures:

1. Transport: Reflects the disutility that individuals or groups experience in traveling from origin to destination using specific transport mode. It's usually expressed in amount of time, cost and effort.
2. Land-use: It shows the spatial distribution and magnitude, quality and character of activities found in each destination
3. Temporal: It addresses the spatial distribution of resources and their utilization at different times.
4. Individual: It shows the needs, abilities and opportunities of individuals depending upon their physical state and access to transport modes. Opportunities depend on people's income, budget, education etc. (Banister, 2012; Bocarejo S. and Oviedo H., 2012; De Montis and Reggiani, 2012)

Table 2. Approach based measures of accessibility

Accessibility Approach	Measures/ Variables
Infrastructure	Speed, travel time, travel speed, congestion length of road, density on road network, overall congestion level in terms of lost vehicle hours (Van Wee, Hagoort and Annema, 2001; Pablo, Juan and Oviedo, 2012).
Activity	Land use & location, time-space measures, potential paths, living, working, recreating, shopping, the number of activities accessible in a given range of travel time or distance (Hansen, 1959; Gutiérrez, 2001; van Wee, Hagoort and Annema, 2001; Dong et al., 2006; Bocarejo S. and Oviedo H., 2012)

Individual Preferences	Space–time accessibility measures, time budgets for mandatory activities, speed offered by transport systems (Bocarejo S. and Oviedo H., 2012)
Mixed	Distances between locations and intermediate destinations to access locations Measures include: travel costs (monetary, time, risk, comfort, quality characteristics), volume (number of people, vehicle units, bus stops, etc) location (from one place to another or many places to many places) (Van Wee <i>et al.</i> , 2001; Pablo <i>et al.</i> , 2012)
Utility	Benefits acquired by people when accessing activities distributed in space, opportunities and challenges, characteristics of individuals, characteristics of different transport mode, time budgets, speed , spatial-temporal constraints, daily schedule of activities (Handy and Clifton, 2001; Dong <i>et al.</i> , 2006; Pablo <i>et al.</i> , 2012)
Social Exclusion	An individual is socially excluded when he or she resides geographically in a society but cannot be involved in its normal activities. These indicators are relational, with a focus upon resource and power relationships between individuals, groups and the state, In living space: neighborhood (including safety, crime); poor local environment; disunity of community; geographical isolation (accessibility); local services (including transport, education), In mobility: it is due to poor or unavailable transport, reduced accessibility to social networks, facilities, goods and services (Kenyon, Lyons and Rafferty, 2002; Arora and Tiwari, 2007; Bocarejo S. and Oviedo H., 2012)
Geographical Location	Proximity to urban opportunities (Geurs and van Wee, 2004; Chen <i>et al.</i> , 2017)

As discussed above, accessibility measures are variable depending on the context of application. Table 2 presents a summary of general approach to measure accessibility fall in 7 broad categories: Individual, Activity, Individual's Preferences, Mixed Measures approach, Utility based measures, Social Exclusion, Geographical Location. The approach to measure access depends on the disaggregation level at which it is measured. At Individual level, individual characteristics, activities, and preferences are taken into account. The context of social exclusion, area access/geographical location comes into account when the aggregation level is to a community. Further, when the communities are combined, and their infrastructure is being assessed for compliance with accessibility and people start to embed accessibility in planning, the cities grow to form accessible places for the community individuals. Although, it might seem on the surface that individual choices would be so disaggregate that integrating them in planning measures would be seemingly impossible, it turns out that the overall accessibility of a place is closely integrated at all levels, ranging from community members to a city. This leads us to understand the core elements of all accessibility studies.

1.6. Core aspects of accessibility indicators: Space, Time, Expense

Accessibility has been measured in different ways in literature. Trend has been to tweak aspects to redefine accessibility for different domains. They either vary the definition of accessibility i.e. define them in relative terms such as real accessibility, accessibility given standard parameters and accessibility under desired preferences or measure them pertaining to certain *variables* relevant in their individual context. Lately, it has been observed that all accessibility indicators have three main aspects: spatial, temporal and economic(Wang *et al.*, 2016). This section explores the use of these accessibility measures in the overall domain of spatial, temporal and economic spectra. The attempt is made to quantify the variables outlined in previous sections in terms of their direct or indirect use in related studies. As the understanding develops, the measures, whatever their domain of study be, are used to make the accessibility measure in the umbrella of space-time-cost. For this the relevant variables are described in table 3 by '+' and not relevant by '-'.

Table 3. Variables used as direct and indirect measures of spatial, temporal and economic accessibility

Usage Matrix	Spatial	Temporal	Economic	Direct/ Indirect Measure
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Distance	+	-	-	Direct
Time	-	+	-	Direct
Cost	-	-	+	Direct
Speed	+	+	-	Direct
Effort	+	+	+	Indirect
Opportunities	+	+	+	Indirect
Congestion	+	+	+	Indirect
Land use	+	+	+	Indirect
Settlement Distribution	+	-	+	Indirect

1.7. Measurement problems with examples

Although the broad aim of accessibility is clear since 1950's as defined by Hansen: the ease of reaching desirable destinations (Hansen, 1959), the spectrum of indicators shown above indicate that the definition of “Accessibility” has been repeatedly used based on the problem at hand and its application in that context. There is an evident overlap between the variables used in different indicators, none of them has the capability of representing the situation in its entirety. It only gives a measure to understand the problem at hand as best as possible given the data sources available. So the variables that have confounding property on each other might be counted more than once while those which cannot be measured in quantifiable terms are prone to be left out or rather just be measured qualitatively.

The other difficulties in calculating accessibility include problems in data quality, zonal structure of transportation planning models, their reliability and adequacy etc. For example: To measure the accessibility of non-motorized transport, knowledge of its travel behavior, reliable data and computational power to be able to use that data, is deficient in its current form.

Many studies choose to ignore intricacies which are dynamically evolving and difficult to measure such as congestion and choose free flow travel as approximation while performing traffic studies.

While gravity-based measures are strong indicators of accessibility as they consider destinations of interest along with the costs of travel (by any mode), and incorporates more complexity into the calculation of ‘opportunities’ (another way of describing a valued destination), they assume that everyone in a measured zone has the same level of accessibility, thereby ignoring all the individual preferences that characterize human behavior.

As for location-based measures, depend rather strongly on the way the internal distance problem is handled. In models based on travel impedance, zones of analysis are poorly matched as compared to their spatial scale of movement. Example: While accounting accessibility by non-motorized transport, the scale of movement of pedestrians is different from that of bicycles and cycle rickshaws, thus it becomes difficult to narrow down the size of the zone of analysis which will directly influence the results of the indicator, thus smaller zones of analysis are preferred.

In network based models, it becomes difficult to account for all the environmental parameters either due to their unavailability of information or due to evolving nature of these parameters (Krizek, 2010).

While measuring accessibility, we tend to ignore internal accessibility components. The reason is that the functional forms used lead to high weights for the internal accessibility. The unreliable data on local transport network gives highly variant results which could lead to unrealistic results. This leads to biased accessibility estimates, especially for large cities. The use of small areas in the case of a grid system clearly leads to a smaller dependence on the internal accessibility, and hence provides a good way of avoiding this problem. While considering effect on potential accessibility because of travel time decay (a halving of travel time leads to a doubling of the weight) contribution of a city to its own accessibility may be considerable for large cities. But travel time decay concept does not hold until the travel time exceeds a critical level (of about 6 hours)(Rietveld and Bruinsma, 2012).As mentioned by Larsson, the method given by Breheny, 1978 (Larsson and Olsson, 2017) to determine accessibility of opportunities (points, destinations, costs), keeping one factor constant and determining the accessibility in relation to other factors, Larsson

found that it has a major limitation of treating all target points as equally valuable, regardless of the travel time and distance which have major influence on relative accessibility of these opportunities (Larsson and Olsson, 2017).

1.8. Conclusion

As the understanding develops, accessibility measures are based on prime framework of using space, time and economic variables. All other variables which have been used in accessibility studies just change their nature due to the variation in the implementation or evaluation scale, field and region. The common problem of interpretation and integration of multiple dimensions of variables are difficult to overcome in the functional form of accessibility indicators. Limitations due to sheer difference in scale of representation and their limited scope of evaluation due to context specific indicator design and qualitative variables become unavoidable sometimes. Accessibility is a broad concept with many domains under its umbrella. It is difficult to cover all indicators in any reliable planning process. At the same time it becomes important to address access issues for the community, accounting their needs and resources. Access and its evaluation is difficult in process while if accounted and addressed properly, could lead to harmonious development of communities and their growth oriented development.

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