

## Evaluating Urban Transportation Accessibility: A Systematic Review of Access Dimensions and Indicators



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### ABSTRACT

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Urban transportation systems and their integration with spatially distributed opportunities are pivotal for ensuring effective accessibility. This study aims to rigorously evaluate urban accessibility by scrutinizing established criteria and measurement approaches within the literature. A systematic literature review was executed, targeting articles selected for their pertinence and citation impact. Through meticulous analysis, four cardinal indicators of access and their respective subsets were distilled. Synthesizing data from 61 scholarly publications elucidated the key indicators of accessibility. The findings underscore the adaptability and utility of these criteria as evaluative instruments and in guiding policy decisions. On the other hand, availability and quality of data, greater attention to travel reliability and user preferences are among the factors that should be considered in the accessibility assessment. The study's insights advocate for a nuanced application of accessibility indicators, promoting their evolution as multifaceted tools in urban planning domains. These results serve as a foundation for future research and contribute to the refinement of methods for comprehensive accessibility analysis in urban settings.

## 1. INTRODUCTION

In the realm of sustainable urban planning and land use, accessibility is of paramount importance, necessitating a judicious balance between the immediacies of mobility needs and the overarching tenets of sustainability. Research consistently underscores the primacy of accessibility as an objective within planning frameworks [1]. Accessibility should be construed not merely as a facet of transportation but as an encompassing construct that integrates various elements vital for in-depth analysis.

This study is predicated on the objective of delineating the interrelationship between accessibility and urban services. Through a comprehensive literature review, it endeavors to deepen the understanding of accessibility and to propel its conceptual development forward.

Accessibility's ultimate aim is the amelioration of urban environments to facilitate complete and equitable utilization by individuals of all abilities. Consequently, contemporary analysis must extend beyond transportation infrastructures to embrace a broader spectrum of contributory elements. The literature reveals a plethora of definitions and methodologies for measuring accessibility indicators, reflecting the complexity and multifaceted nature of the concept.

The influential analysis by Geurs and Van Wee [2] represents a significant portion of the literature that dissects the various components of accessibility and its attributes of interpretability, commonly cited across scholarly articles. Given that an intricate comprehension of accessibility's true

essence owing to its technical and multifaceted nature has the potential to drive societal transformation, this research is committed to a methodical exploration of the nexus between accessibility and urban services. Employing a systematic literature review alongside a network bibliometric analysis has been instrumental in pursuing this aim.

The article is systematically divided into several sections for clarity and coherence: Section 2 introduces the general concept of accessibility, laying the groundwork for subsequent discourse. Section 3 categorizes accessibility criteria, informed by the analytical groundwork of Geurs and Van Wee [2]. Section 4 expounds on the methodological approach underpinning the article analysis. Lastly, Section 5 consolidates and discusses the findings, culminating in a set of conclusions that advance the current understanding of accessibility within urban environments.

## 2. THE CONCEPT OF ACCESSIBILITY

Accessibility is a concept that has played a central role in physical planning over the past 50 years. Improving access is a goal that has now made its way into major transportation planning and transport policymaking worldwide. Hansen [3], in his classic explanation about accessibility and land use, provides the first actual description that accessibility is the ease of reaching desired destinations and is increasingly used as a planning model for displacement. Accessibility enhances performance and activities in specific locations and is a

spatial and social phenomenon that influences mobility. By prioritizing mobility, proper access can be provided, ensuring that people with different abilities can fully utilize the urban environment [4].

### 3. ACCESSIBILITY CRITERIA

In the literature, access criteria have been suggested as a primary tool for gaining a proper understanding of access. Various indicators of accessibility, encompassing theoretical, operational, interpretability, and communication aspects, offer avenues for their utilization in achieving evaluation objectives.

Given that accessibility is defined and measured using different indicators, this section outlines the main approaches based on the literature review:

- **Location and Land Use Criteria:** The first discussed index is the location-based index, which involves the spatial distribution of different land uses, quantified in terms of quantity (residential density, employment) and quality (employment level, housing value, service importance). Measures based on this index provide insights into locations and are commonly used by policymakers to assess land use and transportation comprehensively at the regional and local levels.

This index can be generalized into the following important set for examining corresponding actions:

1. **Gravity-based Criterion:** This criterion measures travel opportunities and incorporates costs discounted based on travel time or distance. It focuses on improving accessibility to destinations and emphasizes the spatial distribution of origins and destinations in relation to land use. The gravity-based criterion is widely accepted in the transportation field due to its strong theoretical foundation and superiority over cumulative opportunity measures [5].

2. **Cumulative opportunities:** This criterion estimates opportunities within a specific range and threshold of attraction-based travel costs. It is essential for clarifying budget allocation debates and investigating people's differential access to various travel methods. However, a widely accepted limitation of this criterion in politics is its failure to consider the effect of competition for available opportunities [6].

3. **Travel Mode Criterion:** This measure, called travel mode, is derived from the location-based index. It focuses on the predominant modes of travel, namely private cars, public transport, and active modes (walking, cycling). It is commonly used in transportation choice studies. It is worth noting that studies comparing access levels by car and transit using location-based indicators provide relatively simple estimates of mode-specific travel time.

4. **Proximity-based criterion:** This index is based on the proximity of key destinations, such as city cores or transit stations, and is particularly associated with walking in many places.

5. **Travel time criterion:** There is a strong positive relationship between this criterion and access. Other access variables within the location-based index subgroup are estimated to be marginally significant. Travel time calculations may also incorporate a mode index, typically relying on available data from transportation models and programs.

- **Transportation Component:** This criterion assesses the effectiveness of the transportation system in bridging the distance between origin and destination and the specific transportation method used. It encompasses criteria based on infrastructure measures and the environmental dimension.

1. **Criterion Based on Infrastructure Measures:** This criterion provides insights into the performance or service level of transport infrastructure, with a focus on the quality of the transport network.

2. **Criterion based on the Environmental Dimension:** it focuses on energy consumption and its external effects.

- **Time-based Component:** This component considers time-related constraints, such as the availability of opportunities at different times of the day and the time individuals have for specific activities. Other time components, including arrival and departure time, waiting time, and total travel time, can be included in this index through multiple estimates [6].

- **Individual Level and Social Component:** This component considers individual facilities, personal limitations, and socioeconomic characteristics to assess access. Research indicates that people perceive access levels differently based on individual indicators, and their willingness to travel to access opportunities varies. Consequently, this access index introduces as relativity, which can lead to biased results when considering the absolute parameters of well-being and sustainability.

### 4. METHOD

The analytical method used in this research is the combination of systematic literature review and a bibliometric analysis approach in terms of quality and combination of results. It provides a deeper understanding of the content of the analyzed issue. On the other hand, this approach is a comprehensive bibliometric analysis, and the development of the subject over time is done using quantitative analysis of publications and their bibliographic features. In bibliometric analysis, publication data such as title, authors, keywords, summary, sources and citations are used as parameters.

In this study, network analysis has also been done using VOS Viewer software. In visual network analysis, nodes represent publications. Its dimension, the number of citations and simultaneously the arcs provide the relationship between two or more publications according to their bibliographic sources.

Searching for articles in scientific databases was considered until 2022. In the first stage of this process, keywords such as access, criteria, time and access, land use, etc., were used to search the titles and abstracts of publications. In the second stage, filters such as the number of citations (an average of 10 citations per year of publication) and DOI identifier (guarantee of authenticity) were considered. Finally, for the qualitative evaluation of the study and considering the purpose of the research, publications from 2010 with more complete coverage of the topic under discussion were selected.

The selected publications cover the period from 2010-2022. At the beginning of this search process, 184 articles were obtained from Google Scholar and Scopus databases. In the following, 114 publications were selected by applying restrictions in order to achieve a more favourable result.

In continuing this process, considering the indicators

proposed by Geurs and Van Wee [2], discussed in the 3rd part of this study, we classified the selected publications and collected information extracted from them in line with the discussed approach. Finally, descriptive analysis was performed by VOS viewer software.

## 5. RESULTS

### 5.1 Review layout

As mentioned earlier, according to the literature, access criteria are divided into several components and subsets. The selected articles are shown as a bibliographic network according to Figure 1.

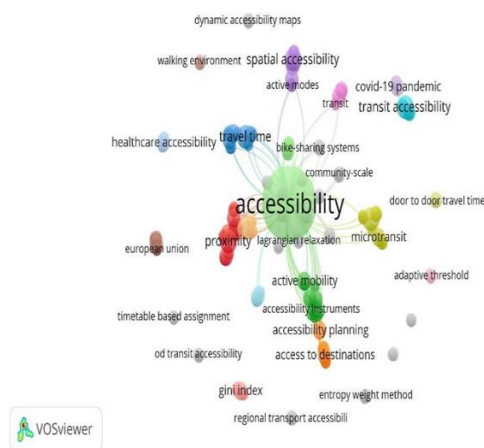


Figure 1. Bibliographic network

Transportation and the built environment were mainly indicators that were considered to be dominant issues. Transportation services have been in focus since 2004, and land value since 2010. After that, other phenomena emerged, such as the bicycle-sharing system since 2012, which has shown its impact on transportation and accessibility.

### 5.2 Approaches

Among the 114 selected articles, 61 articles were separated and analyzed with more attention to the topic under discussion.

Considering the measurement approach of accessibility indicators, travel time is regarded as an effective indicator. On the other hand, access time is directly affected by restrictions and changes in the times when opportunities are actually available can usually be explained by the geographical concept of space-time. The quality, diversity and characteristics of activities affect the perception and experiences of users and the time diversity of the availability of opportunities and public access. These characteristics, along with the population, are considered as an indicator of the attractiveness of the regions. Studies also show the relationship between location and access, the primary variable of which is population. Optimum access also increases the speed of travel and the distance covered simultaneously. On the other hand, it has been stated that proximity to transportation centers can lead to different travel patterns.

Table 1 presents access indicators, parameters used, approach to measuring access indicators and related studies.

Table 1. Main method and data in accessibility studies

Topic	References	Method	Main Data
Transportation criterion (Infrastructure and Environmental Dimension)	[7],[8],[9],[10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33]	SNAPTA, IDW, GMM, SEMCOG, FCA, VISUM, AHP, GWR Method	Transportation data, Landuse, destination data, OSM, VGI, Cost, Operational data (Routes, flow direction, stops), Demographic, CBD, GTFS, ODS, OSM, Distance
Criterion based on Location and Land Use (Travel Mode, Travel Time, Gravity, Cumulative Opportunities, Proximity)	[34], [9], [12], [35], [14], [36], [37], [16], [17], [18], [38], [20], [22], [39], [40], [41], [42], [24], [43], [44], [25], [45], [46], [26], [47], [48], [27], [28], [49], [50], [51], [52], [53], [54], [55], [56], [57], [31], [33], [58], [59], [60], [61], [62], [63], [64], [65], [66]	Clustering, OLR, ML, K- Means, VOT, A-VCA, WATT, GLS, IAO, Mont Carlo, SUR Method, Cubeof Travel Time Gravity, STEM, ISE, Proximity Model, STP, Last Mile, Mozon's Method	Demographic, GTFS, Travel Demand, Travel Purpose, Travel Time, Jobs, Stops, The Number Of Daily Traveling, Activities, OD, GIS Data, TAZ data, Physical Data, Spatial and Geographic Data, Cost, Travel Behaviour Data, OSM, The Number of Disabled People, POI
Individual Level and Social Component	[67], [15], [36], [37], [20], [22], [68], [47], [48], [69], [49], [70], [31], [32], [60], [29]	STP, ASTP, FCA, CBA, MCA, WNR, PNR	Demographic (Such as Household Size, Income, Car Ownership, Education Survey Data)
Time-based criterion	[66]	Dijkstra's Shortest Path Algorithm	GTFS

In the approach of measuring accessibility, the spatial network analysis method (SNAPTA) has shown a good potential in analyzing and achieving more efficient results in determining the effects of transportation infrastructure. It should also be mentioned that travel time, as an essential indicator, played a role in almost all analyses. A good method for its analysis is the cube of travel time and review based on the last mile and space-time prism (STP), which has been able to reflect adequately the access gap based on the person, time, and transportation. On the other hand, the K-Means method has achieved more complete results based on individual limitations and social characteristics. Finally, Mozon's proposed method of balancing the benefits of access in combination with the surrounding environment has been shown with good potential and therefore has been considered.

#### 5.2.1 Land use and location criterion

By using more complete data from the built environment, this index can improve its application and provide a more realistic analysis of itself. In particular, it is also important to know the opportunities of the destination for access, which have not been taken into account in the access criteria until today. The correlation between access and land value is not adequately established, as it plays a crucial role in transportation investment and urban planning. Scholars argue that different factors related to land use, such as density, composition, connectivity, and walkability, along with a user pattern that promotes greater accessibility, can reduce the time required to reach various activities. It is needed, and therefore it will cost more. In fact, the patterns of land and place use that are presented by planners as a desirable spatial strategy are a logical expression of access.

Mondschein and Taylor [33] show that the increase and decrease of access to neighbourhood networks are related to the increase and decrease of mobility in different modes in relation to the development of density. Of course, in another research, it has been stated that such density development may make the services more expensive and also spend more time in achieving the associated goals [66].

#### 5.2.2 Travel mode criterion

From a travel mode choice perspective, providing higher workplace and residential accessibility for middle-income earners has the potential to support greater use of transportation, especially public transportation. The findings of the study conducted in the United States on individuals residing near rail transit stations, using location-based indicators, indicate that the regional availability of job opportunities, transportation options, and the urban layout collectively influence the effectiveness of people's choice of transportation for commuting [62]. Previous research has also recognized the influence of mixed land use, population density, and transportation mode preferences on people's commuting behaviour.

In their research, A'rachman and colleagues [63] propose that the adoption of car usage is influenced by the characteristics of the local and subregional built environment, such as walkability and access to public transportation for work purposes. They argue that efforts to promote dense, mixed-use neighbourhoods should extend beyond residential areas. In contrast, a separate study conducted in Brazil suggests that this particular factor is not closely associated with accessibility, especially for affluent individuals who have access to public transportation but still choose to live in

locations that prioritize car usage. Consequently, their commuting primarily relies on personal vehicles. This finding contradicts the existing literature, which emphasizes the significance of land use variables and mode selection. The researchers [64] further note that individuals with lower incomes are more dependent on public transportation, regardless of the access conditions. Therefore, this issue has the potential to challenge the perceptions derived from this index.

#### 5.2.3 Travel time criterion

A more widely accepted measure of perceived impedance is acknowledged to be superior to distance when assessing walking accessibility. The duration of each trip is influenced by both the mode of transportation and the time at which it is undertaken. Consequently, it is crucial to incorporate it in a proper manner in order to make an accurate evaluation. It should be noted that travel time varies considerably with different transportation modes throughout the day and night, and this aspect should be taken into account when conducting evaluations. Moreover, travel time serves as a sensitive criterion for transportation policy as it responds to changes in supply and demand. Typically, travel time is determined by calculating the average of recorded traffic data or the time it takes to travel freely in the absence of traffic data [59]. Various studies have demonstrated that the uncertainty associated with travel time significantly impacts individuals' activity-travel planning [20].

Chen et al. [49] demonstrate that uncertainty in travel time can have a greater impact on individuals with limited access, exacerbating overall disparities in accessibility. This highlights a significant negative consequence for different population groups in terms of their ability to access services. Consequently, there is a growing need for methods to assess access equality in the presence of travel time uncertainties. The choice of activity locations, overall transportation network efficiency, and cost are also influenced by travel time. Tahmasbi and Haqshenas [61] have found that assigning equal importance to different aspects of travel time evaluation leads to an overly optimistic assessment of spatial conditions, which hinders a more accurate understanding of transportation.

#### 5.2.4 Gravity-based criterion

This criterion was first stated by Hansen [3], which, unlike the cumulative criterion, contains a more attractive concept and on the other hand shows greater compatibility with travel behaviour. Therefore, measuring based on this index have become the basis of transportation demand and distribution of conventional travel.

Bunel and Tovar [57] found out from the model proposed by Shen and by combining the attraction criteria and cumulative opportunities that the measurement of accessibility is very sensitive to the measurement characteristics and the correlation between accessibility capabilities based on time and based on distance are low. Giannotti et al. [58] states that researchers and policymakers should pay attention to job access calculations when applying mobility planning because, just as it can prevent the correct identification of inequalities, it can negatively make all trips based on individual choice for long period and spend a portion of their income to get to work, and otherwise gravity-based actions based on observed journeys, reducing distance price and considering long commutes appear as the

willingness to travel longer. While according to this index, the attractiveness of certain places will be overestimated, which will have a misleading effect.

Matas et al. [60] also found that this index (without competition) had an effect on the probability of women's employment in Barcelona and Madrid. But on the other hand, some researchers showed its ineffectiveness or low effectiveness in access such as access to jobs.

#### 5.2.5 Cumulative opportunities

This criterion requires the selection of a travel time threshold that can significantly affect the results of the transportation and equity project evaluation. In the past decades, it has been the most common criterion used in the analysis of accessibility and the evaluation of its effects and transportation policy. Because it approximates the number of opportunities that can be obtained in a given trip. Two major advantages have been mentioned for this index. First, it is compatible with the conceptual definition because it considers both spatial locations and transport impedance. Second, it is easier to calculate and understand compared to other criteria to measure opportunities based on it.

The research aims to emphasize the impact of competition for various urban services on measuring cumulative opportunities and incorporating a competitive element into the measurement. The findings demonstrate that considering competition alters the spatial patterns of access and its equality. By accounting for supply and demand imbalances, this approach allows for a more precise assessment of spatial disparities in access, thereby enhancing the usefulness of the overall opportunity measure [55].

An analysis conducted using this index reveals significant disparities in accessibility among seniors and non-seniors, as well as between seniors residing in urban areas versus suburban areas, and between seniors who own vehicles and those who do not. The estimates indicate that travel behaviour varies considerably across different locations. When combining estimates of average trip distances with the distribution of healthcare facilities, it becomes evident that residents of Montreal's suburbs, despite having greater mobility, experience lower levels of access compared to residents of the city center. This effect is particularly pronounced among the elderly. The study focused on examining potential access levels [45].

#### 5.2.6 Proximity criterion

Meanwhile, some researchers are highlighting another newly introduced measure called the "proximity index." This index is based on the proximity of essential destinations, such as city centers, and transportation infrastructure, such as transit stations. In many areas, this index strongly correlates with walking, despite the common assumption that households generally prefer less densely populated areas. Various models on residential location selection have indicated a positive correlation between population density and this index, as well as residential location choices. Notably, when considering this measure and location, young college-educated individuals who live alone show solid preferences for walking and access to transportation.

The research findings demonstrate that adopting a collaborative and inclusive development process based on this criterion can lead to user-centred solutions with considerable potential for more effective and efficient access planning and promoting active mobility [46].

#### 5.2.7 Transportation criterion

Sustainability in transportation infrastructure not only requires balancing the environment and economy, but it's also important to ensure equitable transportation services for disadvantaged social groups. Access to transportation plays a significant role in residential location choices and job opportunities. It's especially crucial for the well-being of physically disabled individuals who may not have alternative means of mobility. Access to metro and rail services is necessary for job access, as they offer frequent and efficient transportation.

Lin et al. [32] studied various aspects of the transportation system and its infrastructure and the aging population and found that key variables such as distance from the origin to the station, walking distance, service and quality of facilities, and connectivity all influence accessibility for older adults.

Chen et al. [49] show that there is a greater disparity between the elderly and the disabled when comparing demand with other modes of transport, indicating a lack of adequate distribution of transport infrastructure.

Oviedo et al. [31] suggest that the completion of the BRT system has reduced employment access in socioeconomically disadvantaged neighbourhoods but improved access in prosperous areas, showcasing its potential impact and usefulness as a measurement tool for opportunities.

#### 5.2.8 Environmental dimension

In transportation policy and planning, it is essential to acknowledge the significance of climate change reduction goals. The context of these goals should be understood within the broader framework of transportation and access. The decisions made regarding urban development have a direct impact on the amount of greenhouse gas emissions generated by transportation. Therefore, it is crucial to pay special attention to the consequences of investments in this sector. These investments directly influence the choice of transportation mode, which in turn affects the emissions produced per passenger-kilometer. By incorporating the environmental access index into low-carbon mobility planning, we can create conditions that promote proximity, activity, and carbon-neutral transportation. The findings reveal that there are noticeable variations in carbon footprints across different locations, both at local and business levels. Therefore, considering the urgent need to mitigate the adverse effects of transportation activities, it is necessary to evaluate and implement solutions that can effectively reduce these effects. These evaluations and solutions will be instrumental in making strategic decisions regarding land use and transportation planning.

Kinigadner and Buttner [24] show that access tools cannot directly determine or reduce CO<sub>2</sub> emissions, and therefore transport planning switches to low-carbon mobility options and a central performance indicator based on the environmental dimension that is important for accessibility.

Cheng and Chen [22] in their research state that accessibility is perceived as the most problematic factor by travelers. They consider age, frequency of activities, and environmental awareness to be significantly effective on users' perception.

#### 5.2.9 Individual component and social dimension

An adequate level of access to urban services is essential for quality of life and well-being. Therefore, it is important for policymakers to consider the distributional equality

assessment between people in different socio-spatial groups. Theoretically, the access level of a person is evaluated using the individual access criterion. Most individual evaluations are based on the geographical concept of space-time prism (activity spaces under different space-time constraints. On the other hand, the ability of people to exploit a specific physical field of access differs according to their financial, cognitive, and physical abilities. Therefore, person-based access works completely differently due to the performance and capability of personal and social preferences and characteristics, this point is also considered as a challenge of access.

Alvarez et al. [29] discovered that the elderly strongly favour walking when accessing different retail options. However, this finding contrasts somewhat with previous studies that emphasized the elderly's reliance on motorized transportation to reach important destinations.

Chen et al. [65] conducted one of the first studies using individual activity space extracted from mobile phone big data instead of daily navigation data to assess traditional activities in cell towers and concluded that human mobility can reduce spatial inequality for people living in different geographical areas.

On the other hand, it has been stated that social characteristics such as age, gender, and monthly income significantly affect people's preferences for switching modes of transportation.

Gender has been considered as a strong predictor among social characteristics in the choice of transportation mode, and is stated that women generally show more willingness to use public transportation.

## 6. CONCLUSION

Accessibility measures usually demand greater data and resources compared to similar mobility measures. It is crucial we take advantage of emerging data sources like Global Positioning System data for precise tracking of passenger movements, social media data for inferring travel preferences and goals, transport field specifications, and automatic passenger counters. These new and innovative data sources play a vital role in obtaining accurate information.

Literature review shows in order to consider many dimensions of access, in addition to the criteria, more attention should be paid to the reliability, cost, passenger characteristics (such as taste, justifications and restrictions), safety, travel aesthetics and destinations. One of the main limitations stated for the accessibility criteria is that these only consider a specific goal of the trip and a specific time to make the trip or the individual's state. It is worth mentioning that some research considers walking distance or time required for access and exit to transportation, but pedestrian and bicycle access part of other modes mentioned about Private Mobility Vehicle (PMV) usually are not considered in studies. In addition, researchers often use the distance of a person's location to the usual walking transportation for basic prediction and evaluation of transportation-related economic development and also consider individual characteristics in this issue. The obtained results show that young people and men are more inclined to devote time to walking to reach the transportation station than the elderly and women, respectively. On the other hand, car ownership, household income, and household size also have important effects on

access. Households with more vehicles, higher income, and more members are more likely to limit access to certain mode choices.

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