Richard L. Church
James R. Marston

Measuring Accessibility for People with a Disability

This paper discusses some of the inherent problems associated with measuring accessibility for people on a landscape of surfaces, barriers, and travel modes. Along with this discussion we propose a new perspective for measuring accessibility with a focus on people with differing abilities. Even though our focus is on people with a physical disability, such an approach can be easily extended and is able to be generalized to other needs and differences. Traditional measurements of accessibility are flawed, as they fail to directly account for mobility and physical differences among people. They ignore structural barriers and individual mobility limitations that affect travel time, effort, and even successful completion. To make sense of this dilemma, we propose an accessibility measurement framework that includes measures of absolute access, gross access, closest assignment access, single and multiple activity access, probabilistic choice access, and relative access. Most of these measures of access have been proposed by others, but our framework attempts to codify an approach that helps to overcome weaknesses in using only the absolute access measurement currently used in ADA compliance. Such measures can be used to map accessibility as well as to help select the mitigation or renovation projects that yield the greatest increase in accessibility for people with disabilities. We argue that for many urban and building design problems providing absolute access for people with physical disabilities should be accompanied by the use of a relative access measurement, so that removing barriers can be done in the order that provides the greatest improvement in access for a given level of expenditure.

1. INTRODUCTION

Accessibility is an important characteristic of the geography of space, whether it involves a small area (e.g., elements within a building) or a large region (e.g., elements within a metropolitan area). It is frequently included as a goal in transportation planning, land use planning, and building design. The reason for this is that most would argue that accessibility is something to value and improve in an urban setting. Beyond acknowledging the importance of accessibility as a goal in planning, it has seldom

Richard Church is a professor of geography in the Department of Geography, University of California at Santa Barbara. E-mail: church@geog.ucsb.edu. *James Marston is a postdoctoral researcher in the Department of Geography, University of California at Santa Barbara. E-mail:* marstonj@geog.ucsb.edu.

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been translated into performance measures by which policies are evaluated (Handy and Niemeier 1997). Without an accepted measurement approach for accessibility in a planning problem, it is difficult if not impossible to compare alternatives in a rational manner with respect to changes in accessibility. Perhaps Gould (1969) stated it best when he said: "accessibility is.... a slippery notion.... One of those common terms that everyone uses until faced with the problem of defining and measuring it." There have been some notable exceptions to the paucity of using a measurable accessibility criterion in public policy. One of these is the definition of accessibility for people with disabilities in their approach to a building. The American with Disabilities Act (ADA) states in section 4.3.2 under the title of "Accessibility Guidelines for Buildings and Facilities" the following:

> At least one accessible route within the boundary of the site shall be provided from public transportation stops, accessible parking, and accessible passenger loading zones, and public streets or sidewalks to the accessible building entrance they serve. The accessible route shall, to the maximum extent feasible, coincide with the route for the general public

Measuring accessibility for ADA compliance, is then translated into a simple test by the policy: at least one accessible route to a building entrance must be provided from the street, from passenger loading zones and when appropriate from public transit stops and public parking. It is easy to test compliance for such a policy in that either appropriate access is provided or it is not. Thus, the public policy on access for people with disabilities boils down to: it is either provided within an absolute sense or it is not. This means that accessibility requirements within the context of the ADA rules are standards-based. It is important to recognize that the Code of Federal Regulations (28 CFR Part 36) dealing with the standards for accessible design describe how accessibility to specific elements (e.g., telephone, drinking fountain, or toilet facility) should be accomplished as well as the provision of accessible routes to such elements and building spaces. Not all elements need to be accessible, just a minimum required number. Thus, the measurement of accessibility is defined to the extent that it is easy to measure compliance. Although each element (e.g., toilet) is important, our objective here is to discuss the general concept of accessibility with respect to people with disabilities.

It should be acknowledged that the above policy and implied measurement approach (i.e., standards-based) has led to the improvement of building access in every city and town in the U.S. for people with physical impairments. Although this standards-based approach has been valuable, it lacks the sensitivity that other measures of accessibility might provide. Since the standard is to ensure that absolute access has been provided, little attention has been devoted to the value or quality of the access provided. Further, providing a second access route to a building is not given any value, by virtue that a first access route meets the standard. This paper focuses on the weakness of this standards-based approach without some attention being given to the value of relative access. Our objective is to present a paradigm for measuring access for those with physical or mobility impairments within an urban landscape, that extends beyond the standards-based approach. This proposed approach is sensitive to both the number of routes and the values of each access route provided. It is hoped that this proposed paradigm will help pave the way for future accessibility research as well as form the basis for which the current standards-based approach is enhanced in urban planning and architectural design. In the next section we present an overview of the literature on accessibility measures. In the subsequent section we begin the process of describing how such measures can be extended to people with a physical disability and enhance the standards-based approach of absolute access that is dictated by the ADA guidelines. Then, we propose several new measures of relative access that we believe meet the spirit of the current law and provide guidance for improving urban design for people with disabilities. We demonstrate these concepts with several simple access issues faced by individuals on the University of California at Santa Barbara campus. We conclude with recommendations for future work.

2. MEASURING ACCESS, A REVIEW

Accessibility is determined by the spatial distribution of potential destinations, the ease of reaching each destination, and the magnitude, quality, and character of the activities found there (Handy and Niemeier 1997). The greater the number of potential destinations within some defined time or distance range, the greater the accessibility. The closer such choice destinations are within this maximum range, the higher the level of accessibility. An accessibility measure estimates the level of access to some type of activity from a starting location or home location to one or multiple locations of that activity given a travel mode, distance, time, and cost constraints. Weibull (1976) has presented an axiomatic framework for the development of accessibility measures. Conceptually, there are seven main types of measures for accessibility that have been the subject of a number of papers in the literature: 1) counting; 2) total sums of distances; 3) closest available; 4) gross interaction potential; 5) probabilistic choice, 6) net and maximum benefit; and (7) absolute. Albeit, there are other proposed accessibility measures, the above classes capture many of the elements of measuring access.

The simplest approach involves a count of the number of locations at which an activity can be found within some maximum distance, time or cost of travel from a given location or point i (Wachs and Kumagai 1973). Talen and Anselin (1998) call this a "container" measure. This means that the accessibility of activity k for a person at location i using travel type l can be calculated as:

$$A_{ikl} = \sum_{j \in M_{ikl}} O_{jk} \tag{1}$$

where:

A_{ikl} = the accessibility of person i or zone i with regard to activity k and travel type l
O_{jk} = the number of opportunities for activity k at location j.
d_{ijl} = the distance, travel time, or other measure of effort separating i and j for person of travel type l.
s_{kl} = the maximum distance or range over which an activity is considered accessible for travel type l. One can also use travel time or cost as a criterion as well
M_{ikl} = $\{j \mid d_{ijl} < s_{kl}\}$, the set of activity locations considered accessible.

Equation (1) represents a simple count of the total number of places where activity k is considered accessible in relation to location i and travel type l, within some maximum travel distance, time, or cost. The larger this value the greater number of opportunities are within reach of location i for activity k and the better the accessibility. We have chosen to differentiate possible differences in travel mode as well as individual by the index l, e.g., an older women who owns a car or a young adult who uses a wheelchair (see Hagerstrand (1970) for an introduction to time, space, and mobility constraints in travel; Miller (1991) and Kwan (1998) for a framework on measuring individual accessibility within a space-time framework; Hanson (1995), Hanson and

Schwab (1987), and Kwan (1999) for a discussion on travel and accessibility differences among people; and Marston, Golledge, and Costanzo (1997) who investigated the travel behavior for those who are vision impaired and rely on public transit). Pirie (1979) stated that zonal accessibility measures not only neglect the distribution of activities within a zone, but also assume that all individuals within a zone face the same set of opportunities. We use the index i to represent a location about which accessibility is to be measured, not a zone. If the index i is used to represent a zone, then the issues raised by Pirie are relevant.

The first measure of accessibility captures distance only in terms of some prespecified maximum distance, time, or cost of travel. It does not distinguish among the accessible sites of the activity to location i, in terms of distance. Ingram (1971) proposed a measure where accessibility at a given location i is defined as the sum of the spatial separations from all other locations j to that location. We can represent this measure as:

$$A_{ikl} = \sum_{j} d_{ijl} O_{jk} \tag{2}$$

In general, the larger the value, the less accessible are the activities for a given i. A central location among a distribution of points is more likely to have a lower accessibility value, and hence be more accessible than other points. If one imposed a maximum distance range for accessible sites (like in equation 1), then it would be difficult to compare values across the landscape, because a sum may be low (and hence, suggest great accessibility), when the sum only included 1 accessible site within the range as compared to the presence of many more available sites. Rather than sum over all possible activity locations, regardless of distance it makes sense to sum up through the m closest activity locations for activity k. This modified measure would represent a total sum of distances to the closest set of activity points. Then, a comparison of accessibility at various locations across a landscape would be meaningful.

In many public services, especially emergency services, accessibility is measured in terms of the closest available server or location. Access, then, is not based upon a gross number of opportunities and their proximity, or on personal choices, but on how far the closest server is from a given i. This accessibility measure has been used as a proxy or surrogate measure of effectiveness in the location of public services (Hodgart 1978). We can formalize this using the previous notation as:

$$A_{ikl} = d_{ikl} \tag{3}$$

where d_{ikl} is the closest location to i having a large enough amenity of activity k to serve a person at i with access type l. It should be recognized that the closest activity k to a location i may differ among those of different access types. This accessibility measure has been formalized in the p-median location problem where an activity is located on a network among p-sites out of n sites in order to maximize accessibility. (Hakimi 1964; ReVelle and Swain 1970). Whereas most other accessibility measures increase in value with increasing accessibility, this measure decreases in value as accessibility increases. Thus, when using this type of accessibility measure in urban design, the sense of optimization would be to minimize.

We know that people do not necessarily choose to go to their closest available activity when given a choice. The size or attractiveness of the activity site, the distance, and available travel modes all play a role in that choice. One of the models that has been used to distribute trips among various destinations is the gravity model. The gravity model has been used in a number of different types of applications to estimate the interaction between one location and another. The gravity model estimates interaction in terms of attractiveness of an activity at a given location j (e.g., number of jobs, size of retail space, etc.) and distance. Hansen (1959) was the first to propose a gravity-based accessibility measure for some activity k, in the following manner:

$$A_{ikl} = \sum_{j \in M_{ikl}} O_{jk} d_{ijl}^{-\beta_l} \quad (4)$$

where:

β_l = empirical constant representing the inhibiting effects of distance (time or effort) on trip making for travel type l.

The above equation represents a gross measurement of accessibility for a person of type l starting at location or zone i with respect to some activity k. The higher the value of gross accessibility, the greater the access and number of opportunities for a given activity. Gross accessibility to a given activity (e.g., shopping for shoes) is the sum of all such activities within some maximum time, distance, or cost limit, each discounted by how distant each activity is away from location i. An activity location is counted high when it is close, and low when it is far away. This discount is based upon how distance or time affects the possibility of making a trip to that location for that activity. Pooler (1987, 1995) presents a critical discussion on this type of "potential" accessibility model. We have taken the liberty of extending the accessibility measure suggested by Hansen by adding subscripts for the type of activity (k) and the type of person (l). It makes sense to represent different types of people, based upon their mobility status (Hanson 1995; Marston, Golledge, and Costanzo 1997). For example, if a sub-population at a zone can only move about by bus, then their accessibility to a given activity k from zone i will be different than those who own cars and can use either the bus or their car. Examples of such differences are given in Hanson and Schwab (1987). From a more rigorous perspective, one can generate a model of accessibility related to (4) as:

$$A_{ikl} = \sum_{j \in M_{ikl}} O_{jk} e^{-\alpha d_{ijl}} \quad (5)$$

where the distance attenuating function is of an exponential form. Although the distance decay function may be expressed in many ways, the negative exponential form is probably the more widely accepted form used. In the remainder of this paper we will use the simple distance decay form of equation (4), even though the form in equation (5) is applicable as well.

People make choices in travelling and destination. The gross accessibility measure sums up all possible opportunities (discounted by a function of distance) over a range of distance, time, or cost. However, it is unlikely that each person actually visits each activity site. More than likely, a choice will be made. Perhaps people with mobility type l may choose to go to one of two malls for shoe shopping, even though there are several nearby stores. The intervening opportunities model attempts to capture different competing elements (like size and distance) in consumer choice (Stouffer 1940). Even trip chaining may make a more distant activity site the most suitable (Hanson 1980). The simplest form of measuring accessibility based upon probabilities can be done in the following way:

$$A_{ikl} = \sum_{j \in M_{ikl}} p_{ijkl} d_{ijl} \tag{6}$$

where p_{ijkl} = the probability that a person in zone i will go to zone j for activity k involving travel type l. This measure represents the average distance of travel to activity k as the distance to each site j times the probability that that site is the choice (Geertman and van Eck 1995). One approach to estimating the probability of selecting a given location j can be to divide the accessibility potential of that site by the sum of all of the accessibility potentials generated at i for an activity k.

$$p_{ijkl} = \frac{O_{jk} d_{ijl}^{-\beta_l}}{\sum_{r \in M_{ijkl}} O_{rk} d_{irl}^{-\beta_l}} \tag{7}$$

Wang (2000) used equations like 6 and 7 to estimate job accessibility by transportation analysis zones in Chicago. We call this a probabilistic or choice-based accessibility measure. Since the sum of the probabilities over all j should equal 1, this model does not "double count" activities, but only accounts for those activity locations actually used. This at first may seem trivial, but consider the following real example. In an Agency for International Development project involving the location of health clinics in Colombia, Church (1979) discusses a situation where a clinic located in one village would not necessarily serve the inhabitants of a nearby village if there was a major cultural or political divide. A gross accessibility measure applied to the village would rightly consider it accessible. A choice accessibility model applied to the village would indeed capture the fact the nearby clinic would be "tabu."

It makes sense that individuals might travel based upon making those choices that maximize their net benefits, or simply put, maximize their consumer surplus. An accessibility measure for a given location i directed at some activity k could be a model that estimates the benefit associated with making the choice of location j that maximizes their benefit. Alternate structures are possible, like the sum of net benefits over all feasible choices (see, for example, Miller (1999) who provides a framework for measuring accessibility benefits within transportation networks).

Finally, it is important to note that accessibility can be measured in an absolute format. For example, access is either provided or it isn't. Either a building can be approached and entered by a person using a wheelchair or it can't. As stated earlier, absolute access is commonly used as a standards-based approach for measuring physical access. Either bathrooms have been retrofitted or built for wheelchair access or they haven't. As long as there is at least one accessible activity location for each activity type, for a given location i, absolute access has been provided and deemed acceptable. It makes sense, however, to use the other access measurements for people with disabilities (like closest available, gross access, and probabilistic choice access) in addition to absolute access as figures of merit for measuring the effectiveness of building retrofit plans, urban design, and new building layouts. For example, a ramp at the rear of a structure may provide absolute access, but it may make all people who need such a ramp to go out of their way as compared to a typical user. That is, absolute access doesn't capture the qualities of access measurements given above.

In the next section, we focus on the measurement of access for multiple activities. Although, all of the measures discussed in this section can be described within a multiple activity set, we will focus on gross-potential, probabilistic choice, and closest distance.

3. ACCESSIBILITY MEASURES FOR MULTIPLE ACTIVITIES

When measuring accessibility, it is important to look over the range of possible activities. That is, individuals don't just shop for shoes, but they go to the movies, visit the doctor, attend religious services, etc. They may have daily or weekly routines that represent a range of activities. The accessibility of various activities will differ, but for an individual, what is most meaningful is the totality of activity accessibility. To capture this consider the following equation of Total Gross Accessibility:

$$A_{il} = \sum_k \sum_j O_{jk} d_{ijl}^{-\beta_l} \tag{8}$$

where:

A_{il} = the total of Gross accessibility over all types of activities for an individual at i of type l.

Adding all accessibility measures for a given location and access type represents the grand total of all gross accessibility measures. There is the potential to have scaling problems as some activities are more important than others. To accommodate for this, we can weight each activity by some measure of importance. For example, let's consider the frequency of need (e.g., trips per year) for an activity as an importance weight for that activity. Thus, we can define Weighted Gross Accessibility as:

$$A_{il} = \sum_k f_{ikl} \sum_j O_{jk} d_{ijl}^{-\beta_l} \tag{9}$$

f_{ikl} = frequency of trips (e.g.,trips per year) for a person of type l located at i going for activity k.

This measure is appealing in that it estimates total accessibility for a location and type of access. Just as there can be different types of people in terms of mobility, there can be different types of people based upon the frequency of use of specific activities. For example, an older person may visit the doctor more often, go to school less often, and volunteer their time at agencies more often than a younger person. A person using a wheelchair may make less frequent or more frequent trips than another person with a different mode of access for a given activity. This is still simplistic, given that people make multi-stop trips and are confined by a space-time prism. Extensions to this simple gross estimate can be made by accounting for such behavior and constraints (e.g., Arentze, Borgers, and Timmermans 1994; Southworth 1985; Recker, Chen, and McNally 2001).

We can also extend the concept of total accessibility for a probabilistic choice model as well:

$$A_{il} = \sum_k f_{ikl} \sum_j p_{ijkl} d_{ijl} \tag{10}$$

This form also sums up accessibility over different types of activities, each weighted by the frequency of activity engagement. Again, trip-chaining behavior is not considered in this simple measurement.

Finally, within a public service context we can create a measure of total access for all activities assuming that each individual is served by their closest server of a given activity type, and weighting each activity by frequency of need or use. By taking the closest available activity access measure and summing over activities weighted by frequency, we get:

$$A_{il} = \sum_{k} f_{ikl} d_{ikl} \tag{11}$$

This measure represents total accessibility as weighted closest available service for each activity. This is often called weighted distance and is the form of accessibility that is used in the multi-type facility p-median problem (see the nested hierarchical and non-nested hierarchical p-median problems of Weaver and Church 1991).

4. RELATIVE ACCESSIBILITY

There are true differences in access based upon the type of individual, l, being addressed. Golledge (1993) discusses the idea that even when considering the exact same geographic space, people with differing abilities must use, access, and travel through that environment using different routes, such that the conception and use of that space is "transformed" for different users. He called for measures that would help explain how people with disabilities access obstacle-ridden space (Golledge, 1994). Let us consider the measurement of accessibility from an office in a university building to the closest coffee cart or café. Let's consider two people, one who uses a wheelchair and the other quite ambulatory, each leaving the same office (2843 Ellison Hall on the UCSB campus) for coffee. This second floor office is close to a stairwell that is on the most direct route to the closest coffee cart (see figure 1). The ambulatory person leaves the office, goes down one flight of stairs, and exits the building on the east entrance, bounds down a few more steps, and then makes a beeline for the coffee cart across the plaza, east of the building. The person using the wheelchair heads to the bank of elevators in the center part of the building, waits for an elevator, and then takes it to the first floor. That person exits the building through the front (south facing) doors, and then heads east around the building to the plaza, and then towards the coffee cart. Thus, they both have chosen and reached the same cart. The routes for both individuals are depicted in figure 1.

For both people the cart is accessible in terms of an absolute measure. In fact, each measure described above for a single activity accessibility measure could be used. For this example, it makes the most sense to apply the closest available access measure, i.e., the distance, time, or effort it takes to travel to the coffee cart from the office. For the ambulatory person, the route takes approximately 40 seconds. For the person using a wheelchair, the route is longer as it involves a less direct route and an elevator wait and ride. Such a trip is approximately 3 minutes and 30 seconds. The effort taken in terms of time spent is 5.25 times that of the ambulatory person. We can express the differences in accessibility in terms of the person using a wheelchair, l, relative to the ambulatory person, m, leaving adjacent offices (call it location i) in the following way:

$$R_{iklm} = \frac{d_{ikl}}{d_{ikm}} \tag{12}$$

where k represents the activity of getting a cup of coffee for this example, and

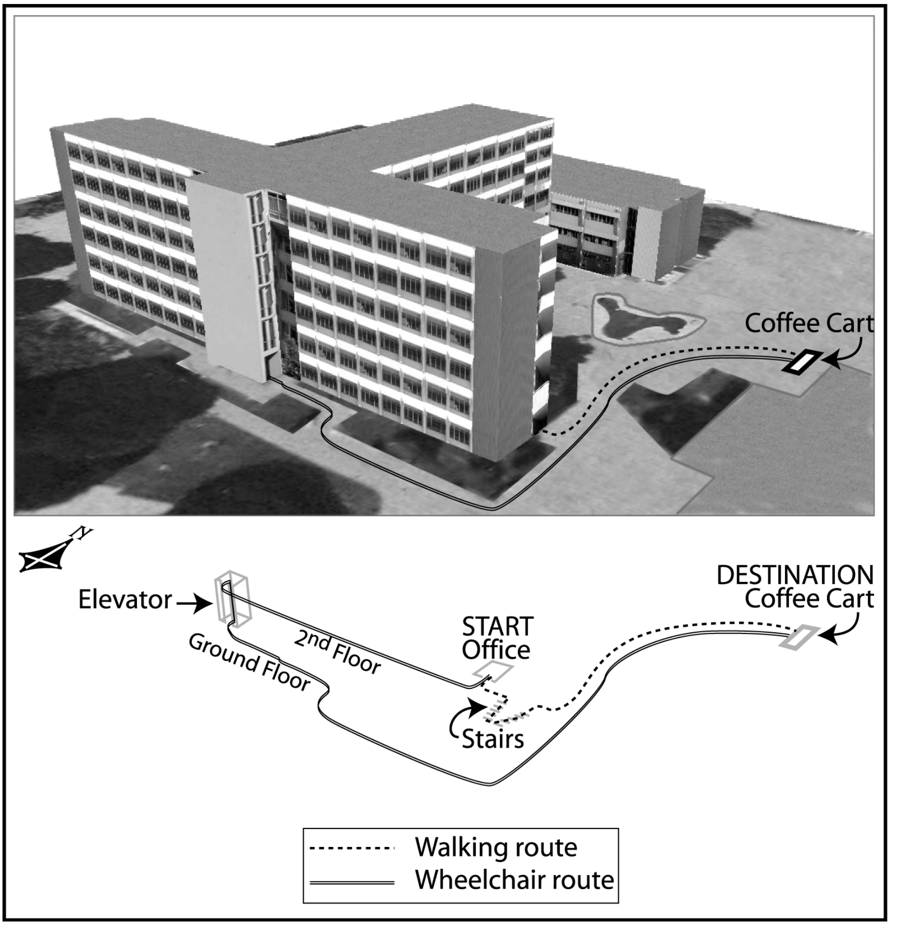


FIG. 1. Traveling between office 2843 in Ellison Hall and the nearest coffee cart on the UCSB campus, where one individual is ambulatory and the other uses a wheelchair.

R_{iklm} = relative accessibility of activity k from location i for person type l relative to person of type m.

If time is used then $R_{iklm} = 5.25$ for our example of getting coffee. Relative access is an important measure because it relates the differences in access relative to individual groups of users as well as it aids in understanding just what a physical impairment or constraint might represent in the effort needed to overcome obstacles in the environment (e.g., stairs and curbs) and travel. Relative access also helps to operationalize the space-time prism paradigm of Hagerstrand (1970) into an easy to understand and computable format. It is important to note that Lee and Lee (1998) have used the term relative access in a different way to represent the number of feasible competing routes to a destination and the number of mode changes. A similar notion, called route factor, was raised by Hay (1973) in analyzing the directness of routes between cities. De Jong and van Eck (1996) have used relative gross access and relative count access as access potentials and presented example maps for a region around Utrecht.

Marston and Golledge (2000) have used this type of time "penalty" to examine constraints faced by visually impaired travelers using their regular navigation methods. They also tested the effectiveness of using an auditory signage system, and compared travel time to those of a sighted user (Marston 2002). Subjects were tested in their relative ability in navigating and making five complex transfers between different transit modes in an urban transit environment.

Relative access can also be determined for a group or sum of activities. For example, let's assume that both people (in the above example) in performing their daily tasks during the work day, must travel three times to the photocopy machine (on the average), take two breaks that allow them to get a cup of coffee, travel several times to the bathroom, and attend several meetings within the building as well as go to lunch. Summing up accessibility over these types of activities and frequencies, we can obtain the following measure of relative access:

$$R_{iklm} = \frac{\sum_k f_{ikl} d_{ikl}}{\sum_k f_{ikl} d_{ikm}} \tag{13}$$

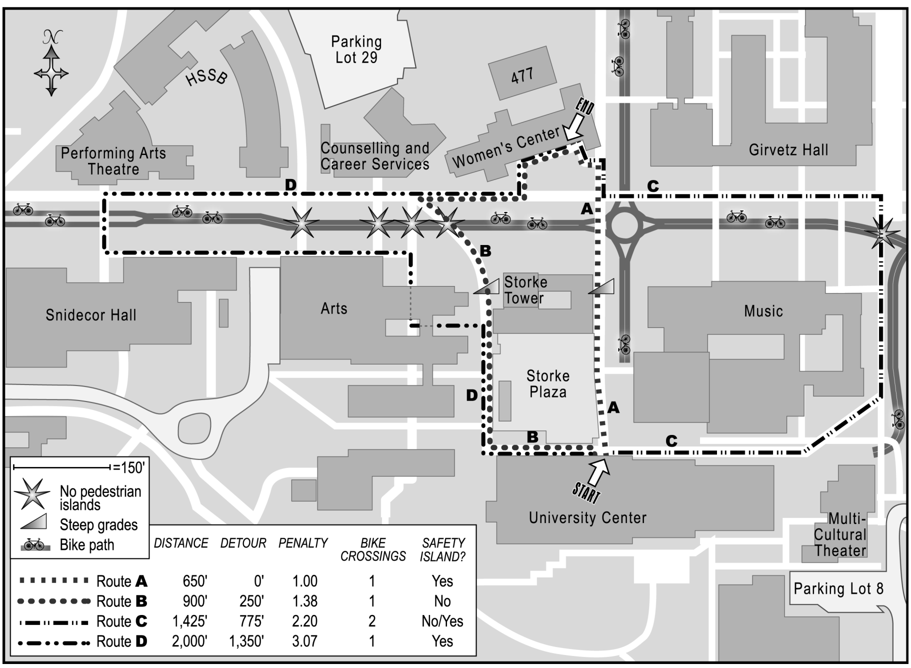
Where R_{iklm} = total relative access of person of type l compared to a person of type m, associated with location i assuming that person of type m has the same frequency of person l. Here relative access compares one class of individuals (access or mode type) to another based upon the same frequency of activities, but compounds the effects of spatial accessibility differences based upon the repetition of such activities

Relative access measures can be used to help understand the impacts of different design alternatives in buildings and public areas. For example, constructing a wheelchair ramp might provide absolute access to a building, but alternative placements of that ramp may differ considerably in terms of the impact on relative access. Whereas an absolute access measure can't distinguish between such positions, the relative access measure helps to measure the impact that the position of a ramp location has on the users. Suppose that a building already has an access ramp and is therefore accessible on an absolute scale and it also has at least one accessible restroom, water fountain, public telephone, etc. Then absolute access won't change if a second restroom is modified to be access friendly. But the gains in relative access might be considerable. That is, relative access is a good measure for determining the impact of barrier removal across the urban landscape or network.

Up to this point, we have introduced the concept of relative access within the context of closest assignment and weighted closest assignment. Actually, relative access can be defined for each of the access measures that have already been introduced. These include gross, probabilistic choice, closest assignment, and absolute as well as single, multiple, and weighted forms. When attempting to modify the landscape to improve access for some segment of the population (e.g., ADA compliance) it is important to provide absolute access. In fact, the implied measure that is used in access compliance is relative absolute access. The issue is to provide absolute access over various disabilities for all circumstances in which access is provided to those without disabilities. In essence, the objective of the ADA program has been to seek relative equivalence in terms of absolute access for various types of individual classes. Unfortunately, absolute access is a relatively crude form of access measurement and neglects the impact of the location of such barrier removals (e.g., lowering a public phone, making a restroom accessible, etc.) in terms of the movements required by those that use them. We argue that not only should access be a goal in terms of ADA compliance, but also that it be measured in terms of both absolute and relative access measures.

5. AN EXAMPLE IN MEASURING RELATIVE ACCESSIBILITY

The above concepts should be relatively understandable without an example. But, a real example encountered in campus planning at the University of California at Santa Barbara (UCSB) should help to underscore the importance of measuring relative accessibility. Even though we discuss this issue with respect to wheelchair users, we should point out that others pushing kids in strollers, paramedics pushing a gurney, courier personnel with a package cart, and campus audio-visual personnel pushing TV carts also encounter the same type of physical barriers in moving across campus. This access problem was presented to the campus ADA committee by one of the authors (Marston) in 1998. The analysis of relative penalty supported arguments made to make several improvements for the routes in question (i.e., an additional safety island for crossing the bikeway and making a route smooth so that it could accommodate those using wheelchairs). Figure 2 gives the layout of the central "core" of the UCSB campus. The University Center, which houses the bookstore and a number of food venders, is located in the bottom right portion of the figure. The Women's Center is located north of the University Center, close to building 477. There are several possible routes that are given in the figure that can be taken in going from the University Center to the Women's Center. A typical person would walk "Route A," which heads directly north along the east edge of Storke Plaza, crosses a bikeway with safety islands, and then makes a slight jog to the entrance to the Women's Center. The distance of this route is 650 feet. This heavily traveled route offers a bike crossing that splits the two lanes of traffic and offers a safety island so that people cross only one-way bike traffic at a time. Route A is the shortest walkable route and represents the route chosen by those who are relatively ambulatory.



	DISTANCE	DETOUR	PENALTY	BIKE CROSSINGS	SAFETY ISLAND?
Route **A**	650'	0'	1.00	1	Yes
Route **B**	900'	250'	1.38	1	No
Route **C**	1,425'	775'	2.20	2	No/Yes
Route **D**	2,000'	1,350'	3.07	1	Yes

FIG. 2. Comparing Routes and Access Between the Women's Center and The University Center.

Unfortunately, the slope of the sidewalk along the east side of Storke Plaza is too steep for many people using wheelchairs. Even though we give this example associated with wheelchair users, people using a manual wheelchair generally must look for another route. One could travel along the west side of Storke Plaza, (Route B), then turn and travel towards the Counseling and Career Center. After crossing the bike way and reaching a major east-west oriented path, they could then head east to the Women's Center. This route is 900 feet or 250 feet longer than that of route A. In addition, the bike path at this point has no divided lanes with a safety island, making crossing more dangerous and difficult. The relative accessibility for having to take route B as compared to that of route A equals $\frac{900}{650} = 1.38$ (or 38% longer than route A). Even though this route is not too much longer than route A and does not have a steep slope, it had broken and cracked asphalt that made this route (Route B) impassable for those using wheelchairs. Until this area was repaved and smoothed, people using wheelchairs had to travel east from the University Center to the end of the Music building, turn north, continue heading north until crossing the bikepath, and then head west to the Women's Center. This route (Route C) adds 775 feet to the trip for a relative access measure (compared to those who are able to travel route A) of 2.19 (i.e., $\frac{1425}{650} = 2.19$) or 119% longer than route A. People using this route also have to cross the bikeway heading north, along the east side of the Music building, where there was no safety island, and then cross another bikeway close to the Women's Center. To avoid this very dangerous bikeway crossing along route C, a person could take Route D, which goes through the Arts building, heads west to Snidecor Hall, goes north across the divided bike path in front of the Performing Arts Theater, and then back east to the Women's Center. This route adds 1350 feet to the trip as compared to Route A, for a relative access penalty of 3.07, or 207% longer. Taking route D was considerably safer than route C. Until route B was repaved so that it was smooth and could allow wheelchair traffic, those people using wheelchairs faced a relative access penalty of 2.2 or 3.07 compared to those who are ambulatory. This level of penalty is not insignificant and can have other adverse effects on access to opportunities. For example, it has been reported to one of the authors that a student at a different university, who had a mobility impairment, took three years to gain her MA compared to the standard two for her cohort; some required classes could not be scheduled in the same term because class times were separated by only ten minutes of travel time and routes did not exist between the classes that could be traveled by her in that time constraint.

If a competitive route exists between an origin and destination that provides access to people with disabilities, then those people face no additional travel penalties as compared to a typical traveler. The greater the disparity between routes available to the ambulatory and those who have disabilities, the greater the difference in relative access. Measuring access only in terms of an absolute access measure does overlook the fact that significant disparities in access may remain between those with an impairment or limited mobility and the typical user.

An accessible route is supposed to coincide, when feasible, with the route for the general public. In many cases it is either not possible or it is cost prohibitive to make the route used by the general public entirely accessible to all people. We believe that the relative access measures proposed in this paper should be used to help make the most cost effective decisions regarding the selection of routes between buildings, like those on a university campus, that should be made accessible when removing barriers.

Hagerstrand (1970) introduced the notions of authority constraints and coupling constraints in describing the concept of the space-time prism. Coupling constraints involve activities where more than one individual meets for an activity and authority constraints involve restrictions on access due to some social, political, or legal restriction on access. Measuring access for people of differing abilities must account for such conditions as well. For example, the scheduling constraints mentioned above involving the person with a mobility restriction hampered that individual from taking specific classes in the same term. Thus, authority conditions (e.g., published class schedules) can have a significant impact on relative accessibility. Forer and Huisman (2000) and Huisman and Forer (1998a, 1998b) discuss space-time accessibility issues within the construct of sequencing and schedules. Including sequencing and scheduling conditions will, in general, exacerbate problems of relative accessibility between people with differing abilities. Just as removing physical barriers to open up new routes of accessibility, it may also be possible to remove "schedule barriers" and improve absolute and relative accessibility by making changes to authority constraints (e.g., change published course schedules).

It is important to recognize that relative accessibility may differ greatly among differing spatial scales. For example, accessibility on a university campus differs from that of accessibility within a city. As overall travel distances increase for the ambulatory, differences in relative accessibility for those with differing abilities will likely decrease. Unfortunately, many daily activities (e.g., going to lunch or using a restroom) involve short trips for the ambulatory, but possibly time consuming trips for those with a disability.

6. CONCLUSIONS

Providing equal access to all is the goal of the ADA. This act has helped improve access to a variety of facilities, including public sector facilities such as parks, libraries, and courthouses and private sector facilities such as stores, motels, and theaters. Even the availability of accessible restrooms plays a role in making the environment of a facility useful. We know that disparities in access will continue to exist, but as money is spent on renovation, remodeling, and removing barriers across the urban landscape, attention should be directed towards making cost effective decisions, decisions that will help make the greatest improvement in overall accessibility. We have proposed that a relative access measure be used in conjunction with the more traditional measure of absolute access to help make such decisions. We have given several examples that show the relative penalty in comparing those using a wheelchair to an ambulatory person. We hope that this discussion and proposal will lead to further research as well as better decision-making.

LITERATURE CITED

Arentze, T. A., W. J. Borgers, and H. J. P. Timmermans (1994). Multistop-Based Measurements of Accessibility in a GIS Environment. *International Journal of Geographical Information Systems* 8, 343–356.

Church, R. L. (1979). An Introduction and Guide to the Site Location of Public Facilities Utilizing the 'Gas Program.' Appendix C to Final Report to AID, Contract AID/TA-C-1363, Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin.

De Jong, T., and J. R. van Eck (1996). Location profile-based measures as an improvement on accessibility modeling in GIS. *Computers, Environment, and Urban Systems* 20, 181–190.

Forer, P., and O. Huisman (2000). Space, time and sequencing: substitution at the physical/virtual interface. In *Information, Place, and Cyberspace: Issues in Accessibility* edited by D. G. Janelle and D. C. Hodge. Berlin: Springer.

Geertman, S. C., and J. R. van Eck (1995). GIS and Models of Accessibility Potential, An Application in Planning. *International Journal of Geographical Information Systems* 9, 67–80.

Golledge, R. G. (1993). Geography and the Disabled—a Survey With Special Reference to Vision Impaired and Blind Populations. *Transactions of the Institute of British Geographers* 18, 63–85

Golledge, R. G. (1994). Disability, Barriers And Discrimination. International Conference on The New Distributional Ethics, Differentiation and Discrimination, Gothenburg, Sweden.

Hagerstrand, T. (1970). What About People in Regional Science? *Papers of the Regional Science Association* 24, 7–21.

Hakimi, S. (1964). Optimum Location of Switching Centers and the Absolute Medians of a Graph. *Operations Research* 12, 450–459.

Handy, S. L., and D. A. Niemeier (1997). Measuring Accessibility, An Exploration of Issues and Alternatives. *Environment and Planning* A 29, 1175–1194.

Hansen, W. G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners* 25, 73–76.

Hanson, S. (1980). Spatial Diversification and Multipurpose Travel: Implications for Choice Theory. *Geographical Analysis* 12, 245–257.

Hanson, S. (1995). Getting There, Urban Transportation in Context. In *The Geography of Urban Transportation* edited by S. Hanson, pp. 3–25. New York: Guilford.

Hanson, S., and M. Schwab (1987). Accessibility and Intraurban Travel. *Environment and Planning* A, 735–748.

Hay, A. (1973). *Transport For The Space Economy: A Geographical Study*. Seattle: University of Washington Press.

Hodgart R. L. (1978). Optimizing Access to Public Services. *Progress in Human Geography* 2, 17–48.

Huisman, O., and P. Forer (1998a). Towards a Geometric Framework for Modeling Space-Time Opportunities and Interaction Potential. Presented at the International Geophysical Union Commission on Modeling Geographical Systems meeting, Lisbon, Portugal.

Huisman, O., and P. Forer (1998b). Computational Agents and Urban Life Spaces: A Preliminary Realization of the Time-Geography of Student Lifestyles. Proceedings of the 3rd International Conference on GeoComputation, University of Bristol (http://www.geocomputation.org/1998/68/gc_68a.htm).

Ingram, D. R. (1971). The Concept of Accessibility, A Search for an Operational Form. *Regional Studies* 5, 101–117.

Kwan, M. P. (1998). Space-Time and Integrated Measures of Individual Accessibility, A Comprehensive Analysis Using a Point-Based Framework. *Geographical Analysis* 30, 191–216.

Kwan, M. P. (1999). Gender and Individual Access to Urban Opportunities, A Study Using Space-Time Measures. *Professional Geographer* 51, 210–227.

Lee, K. and H-Y Lee (1998). A New Algorithm for Graph-Theoretic Nodal Accessibility Measurement. *Geographical Analysis* 30, 1–14.

Marston, J. R. (2002). Towards an accessible city: empirical measurement and modeling of access to urban opportunities for those with vision impairments, using Remote Infrared Audible Signage. Unpublished dissertation, University of California, Santa Barbara.

Marston, J. R., R. G. Golledge, and M. Costanzo (1997). Investigating Travel Behavior pf Nondriving Blind and Vision Impaired People, The Role of Public Transit. *The Professional Geographer* 49, 235–245.

Marston, J. R., and R. G. Golledge (2000). Towards an Accessible City, Removing Functional Barriers to Independent travel for Blind and Vision Impaired, A Case for Auditory Signs. Final Report, University of California Berkeley, University of California Transportation Center, Grant # UCTC 65V430

Miller, H. J. (1999). Measuring Space-Time Accessibility Benefits Within Transportation Networks, Basic Theory and Computational Procedures. *Geographical Analysis* 31, 1–26.

Miller, H. J. (1991). Modeling Accessibility Using Space-Time Prism Concepts Within Geographic Information Systems. *International Journal of Geographical Information Systems* 5, 287–301.

Pirie, G. H. (1979). Measuring Accessibility, A Review and Proposal. *Environment and Planning A* 11, 299–312.

Pooler, J. (1987). Measuring Geographical Accessibility, A Review of Current Approaches and Problems in the Use of Population Potentials. *Geoforum* 18, 269–289.

Pooler, J. A. (1995). The Use of Spatial Separation in the Measurement of Transportation Accessibility. *Transportation Research* A 29, 421–427.

Recker, W. W., C. Chen, and M. G. McNally (2001). Measuring the Impact of Efficient Household Travel Decisions on Potential Travel Time Savings and Accessibility Gains. *Transportation Research Part A* 35, 339–369.

ReVelle, C. S., and R. W. Swain (1970). Central Facilities Location. *Geographical Analysis* 2, 30–42.

Southworth, F. (1985). Multi-Destination, Multi-Purpose Trip Chaining and Its Implications for Locational Accessibility, A Simulation Approach. *Papers of the Regional Science Association* 57, 107–123.

Stouffer, S. (1940). Intervening Opportunities, A Theory Relating Mobility and Distance. *American Sociological Review* 5, 845–867.

Talen, E., and L. Anselin (1998). Assessing Spatial Equity, An Evaluation of Measures of Accessibility to Public Playgrounds. *Environment and Planning* A 30, 595–613.

Wachs, M., and T. G. Kumagai (1973). Physical Accessibility as a Social Indicator. *Socio-Economic Planning Sciences* 7, 437–456.

Wang, F. (2000). Modeling Commuting Patterns in Chicago in a GIS Environment, A Job Accessibility Perspective. *Professional Geographer* 52, 120–133.

Weaver, G. R., and R. L. Church (1991). The Nested Hierarchical Median Facility Location Problem. *INFOR* 29, 100–115.

Wiebull, J. W. (1976). An Axiomatic Approach to the Measurement of Accessibility. *Regional Science and Urban Economics* 6, 357–379.