Tren Urbano Research Progress Report
Executive Summary
Academic Year 1997-1998

Accessibility-Based Evaluation Methods

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May, 1998

ABSTRACT

There is a lot of interest in shifting from travel time-based procedures to accessibility-based procedures for evaluating the impacts of Tren Urbano and for evaluating future planning strategies in San Juan. While conceptually this shift from travel time to accessibility is quite straightforward, practically speaking, the use of accessibility as an evaluation tool is much more difficult due to the inherent complexity of the concept. This research aims at documenting and addressing such complexities in an effort to make the concept of using accessibility as an evaluation tool a viable, practical, and useful endeavor. The research includes a thorough evaluation of existing measures, the testing of a new measure that aims at capturing the true accessibility perceived by individuals, and the development of specific recommendations for application of accessibility-based evaluation methods. Thus far in the research, a list of desirable properties of the evaluation procedure has been defined, qualitative analysis of the existing measures has been performed, a framework for a model of perceived accessibility has been developed, and much of the necessary data have been assembled. The tasks remaining are to assemble the rest of the data, calculate and analyze the performance of the different measures of accessibility, and develop detailed guidelines for the application of accessibility-based evaluation procedures.

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Introduction and Motivation

There is a lot of interest in using accessibility as a tool for evaluating the impacts of Tren Urbano and for evaluating future planning strategies in San Juan. This is a shift in emphasis away from the current state of the practice, which focuses on travel time savings and system throughput as the primary evaluation tools. The newfound emphasis on accessibility derives from the realization that the true objective of the transportation system is to maximize accessibility to opportunities, and that while travel time is related, it is in fact peripheral to the true objective. While conceptually this shift from travel time to accessibility is quite straightforward, practically speaking, the use of accessibility as an evaluation tool is much more difficult due to the inherent complexity of the concept. For example, it is much more difficult to define, quantify, and interpret accessibility measures than it is for a travel time or throughput measures. This research aims at documenting and addressing such complexities in an effort to make the concept of using accessibility as an evaluation tool a viable, practical, and useful endeavor.

Research Objective

The research objective is to examine the fundamentals of the use of accessibility-based evaluation methods in order to make them viable and useful methodologies for transportation planning. The examination includes:

- Definition of the problem
  - the concept of accessibility
  - desirable properties for an accessibility-based evaluation procedure
- Evaluation of existing measures of accessibility
- Pursuit of a true measure of accessibility – one that captures the accessibility perceived by individuals
- Development of recommendations for the use of accessibility as an evaluation tool, which:
  - outline data collection procedures and measurement tools,
  - provide specifics for generating useful summary statistics regarding the quantity and distribution of benefits,
  - account for the trade-offs between data requirements, tractability, accuracy, and the ability to meet the objectives of the agency.

The ultimate objective of the research is to improve the methods used for evaluating transportation investments and policies.

Research Methodology

There are two major aspects to this research: the measurement tools themselves and the use of these measurement tools in an evaluation procedure. Examination of the measurement tools is being performed using several complementary strategies:

- *Qualitative examination of measures*
- *Empirical examination of measures*
- *Pursuit of improved measures*

The research methodology also includes analysis of the connection between the tools themselves and an accessibility-based evaluation procedure. Based on the findings from the examination of the tools, a strategy for selecting the most appropriate measurement tool will be developed that both (a) recognizes trade-offs between data requirements, tractability, and accuracy and (b) best meets the objectives and resources of the agency. Careful consideration will be given regarding exactly how to use such measures of accessibility to develop and interpret summary statistics and charts that reflect answers to the critical policy questions of *who's impacted?* and *how?*. Clearly, GIS will be an important tool in this process.

Definition and Discussion of Accessibility

What is Accessibility? It is the service that transportation (in connection with land use) provides, and it represents the ease with which people can pursue the activities they desire, and businesses can connect with consumers, employees, and goods. It's an abstract concept in that we don't know exactly what it is, but we know it exists in people minds. We also have a sense of what it impacts, for example welfare, lifestyle, quality of life, housing markets, and individuals' decisions such as travel patterns, location decisions, and vehicle ownership. One's accessibility is determined by the characteristics of the household or business, patterns of land use, and the nature of the transportation system, and it is a composite function of many types of trips and factors, with varying levels of frequency and importance.

Big Picture and Scope of Research

It is useful to examine the role of accessibility in the planning process. Figure 1 displays the modeling process used in Urban Planning. Briefly, the model system relies on a variety of inputs that describe the scenario being studied. The model system represents the interaction between transport demand and supply. Demand consists of long term decisions such as firm location, residential choice, and long term activity and travel decisions (e.g. work participation, auto ownership, purchase of transit pass) as well as short term activity and travel decisions (e.g. shopping and recreation or the timing of trips). The procedure is iterated between the production of origin-destination (OD) trip matrices by the demand model, and assignment of the OD matrices by the supply model (resulting in the performance of the network). The model system generates outputs that are used to analyze impacts of alternative policy scenarios.

Accessibility enters the planning process in two primary ways. The first is that accessibility can be used as an exogenous variable in demand models to explain behavior: accessibility impacts location decisions of businesses and individuals, vehicle ownership, and activity decisions. The second is in impact analysis. As mentioned in the

introduction, there is growing interest in using accessibility rather than travel time in evaluation to represent the benefit that changes in transportation and land use have on users.

The focus of this research is on the use of accessibility for evaluation purposes, and not on the dynamics of how accessibility impacts behavior. The research will directly consider accessibility of the individual and only indirectly consider accessibility for businesses.

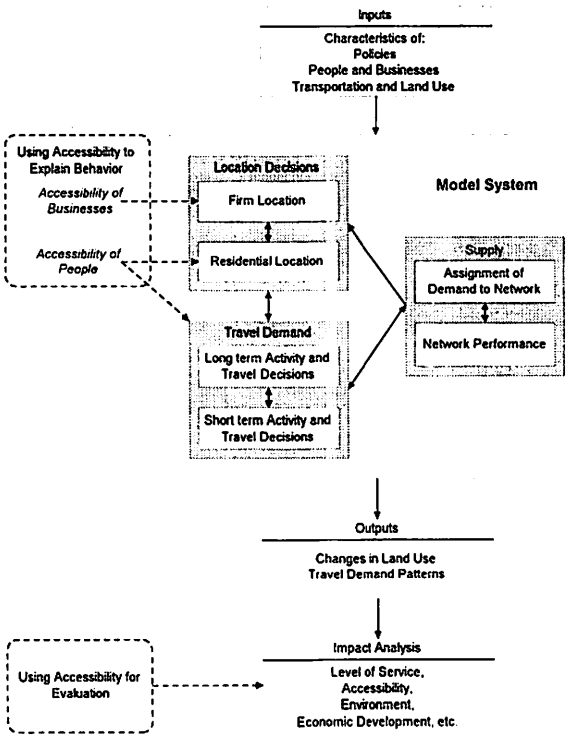

Figure 1: The Role of Accessibility in the Planning Process

Findings to Date and Implications for San Juan

Thus far in the research, a list of desirable properties of the evaluation procedure has been defined, qualitative analysis of the existing measures (including the state of the practice in San Juan) has been performed, a framework for a model of perceived accessibility has been developed, and much of the necessary data have been assembled. The findings are summarized in the following sections.

Desirable Properties for an Evaluation Method

One of the first tasks to be performed was to define the properties that we desire in an accessibility-based evaluation method. While it is expected that this list will continue to evolve, the current status of the list is as follows.

The measure should reflect:

- Marginal impact of distance
- Multimodal aspects of the network

- Heterogeneity of people and activities
- Perceptions of users
- How people travel (e.g. multistop/multipurpose trips)

The measure must be able to provide:

- A measure of accessibility to jobs
- A composite measure of accessibility to all types of activities
- Quantification of the distribution of benefits
- Comparisons across scenarios

The measure must be reasonable in terms of:

- Data requirements
- Tractability
- Interpretability

Description of Existing Measures

Accessibility is a fairly complex and vague phenomenon for which various measures have been proposed and are used in practice. Existing accessibility measures fall into the following three main categories (although there are numerous variants within each class): isochrone, gravity, and logsum.

The isochrone method involves the construction of concentric circles of various cost budgets. The opportunities within each band are then counted and used as a measure of accessibility. Thus the measure is not affected by differences of travel cost to opportunities within the band.

The gravity measure (so called because it is the denominator of the gravity models used for trip distribution) is similar to isochrone, with the addition that the opportunities are weighted by the travel cost of reaching them. The accessibility for an opportunity will increase if either it becomes more attractive or the travel cost decreases.

The logsum measure is derived from logit, the random utility-based discrete choice model. A logit model predicts the choice that an individual makes when faced with a set of alternatives. The model assumes that the individual associates a utility with each alternative and chooses the alternative that has the maximum utility. A measure that can be derived from a logit model is the expected maximum utility that will result from a choice. The expected maximum utility derived from a choice of activities spatially distributed throughout a transportation network can be interpreted as the benefit derived from the transportation and land use system and thus as a measure of accessibility. The logsum accessibility measure can be extended (via nested logit models) to include mode choice, complex trip-chaining or day activity schedules.

The gravity model and a simple (i.e. non-nested) logsum have been proven to be theoretically identical. However, the practical application ends up resulting in quite different models. Gravity models are usually estimated and applied using aggregate zone to zone travel data, which means that gravity models tend to have parsimonious

functional forms (e.g., they are only a function of travel time and number of opportunities). The logsum measures are usually estimated using individual level data; the higher variance in such data results in the ability to include more explanatory variables such as detailed representations of the modes, alternatives, and individuals.

Qualitative Evaluation of Existing Measures

Figure 2 summarizes how well each of the measures performs in terms of the desirable properties that were listed in the last section. In general, the complexity of the models increases with each model that is listed, and the usefulness of the information provided for policy analysis increases.

Method	Accessibility Equation, $A_i =$	Ratings of Properties (- poor, ✓ okay, + good): Marginal Impact of Distance	Multimodal	Heterogeneity of people/activities	Reflects perceptions of users	Trip chaining	Access to jobs	Distribution of benefits	Comparison across scenarios	Data requirements	Tractability	Interpretability
Isochrone	$\sum_{i,C_{ij}<C^*} D_j$	-	✓	✓	✓	-	✓	✓	✓	+	+	+
Gravity	$\sum_j D_j f(C_{ij})$	+	✓	✓	✓	-	✓	✓	✓	+	✓	✓
E[Max Utility] (destination/mode)	$\ln \sum_j \sum_m e^{U_{ijm}}$	+	+	+	✓	-	+	+	+	✓	✓	✓
E[Max Utility] (activity pattern)	$\ln \sum_a e^{U_{ia}}$	+	+	+	✓	✓	+	+	+	-	-	✓

i origin zone; j destination zone; m mode; a activity pattern; A_i accessibility; D_j opportunities; C_{ij} travel cost; U_{ijm} measured utility

Figure 2

Comments on state of the practice in San Juan

The current state of the practice for measuring accessibility in San Juan is a gravity measure with the following form:

$$A_i = \sum_j D_j f(C_{ij}) \qquad f(C_{ij}) = \alpha * C_{ij}^{-\beta} * e^{-\gamma * C_{ij}} \qquad \text{(Barton-Aschman 1993)}$$

where:
- A_i = accessibility from zone i
- D_j = opportunities at destination j
- C_{ij} = travel cost from i to j
- i,j = origin location and destination zone of trip
- α,β,γ = parameters (positive)

The impedance function $f(C_{ij})$ represent the trade-offs that people make between travel cost and opportunities. A different set of parameters is used for each of 5 trip types: home-based work, home-based shop, home-based school, home-based other, and non-home-based, and thus the resulting measure of accessibility has a separate component for each type of activity/trip. The parameters vary among each trip type because travel patterns vary among trip types. For example, people generally are willing to travel farther to work than they are for grocery shopping, and so the impedance function for shopping trips drops off much more rapidly as distance increases than does the impedance function for work trips.

The major advantage of a model of this type is its simplicity. It is based on aggregate, zonal data and only requires inputs of travel costs between zones and the number of opportunities (of various types, e.g. retail space or different types of jobs) within zones. Estimation of the parameters only requires aggregate origin-destination flow matrices for each of the different trip types. However, this simplicity comes at a cost.

Probably the most serious limitation in using this model for the evaluation of Tren Urbano is that the model implicitly assumes auto travel and not does recognize in any sense the multimodal network or the existence of transit. First, the parameters are estimated based solely on auto travel behavior. Recall that the measure is the denominator of a gravity model, and so the parameters come from the estimation of a gravity distribution model. These parameters are estimated by finding the set of values that best reproduce an observed trip-length distribution (e.g., the percentage of trips that fall within 0-10, 11-20, and 20+ minutes) from observed origin flows and destination flows. Because San Juan has minimal existing transit ridership, the parameters that are currently being used were estimated based on auto travel times and an auto trip length distribution. However, transit travel patterns are very different than auto travel patterns, for example they have quite different trip length distributions (and thus would result in different parameters in the gravity model). The basic idea here is that these models include assumptions about the underlying behavior, and to apply the model in a transit context requires thought at the estimation stage.

Behaviorally, a model of auto travel is much more simple than a model of transit travel, and so measuring accessibility provided by auto is easier than measuring accessibility provided by transit. For example, if one is only concerned with accessibility from auto and the transit mode share is low, the transit component can be excluded without greatly impacting the resulting accessibility measures. In addition, travel time is by far the most important factor in auto travel, and so the travel cost equation is easily calculated. One may also want to include monetary costs, however this is not terribly difficult.

Calculating the accessibility provided by transit is much more complicated. Recall that accessibility represents the ease with which the transportation network allows people to pursue the activities they desire. While travel time adequately represents the travel cost component for auto, it is not as straightforward for transit because a transit trip includes many important factors that have different units of measurement and that are weighted differently in terms of importance to the overall quality (and 'ease') of the trip. Such factors include: frequency of service, wait time, in vehicle time, cost, and transfers. A use of a flat travel time component ignores these critical factors and their impact on accessibility. For example, a 20 minute transit trip that is solely on the Tren Urbano provides quite different accessibility than a 20 minute transit trip that has a portion of the trip on a Publico and then a transfer to the Tren Urbano for the remainder of the trip.

The second complicating factor is that mode choice (or the propensity to use transit) becomes a critical factor in one's perceived accessibility. The best example of this phenomenon is that the impact the Tren Urbano has on someone who does not own a car is going to be vastly different from the impact of someone who does own a car. The accessibility measure must capture such differences if the true benefit of the Tren Urbano is to be measured. Aspects such as this can be captured in accessibility measures by directly including demographics that impact the propensity

to use transit (e.g. auto-ownership, income, and number of children) in the model. The important point here is that the benefit is derived not simply from connecting people and activities, it's derived from connecting people who will use the system with the activities that they desire and need.

Another much more minor point is that the model is not representative of how people travel and pursue their activities, in terms of the ability to chain trips and combine purposes. It's a very simplistic representation that only considers point-to-point trips, and completely separates different types of trips.

Due to the aforementioned reasons, it is difficult to believe that the existing gravity model in San Juan is very representative of the accessibility and benefit that people will perceive the Tren Urbano to provide. The lack of attention to transit and its characteristics and the characteristics of individuals makes it difficult to infer the impact that Tren Urbano has on accessibility.

This is not to say that all of the issues discussed above must be dealt with to have a viable measure of accessibility. However, with relatively little effort, the gravity model could be extended to incorporate some of the more critical factors. Specific recommendations would be to include transit in the estimation process, include critical demographics such as auto-ownership, and include greater detail in the travel cost component, e.g. transfers and in-vehicle, access, egress, and wait times. Note that it's not clear that San Juan currently has data to make these minor modifications. In addition, the chances of successfully introducing this higher level of detail would be enhanced by implementing a logsum measure, however, this would require a more substantial data collection effort, including the collection of disaggregate data. This research will aim at better understanding and quantifying the impact that the additional complexity has on the accessibility measure, and the benefits of using different functional forms (e.g. gravity versus logsum).

Proposed Method for Capturing Perceived Accessibility

While capturing some measure of tradeoff between travel and activities, the measures described in the last section are in the end fairly mechanistic measures that represent something that *analysts have defined* to be representative of accessibility, but that do not necessarily reflect the accessibility that is *perceived* by individuals. However, accessibility is a very complex and vague phenomena; it is a function of many types of trips and factors with varying levels of frequency and importance. The specifics of the transportation and land use network, including level of service of public transportation, availability of parking, ease of multipurpose and multistop trips, also are important factors. Also the specifics of the household itself, including household structure, income, and auto ownership have strong impacts on one's accessibility. Conceptually, if one thinks about the factors influencing personal accessibility equations, it's highly unlikely that the underlying equation is a point-to-point based accessibility equation such as isochrone, gravity, or a simple logsum, and it's not even clear that it's a more complicated logsum function (such as the activity-schedule logsum). Therefore, there is a need to both test how closely correlated the existing measures are with perceived accessibility, and to investigate measures that aim at capturing perceived accessibility. In pursuit of this goal, a fundamentally new method of measuring perceived accessibility is proposed as a part of this research.

The idea behind the proposed measure is to use inference to measure accessibility, that is, gather all sorts of information that provides an indication of one's perception of accessibility, and then try to infer from this information the underlying value of accessibility. There are several sources that provide information on perceived accessibility. Accessibility impacts individual's decision of where to live and how many autos to own. Accessibility also impacts residential property values. Direct measures of accessibility (isochrone, gravity, and logsum) are presumably correlated with perceived accessibility, and can also provide information on the underlying value of accessibility.

The approach to measure perceived accessibility is to:

- Directly observe:
  - Residential location decisions
  - Auto ownership decisions
  - Property values
  - Direct measures of accessibility
- Account for the influence of other important variables, such as:
  - Demographics
  - Non-transportation neighborhood and property characteristics
- Infer a value of perceived accessibility for:
  - Each particular type of household, and
  - At each particular type of location
- Finally, aggregate individual values of accessibility to create useful summary statistics that provide information on the magnitude and distribution of benefits.

The concept of the model is depicted in Figure 3. The resulting model is one that combines a latent variable model (e.g., factor analysis), a joint residential choice and auto ownership model, and a property value model as shown in Figure 4.

The proposed model for accessibility of households takes advantage of advances in methodology to generate measures that are, potentially, more reflective of people's perceptions of accessibility. The model also provides a means for evaluating the extent to which traditional measures reflect perceived accessibility, by both direct comparisons of calculated values of accessibility and by the statistical relationships (goodness of fit measures) from the latent variable model.

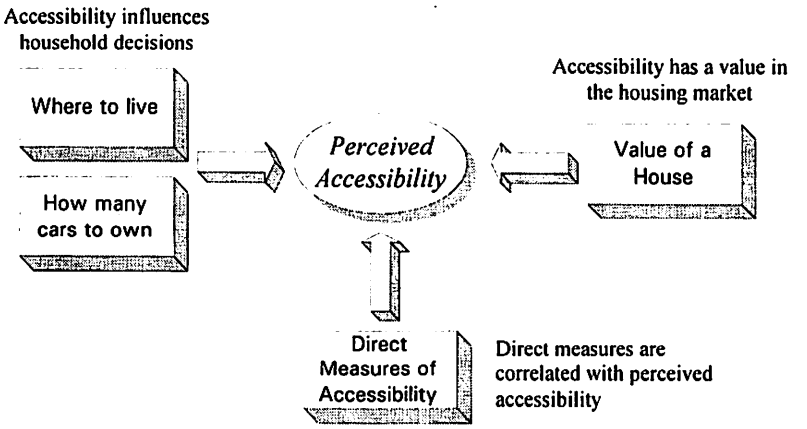

Figure 3: Proposed Measure of Perceived Accessibility –
Infer value of accessibility by observing its influence on observable factors

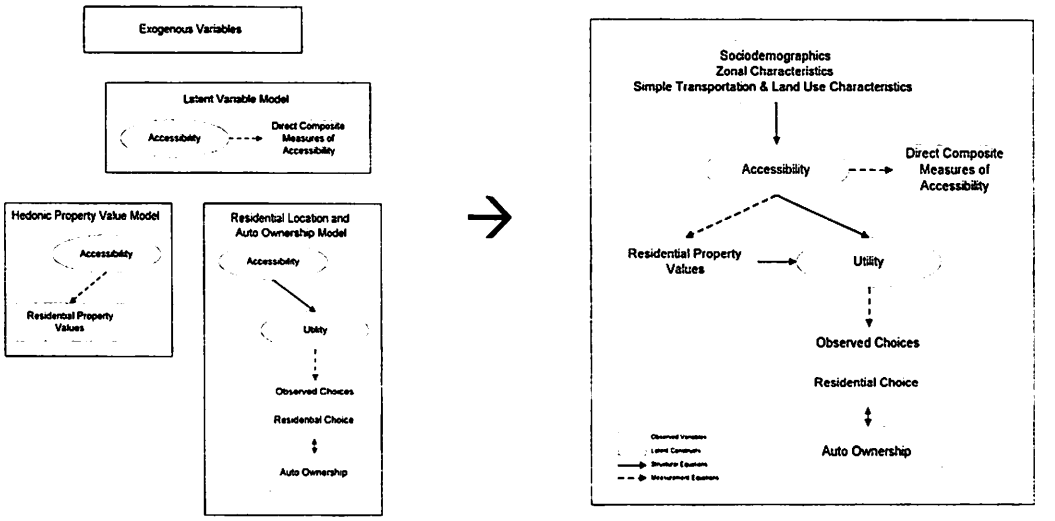

Figure 4: Proposed Measure of Perceived Accessibility –
A combined latent variable, property value, and a residential choice/auto ownership model

Data

The data are needed to calculate both the existing measures of accessibility (isochrone, gravity, and logsum) as well as the data to support the model of perceived accessibility. The methodology is based on a realistic, yet extensive data set, including data on:

- households (individual level demographics and detailed travel/activity patterns on a typical day)
- residential properties (value, location, and attributes)
- zones (land use, schools, crime)
- transportation network (layout and service levels)

It's important to note that the data required for the research is not necessarily the data required for application of accessibility-based evaluation methods. In fact, one of the purposes of the research is to investigate the usefulness of the additional data and model complexity. However, to fully investigate accessibility measurement tools and to make recommendations on conducting accessibility-based evaluation methods requires the extensive data set.

Unfortunately the necessary data required for this analysis does not currently exist for San Juan. In fact, even the first level of analysis of comparing the existing measures of accessibility (gravity, isochrone, and simple logsums) cannot be performed on data from San Juan, because there is no disaggregate data to support the calculation of the logsums. Therefore, a data set for a city other than San Juan must be used for the analysis. Fortunately, Portland, Oregon already has collected the data necessary for the analysis and so the analysis will be performed based on this data set.

While it would be preferable to estimate the model using data from San Juan, it is important to note that the focus of the research is on developing procedures for accessibility-based evaluation. The focus is not directly to produce and analyze numbers regarding impact analysis for various future scenarios in San Juan, although clearly an improved ability to produce and analyze the numbers is a direct goal. Thus, even though the analysis will be made based on data from a different city, we can still provide solid recommendations for accessibility-based evaluation methods for San Juan.

Portland has collected all of the required data, and it will not be necessary for us to collect any new data. Much of the necessary data has been assembled from the Portland MPO. The outstanding data include social data (crime and schools) and the GIS databases (zone and transportation network).

Future Work

The groundwork for this research has been established. The remaining work involves continuing the qualitative analysis of the measures, collecting the outstanding data (listed under the section on data), estimating the models, analyzing the performance of the different measures, and to think much more carefully about how to generate useful summary statistics representing the magnitude and distribution of the benefits, including how to display and interpret these data. The final deliverable will be detailed guidelines on performing accessibility-based evaluation including data collection, tools, and analysis.