

# Analysis of Activity-Based Accessibility

by

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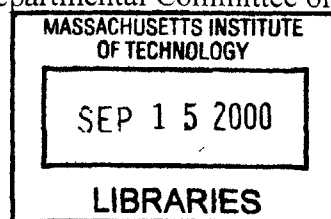
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## Abstract

This analysis studies the properties and performance of the Activity-Based Accessibility (ABA) measure, which is generated from the Day Activity Schedule (DAS) model system. The DAS model is an integrated system representing all the activities and trips taken throughout a whole day. It uses the concept of activity pattern, which refers to the sequences, structures and relationships among all the activities and trips taken by an individual during a whole day. The ABA is defined as the expected maximum utility over the choices of all the alternative activity patterns. In this way, the ABA measure reflects an individual's whole day travel schedule; traditional measures of accessibility focus on a single trip (e.g. the work trip).

Data from Portland, Oregon, was used to explore the empirical properties of the ABA. It shows that the ABA is a comprehensive measure with the capability to reflect each individual's perception of the interrelationship between the land use pattern and transportation system. The ABA displays reasonable sensitivities over the three important components: land use patterns, level-of-service of transportation systems and taste variations across the population. By comparing the ABA with traditional trip-based measures, including isochrone measures, gravity-based measures and the simple utility-based measures, the study highlights the advancement of the ABA measure. Among traditional measures, the simple utility-based measure based on a destination-mode choice model is the most advanced. The comparison between a work trip simple utility measure and the ABA measure demonstrates that the results differ; the simple utility-based measure is impacted more by both the CBD and transit, whereas the ABA shows a heavier influence of auto and non-CBD activity centers.

Thesis Supervisor: Moshe E. Ben-Akiva  
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# TABLE OF CONTENTS

<b>CHAPTER 1. INTRODUCTION AND BACKGROUND .....</b>	<b>7</b>
1.1 ACCESSIBILITY .....	7
1.2 MOTIVATION .....	8
1.3 RESEARCH OBJECTIVES.....	10
1.4 DAY ACTIVITY SCHEDULE MODEL SYSTEM AND ACTIVITY-BASED ACCESSIBILITY .....	11
1.4.1 <i>The Portland implementation of the DAS.....</i>	<i>12</i>
1.4.2 <i>The activity-based measure of accessibility .....</i>	<i>13</i>
1.5 OUTLINE OF THE THESIS .....	14
<b>CHAPTER 2. LITERATURE REVIEW.....</b>	<b>15</b>
2.1 APPLICATIONS OF ACCESSIBILITY .....	15
2.1.1 <i>Accessibility of a geographical area.....</i>	<i>15</i>
2.1.2 <i>Accessibility of transportation infrastructure.....</i>	<i>17</i>
2.1.3 <i>Accessibility of a business.....</i>	<i>17</i>
2.1.4 <i>Accessibility of individuals.....</i>	<i>18</i>
2.2 MEASURES OF ACCESSIBILITY .....	19
2.2.1 <i>Isochrone measures.....</i>	<i>20</i>
2.2.2 <i>Gravity-based measures.....</i>	<i>21</i>
2.2.3 <i>Utility-based measures.....</i>	<i>22</i>
<b>CHAPTER 3. METHODOLOGY.....</b>	<b>24</b>
3.1 DEFINING A GOOD MEASURE OF ACCESSIBILITY .....	24
3.2 OVERVIEW.....	26
<b>CHAPTER 4. ANALYSIS OF ACTIVITY-BASED ACCESSIBILITY (ABA).....</b>	<b>28</b>
4.1 STUDY AREA AND DATA SETS .....	28
4.2 DISTRIBUTION OF ACTIVITY-BASED ACCESSIBILITY .....	28
4.2.1 <i>The issue of scale and the ABA .....</i>	<i>29</i>
4.2.2 <i>The method for ABA unit translation .....</i>	<i>29</i>
4.2.3 <i>Distribution plots .....</i>	<i>30</i>
4.3 SENSITIVITY TO SOCIOECONOMIC STATUS .....	34
4.3.1 <i>Market segments defined by income.....</i>	<i>34</i>
4.3.2 <i>Market segments defined by car ownership .....</i>	<i>35</i>
4.3.3 <i>Market segments defined by employment status.....</i>	<i>36</i>
4.4 SENSITIVITY TO LEVEL-OF-SERVICE OF THE TRANSPORTATION SYSTEMS .....	37
4.5 SENSITIVITY TO RESIDENTIAL LOCATIONS .....	40
4.5.1 <i>Sensitivity to residential locations at individual level.....</i>	<i>40</i>
4.5.2 <i>Sensitivity to residential locations at market segments level.....</i>	<i>46</i>
4.6 CONCLUSIONS .....	51
<b>CHAPTER 5. COMPARISON OF ABA WITH TRADITIONAL MEASURES .....</b>	<b>52</b>
5.1 COMPARISON WITH ISOCHRONE MEASURES.....	52
5.2 COMPARISON WITH GRAVITY-BASED MEASURES .....	53
5.3 COMPARISON WITH SIMPLE UTILITY-BASED MEASURES .....	56
5.4 CONCLUSION .....	59
<b>CHAPTER 6. SUMMARY AND FUTURE RESEARCH.....</b>	<b>60</b>
6.1 SUMMARY .....	60
6.2 FUTURE RESEARCH.....	61
<b>BIBLIOGRAPHY .....</b>	<b>65</b>

## LIST OF FIGURES

Figure 1 Portland Day Activity Schedule model system.....	13
Figure 2 Distribution of accessibility in temporal unit.....	31
Figure 3 Accessibility values before transforming the units.....	31
Figure 4 Distribution of accessibility in monetary units .....	33
Figure 5 Distributions of accessibility for market segments defined by income levels.....	34
Figure 6 Distributions of accessibility for market segments defined by auto ownership ...	35
Figure 7 Distributions of accessibility for market segments defined by employment status .....	36
Figure 8 Changes in accessibility values as a result of transportation pricing policies .....	38
Figure 9 Accessibility and land use plots .....	42
Figure 10 Accessibility plots as a function of car ownership.....	43
Figure 11 Accessibility plots as a function of employment status .....	45
Figure 12 Base cases for short-term and long-term analysis.....	46
Figure 13 Average accessibility of the whole population and walk time from home to transit .....	47
Figure 14 Accessibility plots for market segments defined by income levels .....	48
Figure 15 Accessibility plots for market segments defined by car ownership.....	49
Figure 16 Isochrone measures defined by different land use variables.....	53
Figure 17 Gravity-based measures for different trip purposes.....	55
Figure 18 Utility-based measures of accessibility.....	56
Figure 19 Comparison between ABA and simple logsum measure.....	58

## LIST OF TABLES

Table 1 Measures of accessibility.....	20
Table 2 Characteristics of people with accessibility higher than 3800 minutes.....	32
Table 3 Characteristics of people with higher sensitivity as a result of a peak hour toll .....	39

# **Chapter 1. Introduction and background**

## ***1.1 Accessibility***

“Accessibility”, although a widely used term, in the transportation-planning arena, is an abstract concept. Researchers have defined this term in various ways, and have also constructed numerous mathematical formulations to measure its value. In general, accessibility is considered essential in evaluating the interrelationships between patterns of land use and the nature of transportation systems. On one hand, the planning of a transportation system depends on the forecast of land use; on the other hand, the distribution of the land use is impacted by the transportation system. Thus, the indexes of accessibility that describe the correlation between these two sectors have been used extensively by researchers and policy makers, especially in assessing the existing transportation system and forecasting the performance of the system. One of the definitions of accessibility is “the ease and convenience of access to spatially distributed opportunities with a choice of travel” (Department of Environment, 1996).

The difficulty is how to quantify accessibility to represent both the pattern of land use and the nature of the transportation system and their interrelationship. Researchers have come up with various ways by using different variables and functions, which results in a variety of accessibility measures.

## **1.2 Motivation**

Since accessibility is a critical indicator of the interrelationship between land use and transportation systems, it has become an essential factor in many transportation planning issues, including:

- *Urban development and transportation planning.* In earlier urban and transportation planning practices, improving mobility was considered the primary objective. In order to provide enough mobility for travelers, problems of congestion were addressed by building up more infrastructures. At a time when automobiles were prohibitively expensive to most people, and when the transportation demand was increasing very slowly, these types of methods would work well in reducing traffic congestion. But now, with rapid increases in traffic demand, this method merely results in a higher level of congestion by attracting more traffic to newly improved roads. The decisions derived from these methods turned out to be not efficient, by neglecting the interrelationship between transportation systems and urban land use. The problematic area in the example must be a place providing more activities than other area. The improvement in the infrastructure would only result in a higher demand from the travelers.

With lessons learned from previous experience and more research on accessibility and travelers' behavior, the goal of urban development and transportation planning has been shifted from focusing on the "vehicular mobility" to the "personal mobility" (Dalvi, 1978). This improvement results in the change from aiming to reduce traffic congestion to providing higher accessibility (Wilson, 1972). Therefore, more attention has been paid to providing an easily accessible city to decrease traffic congestion. A highly accessible city does not mean a city with higher road occupation rate, but is an area that would provide residents with satisfied convenience to access desired activities. This requires careful coordination between the transportation network and



the distribution of land use. Therefore, solutions aiming at providing higher accessibility may not need any modifications on a transportation system. In some cases, redistribution of the activity opportunities may be more effective in increasing the accessibility (Morris, Dumble and Wigan, 1979).

- *Regional economic performance evaluation.* In regional economics, accessibility basically concerns land, labor and capital (Bendavid, 1974). All these are impacted by the transportation system around that area. It was presumed that the investment and construction of a new road would boost the regional economy. However, over time, it has been realized that neither the investment of transportation infrastructure, nor the number of companies, nor the total provision of employment opportunities affects regional economic performance, but their correlation, which is represented by the accessibility values.
- *Residential choice modeling.* In reality, when people make decisions on where to live, they usually base their considerations on numerous aspects, including (a) socioeconomic background, such as the work location of the primary members within the household; (b) land use pattern around the area; (c) the crime and education level of the area; and (d) the nature of transportation system that allows them access to their desired activities. The important role of accessibility in residential choice has been realized in the practice of behavioral modeling (Gunn, 1994).
- *Alternate transportation plans evaluation.* A good transportation plan is not one that would provide more mobility to the travelers, but one that could take the residents to their desired activities with an adequate level of convenience and satisfaction. So a very important innovation is to put the transportation system into the context of an existing land use system. Accessibility measure is thus the best choice in evaluating alternate transportation plans. For example, Koenig (1980) utilized the accessibility indicator to assess the net utility of alternative road networks.

Because of the important role that accessibility measure plays, a variety of measures of

accessibility have been brought forward and adopted in the current practice of transportation planning. Most of these existing measures are based on separate trips, and are called “Trip-Based” measures. In the trip-based measures, the conceptual units of analysis are separate trips. But in reality, people usually make their travel decisions based on their needs to get involved in activities rather than to enjoy a single trip. For this reason, the role of trips is actually to connect the series of activities that the traveler would like to pursue. Consequently, trips are highly correlated with each other. For example, the mode from work to shopping on the way home is highly associated with the mode one chooses when he goes to work. Trip-based models could not describe this type of interactions between sequential trips.

Trip-based models are usually easy to implement in practice, especially at the aggregate level. But they have displayed their weakness in modeling traveler’s behavior. At the same time, the studies of existing measures have illustrated that a good measure of accessibility is very important in transportation and land use planning. This research is an attempt to overcome the deficiencies of the existing measures by investigating the properties and performance of a new measure, the Activity-based Accessibility (ABA).

The ABA discussed in this analysis is generated from the Day Activity Schedule (DAS) model system, which is an activity-based model and thus the measure of accessibility generated from this model is so called “Activity-Based Accessibility”. The DAS model explores an innovative way in modeling individual’s travel demand. Rather than model independent trips, the DAS models the whole day schedule consisting of multiple activities and trips taken by an individual. This model thus captures people’s behaviors and decision-making processes in a more realistic way.

### ***1.3 Research objectives***

This research endeavor is primarily aimed at investigating the Activity-Based Accessibility in terms of its properties and performance and demonstrating that the ABA is an advancement of the state of the art in the research of accessibility measures. This is performed by not only examining the ABA itself, but also by comparing it with the

traditional measures of accessibility.

#### **1.4 Day Activity Schedule model system and Activity-Based Accessibility**

Activity-Based Accessibility is derived from the Day Activity Schedule (DAS) model system. The Day Activity Schedule model is first proposed by Ben-Akiva, Bowman and Gopinath (1996), and it is implemented first with the data from Boston by Bowman (1995) and Ben-Akiva and Bowman (1999). And then the DAS model is implemented in Portland, Oregon by Cambridge Systematics, Inc. et. al. (1997), after which Bowman (1998) refined this model system in his dissertation. This section is based on the description of the DAS presented in Bowman (1998). The DAS model system models people's travel demand in an innovative way. It regards the activities taken in a whole day context as the basis for modeling people's behavior. This is based on the idea that the physical act of travelling is derived from people's desire to pursue various activities.

The DAS model is based on the concept of an *activity pattern*, which covers the interrelationship between the different activities and the trips that link an individual with all these activities. The activity pattern refers to the sequences, the structures and the interactions among all the activities and the tours<sup>1</sup> taken by an individual during a whole day. It represents the basic decisions of activity participation and priorities, the types of the tours, and the locations each activity occurs, at home or on tour. Each activity pattern is defined by (a) the primary activity of the day, (b) whether the primary activity occurs at home or away from home, (c) the type of tour for the primary activity, including the number, purpose and sequence of activity stops, (d) the number and purpose of secondary tours, and (e) purpose-specific participation in at-home activities.

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<sup>1</sup> Tour is defined as a journey beginning and ending at the same location. (Bowman, 1998)

With the inclusion of the concepts of activity pattern and tour, the activity-based model distinguishes itself significantly from the traditional trip-based models. It actually formulates an “activity-trip” network within a whole day schedule. Two important features in this network are: first, the “links” are the trips that connect all the activities taken during the whole day, and because of this, the activity-based model covers multiple trips, with multiple modes, destinations and purposes; and second the “nodes” are the activities to associate the sequences of the trips, so this model covers the interrelationships between trips. By formulating this “activity-trip” network, the ABA measure possesses remarkable advancement over the trip-based models, in which only one trip could be covered. To provide an example of the advantages of the activity-based model, take the example of a peak hour toll. In this case, the possible responses may include the changes in destination, timing and mode. In addition, the imposition of the toll may result in activity participation adjustment, changes in the sequences of activities, and tradeoffs between at-home and on-tour activity locations.

#### 1.4.1 The Portland implementation of the DAS

For the analysis presented here, a published implementation of DAS is used. It is the second implementation used by Portland, Oregon to model and forecast people’s travel demand over Portland metropolitan area. In this implementation, the DAS model consists of five levels of choices, which are:

- Day activity pattern models
- Home-based tours time of day models
- Home-based tours mode and destination choice models
- Work-based sub-tours models
- Intermediate stop locations models for car driver tours

The upper level choice conditions the lower level choice, and the lower level choices inform the upper level with the expected maximum utility over the lower level. The top-level model in this structure is the choice of activity patterns. Because the choices over activity patterns are believed to be affected by the expected tours included in the pattern, the utilities of the activity patterns are set to have a component for the expected utility of

its tours. The lower level models describe the choices over the travel patterns, including the travel time, mode and destination, and work based sub-tours, see Figure 1.

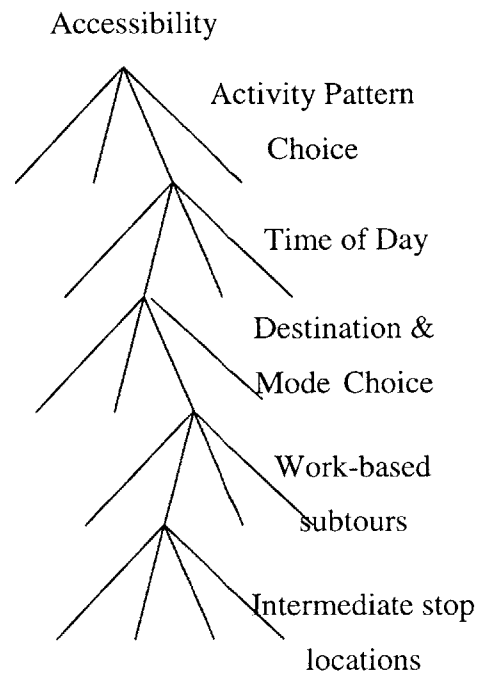


Figure 1 Portland Day Activity Schedule model system

### 1.4.2 The activity-based measure of accessibility

The ABA derived from this activity-based model system is defined as the expected value of the individual's maximum utility among the available activity patterns, given a residential location. It departs substantially from the existing trip-based measures because their fundamental concepts and the definitions are essentially different. A detailed comparison between the traditional trip-based measures and the activity-based measures will be represented in later chapters. The key aspects to the ABA measure are:

- It reflects the decision-making process of travel and activity scheduling.
- It captures the chaining of the trips and interactions between different modes, and it also captures multiple purposes and time schedules of activities.
- It is a comprehensive measure, capturing not only the nature of land use and properties of the transportation systems but also the socioeconomic characteristics of the individuals.

Whether this complex and comprehensive measure behaves better or not can be only tested from its performance in the practice of transportation planning.

### ***1.5 Outline of the thesis***

This thesis starts in chapter 2 by reviewing the literature on the definitions of accessibility and ways of measuring accessibility. In chapter 3, the methodology used in this analysis is introduced. In chapter 4, the analysis of this ABA measure is conducted, which consists of the distribution and sensitivity analysis. At first, the accessibility values for every person in the population are calculated and its distribution over the whole population is examined. And then the sensitivity analysis studies the sensitivity of ABA to three classes of variables, including socioeconomic characteristics, land use patterns and level-of-service of transportation systems. In chapter 5, the ABA is compared with traditional measures of accessibility. Finally, in chapter 6, the conclusions from this study are presented, and the future research directions are proposed.

## **Chapter 2. Literature review**

The concept of accessibility has been widely used ever since the 1950s when the gravity theory is rigorously legitimized by Isard at the First Regional Science Meeting in 1954 (Reggiani, 1998). Accessibility is regarded as a fundamental concept in the area of transportation and urban planning. People with different understanding or different purposes of the term have defined and measured accessibility in various ways. This chapter presents a review of the literature on this topic. It is organized in two parts, in section 2.1, the various areas that people apply the concept of accessibility are presented; and in section 2.2, the three classes of measures to evaluate the accessibility are discussed.

### ***2.1 Applications of accessibility***

As mentioned before, there exist numerous ways to define the term of accessibility. This chapter presents the definitions found in the literature according to the objects that accessibility refers to. Accessibility could be defined as a property of a geographical area, transportation infrastructure, a business or an individual.

#### **2.1.1 Accessibility of a geographical area**

The notion of accessibility to a geographical area is essential in urban planning and regional economic analysis. This type of accessibility could be represented by the land use pattern, the regional economic development, the job opportunities and the access to these opportunities, which are all important considerations in urban planning and economic development strategy.

For example, the early practice of urban planning used to follow the pattern of a distributed urban structure, in which different zones were assigned to provide different services and utilities. The long distance from home to work, and from home to shopping resulted in high demand of traveling, and thus traffic problems, including traffic jams, air pollution, etc. In recent years, it has been realized that a highly accessible city should be in the

pattern that can provide easy access to social and economic opportunities. So the idea of a “compact city” is proposed (Cervero, 1996). The “compact city” is one with various functionalities of the urban area mixed together, so that people can get involved in different of activities without much demand on auto-transportation. The “compact city” is aimed at providing friendlier environment to pedestrians and discouraging the use of automobiles. The objective is to increase accessibility provided by non-motorized travel. According to the study conducted by Duchateau (1998), people’s demand to get to opportunities result in their demand of mobility, but the constraints on the supply of enough mobility combined with the fast increase in the demand result in the traffic problems. So the key point to resolve this problem would be to look at both the mobility and the accessibility.

Another part of the literature on accessibility of locations is focused on the employment access and economic opportunities within an area. According to O'Regan and Quigley (1999), the motivation for the research on this topic was started by the 1965 riots in Los Angeles. Former CIA director McCone concluded that lack of jobs and inadequate transportation to jobs played a large role in creating the unrest in urban areas. The continuing decentralization of jobs to more attention on the accessibility to them by the transportation system. Increasing the accessibility to employment opportunities is given particular consideration in urban and regional planning, which is especially important to those people with low income and low availability of cars.

People with high income and more cars per household generally would prefer to living in a suburban area with better environmental conditions and also tend to prefer commuting by car. But those households with low income and with no car must depend on the public transportation network in the downtown area to get to the activities they would like to enjoy. So the employment accessibility and the transit accessibility are other important topics in the literature on accessibility and regional economics. As early as in 1972, Wachs and Kumagai (1972) illustrated that accessibility to jobs and urban services is an important factor in evaluating the qualities of urban life. The relationship between job accessibility and transit accessibility is also realized to be an important factor in urban and



transportation planning. This could be shown by two projects. The first study is conducted by Rice Center and VIA Metropolitan Transit in 1983. They performed an analysis to assess eight alternative downtown transit plans given the projected employment growth. The second one is presented by Zhang, Shen, and Sussman (1999), in which they studied the policy to enhance the job opportunities in order to complement a rail transit investment in San Juan, Puerto Rico.

### 2.1.2 Accessibility of transportation infrastructure

The analysis of accessibility of transportation infrastructure is very important in investment assessment, where accessibility is defined as the measure of people's access to economic and social opportunities (Parolin, Nichols, and Mcdougall, 1994). It has been realized that only if the projected infrastructure provides better chances for people to get to the social and economic activity opportunities, would the investment be profitable. Among the early studies, Leonardi (1978) developed a mathematical programming approach to optimize the location of the facility by to maximizing the expected value of accessibility. An example for the recent work is the analysis by Diaz (1999), in which he concludes that the primary positive impact of rail on property values is the impact due to accessibility.

### 2.1.3 Accessibility of a business

Accessibility is also a critical consideration for a business when deciding where to locate. So the application in this context requires that accessibility reflect the business's attraction to surrounding households and potential customers. A number of ways to account for a business's accessibility have been proposed.

The simplest form is to count the number of households within a certain distance from the shop. It assumes that people will go only to those shops that can be reached within a certain amount of travelling. The longest possible distance from home to shop that people would travel defines a "market area". A precise definition of the market area is very important but difficult. Because, the longest distance that people will travel to go shopping varies according to many different considerations, including the decision-maker, the time

of shopping, the reason for shopping, etc. So, Hodgart (1978) proposes the idea to distinguish the deterministic market area from the probabilistic market area. Ritsema van Eck and de Jong (1999) realize the accessibility of one shop is also impacted by the accessibility of other shops. So, in their analysis, they calculate the accessibility of shops with consideration of spatial competition between individual shops or between chains of shops. Another way to measure the accessibility of shops is to calculate the access to the goods and services the shop provides. Guy (1983) developed a measure, called the “shortest distance” measure. It considers only “those types of shop which surveys have shown consistently to be required close to the home by consumers. The measure itself is primarily of accessibility to retail goods and services, rather than to shops.”

All these measures consider only separated trips from home to shop, they could not cover the schedule or context of the shopping trips or the shopping trips originated from other locations. The majority of the current literatures on accessibility to shops or business units are lack of explicit behavioral theory.

#### 2.1.4 Accessibility of individuals

Among the existing literature on accessibility, there is also some research analyzing the accessibility at individual and household level. These types of accessibility are based on individual travel behaviors, and define accessibility on a more solid behavioral consideration. This research was started on the basis established the work of Domencich and McFadden (1975), in which they developed a theory of demand, for populations of individual economic consumers, and Ben-Akiva and Lerman (1977), in which they developed a measure of accessibility based on the application of random utility theory to individuals’ decision process; and.

In recent literature, many scholars examine the interrelationship between travel and accessibility, in which they defined accessibility as a measure of “potential for travel”. This comes from the notion that people with a higher level of accessibility travel easier and thus have higher demand of traveling. For example, Sheppard (1980) constructed a model

showing that the demand for traveling is a function of accessibility to opportunities. And Ghosh and McLafferty (1984) concluded from their research “the rate of multipurpose shopping depends on the consumer’s location to shopping opportunities”. Hanson and Schwab (1987) questioned the conclusion that higher level of accessibility implies higher demand of traveling, and conducted a study at the individual level. From their analysis, they found that:

“High accessibility levels are associated with higher proportions of travel, ..... lower levels of automobile use, reduced travel distances for certain discretionary trip purposes, and smaller individual activity spaces. .... Overall, accessibility level has a greater impact on mode use and travel distance than it does on discretionary trip frequency.”

This conclusion is very interesting, especially at a time when many researchers have assumed a very strong relationship between trip frequency and accessibility. This unexpected result from Hanson and Schwab’s (1987) work sheds light on the importance of the analysis of accessibility at the individual level, instead of at the zonal or aggregate level.

## ***2.2 Measures of accessibility***

In the current literature, there are numerous ways to measure the values of accessibility, and also many ways to classify these measures. Following Handy and Niemeier (1997), accessibility measures are classified into three categories: the Isochrone measures, the Gravity-based measures and the Utility-Based measures. The classification is summarized in Table 1, and each category is discussed in details in the following sections.

	<b>Mathematical Formulation</b>	<b>Authors</b>
Isochrone	$Acc_i = \sum_j a_j$ $Acc_i = \sum_j W_j a_j$ <p><math>a_j</math> is the attraction of destination zone j</p>	Wachs & Kumagai 1973; Vickerman 1974; Oberg 1976; Black and Corey 1977; Breheny 1978; Mattson & Weibull 1981; Moretti 1985; Cattan 1992; Gutierrez & Urbano 1996
Gravity-based	$Acc_i = \sum_j a_j f(c_{ij})$ <p><math>f(c_{ij})</math> the impedance function of travelling from zone i to zone j</p>	Hansen 1959; Huff 1963; Ingram 1971; Wilson 1971; Schneider & Symons 1971; Domanski 1979; Weibull 1980; Fotheringham 1986; Broucker 1989; Nijkamp & Reggiani 1992; Bruinsma & Rietveld 1993; Rietveld & Nijkamp 1993; Forslund & Johansson 1993; Bibby & Capineri 1997; Zhang, Shen & Sussman 1999
Utility-based	$Acc_i = E(\max_{i \in C_n} U_{in}) = \frac{1}{\mu} \ln \sum_{i \in C_n} \exp(\mu V_{in})$ <p>where <math>U_{in} = V_{in} + \varepsilon_{in}</math>  <math>\varepsilon_{in}</math> is iid Gumbel            with <math>\text{var}(\varepsilon) = \pi^2 / 6\mu^2</math></p>	Neuberger 1971; Wilson 1976; Williams 1977; Leonardi 1978; Williams & Senior 1978; Ben-Akiva & Lerman 1979; Leonardi & Tadei 1984; Broucker 1989; Forslund & Johansson 1993

(Revised from Reggiani, 1998)

Table 1 Measures of accessibility

### 2.2.1 Isochrone measures

Isochrone measures are also referred to as “cumulative opportunity” measures. This type of measure simply counts the number of opportunities that could be reached within a given travel time/cost or distance. This type is the simplest. By defining a range of travel time/cost or distance, they actually define a weight to all possible opportunities. For the opportunities out of this range, the weight is set to zero and those within this range as 1. This is shown in equation 2-1.

$$Acc_i = \sum_j W_j a_j \quad (2-1)$$

$a_j$  represents for the opportunities in a zone  $j$

$$W_j = \begin{cases} 1, & \text{if } c_{ij} \leq c_{ij}^*, \text{ } c_{ij}^* \text{ is the defined band within which the activity} \\ & \text{opportunities can be accounted.} \\ 0, & \text{otherwise.} \end{cases}$$

An example of this type of measure is the “total number of employment opportunities within 30 minutes walk from transit”. From this example, the two most important weaknesses of this measure can be identified. First, how large should the range be? Second, you can choose the total employment, but why not choosing “total retail employment”? The results will be very different depending on the selected range and variable. Because of the lack of determinant ways to define the range or the variables, this type of measures are not ideal in most cases.

## 2.2.2 Gravity-based measures

Gravity-based measures are so called because they are derived from the denominator in the gravity model for trip distribution. A generic formulation of gravity-based measures to calculate the accessibility of zone  $i$  is

$$Acc_i = \sum_j a_j f(c_{ij}) \quad (2-2)$$

Where

- $j$  the possible destination zone from zone  $i$
- $a_j$  the activity opportunities in zone  $j$
- $f(c_{ij})$  impedance function of traveling from zone  $i$  to zone  $j$ .

In these measures, two components are considered,  $a_j$  accounts for the attraction of zone  $j$ , and  $f(c_{ij})$  represents the impedance induced by traveling from zone  $i$  to the possible destination zone  $j$ . In most cases,  $f(c_{ij})$  includes the travel time/cost in a negative exponential form. The different formulations of  $f(c_{ij})$  result in many different measures of gravity-based measures of accessibility.

This type of measure reflects the fact that the farther the opportunity is, the lower the impact of the opportunity on the accessibility values. In this way, the Gravity-based measures represent the interrelationship between transportation system and land use patterns. But these measures neglect the variations across individuals. From the Gravity-based measure, the retired old grandpa has the same value of accessibility as his grandson, who is a college student, just because they live together.

In the definition of this measure, if the impedance function  $f(c_{ij})$  is defined as a step function, in which the value is 1 within the range defined to count the activity opportunities and the value is 0 outside this range, then the Gravity-based measure is identical with the Isochrone measure. And thus the Gravity-based measure has the same weakness, which is that the Gravity-Based measures accounts for only one trip, such as the work trip starting from home. This actually constrains the usage of the gravity-based accessibility measures.

### 2.2.3 Utility-based measures

Utility-based measures are based on the random utility theory, see Domencich and McFadden (1975). It is assumed that people always select the alternative with the highest utility. Due to the various impacts from considerations that are hidden or difficult to capture, the utility is not known with certainty to the analyst, and therefore is treated as a random variable. The utility of an alternative is composed of two components. The first is called systematic utility, which is make up of the properties of the alternative and the characteristics of the decision maker that are assumed to impact the decision. The other component is called the disturbances, representing the randomness of the utilities. In order to obtain a tractable form, the disturbances are assumed to be identically and independently Gumbel distributed with a scale parameter  $\mu$ . Under this assumption, the expected maximum utility of individual  $n$  over his choice set  $C_n$  is:

$$E(\max_{i \in C_n} U_{in}) = \frac{1}{\mu} \ln \sum_{i \in C_n} \exp(\mu V_{in}) \quad (2-3)$$

where,  $V_{in}$  is the systematic component of the utility for individual  $n$  choosing alternative  $i$ ;

The expected maximum utility is defined as the *accessibility* of individual  $n$  over a choice situation, such as a destination choice, to represent an individual's perception of the interrelationships between land use patterns and transportation systems that he faces. One of the major advantages of the utility-based measures is that they can be defined at the individual level, and therefore can reflect the sensitivity of the choice decision to people's socioeconomic characteristics. This type of measure is the most advanced one among the existing measures.

Among the traditional measures, all of them are trip-based measures, in which people's accessibility values are calculated based on their choices over separate trips. So a trip-based measure can cover only one trip, with one purpose, one mode and one destination. It neglects the chaining of the trips and the time schedule for the trips. The ABA studied in this thesis is based on all the activities and trips taken during a whole day. Therefore, the ABA can cover multiple purposes, multiple modes and destinations, and also the sequences of the trips and the time schedule of the activities. The detailed comparison between the ABA and the traditional measures will be conducted in chapter 6.

## Chapter 3. Methodology

In this chapter, before conducting the analysis, the features that a desired accessibility should possess is proposed, and then the methodology and study structure starting from next chapter are presented.

### 3.1 Defining a good measure of accessibility

Accessibility is an abstract concept. It considers both the transportation system and the land use pattern, which could be presented by many different variables. It is thus almost impossible to set up a definite mathematical rule on how to measure accessibility. From the review of the literature, there exist a myriad of ways to calculate the values of accessibility. Each of them has some advantages and disadvantages. In most cases, it is not obvious which measures are better than the others. It is possible to define what a good measure of accessibility would be like according to the reason that it is used. The points listed following are from the general point of view. In most cases where accessibility takes the key role in analysis, a good measure of accessibility should possess the following properties:

- *Behaviorally strong.* This is among the lower level requirement, but in most cases, it is not easy to be satisfied. In both transportation and urban planning, modeling and representation of people's behavior are always an essential but challenging issue. A good measure of accessibility needs to have a very strong behavioral explanation and can reflect people's choice behavior logically and correctly.
- *Reasonably flexible.* A good measure of accessibility should be applicable to various purposes of application. It is more convenient and desirable to have a measure that could be used in different contexts, at least to some extent. For example, in a same area, two policies are in discussion, one is whether or not to build a new bus line; the other is whether a toll should be imposed. If there exists a measure applicable to both



of these two cases, what is needed is only to compare the changes in the values of accessibility caused by each of these two scenarios. By combining this with some social impact considerations, the officials can make the decision on which way to choose. This will reduce most of the work resulted in situations when different measures have to be explored, and different data sets have to be collected.

- *Adequate sensitivity.* Accessibility is a key index in capturing the interrelationship between land use and transportation systems, and thus a good measure of accessibility should possess enough sensitivity to the changes in either the property of land use or the level of service of the transportation system. More importantly, it should reflect the changes in the interrelationship between land use pattern and transportation system.
- *Satisfactorily comprehensive.* As accessibility is also a very important input in residential choice modeling, it should be inclusive enough to reflect the consideration that people have when choosing where to live. By consulting an individual's behavior, it shows that multifold factors impact his/her choice of dwelling locations. The considerations generally include the pattern of land use around the prospective living place. This reflects the activity opportunities, such as shopping stores; and the way to get to these activities, that could be described by the nature of the transportation network within reach. It also should cover the perception differences in accessibility for people with different socioeconomic backgrounds. Furthermore, as the residential location choice is a long-term decision, an accessibility measure reflecting the longer-term behavior would be preferred.
- *Comparable across individuals.* Accessibility is desired as a property of a person when living in a given location. If an individual can receive a higher value of accessibility in one place, it indicates that he will prefer to live there. If one individual has a higher value of accessibility than another person does when living in a same place, it suggests that the first person has a better chance to reach activity opportunities and live a better life than the other one. So, accessibility should be comparable not only across residential locations for a single individual, but also across decision-makers.

- *Computationally efficient.* A good measure of accessibility should be efficient and simple in terms of calculations. And also, it should be easy to handle. A too complicated measure may possess very nice properties theoretically, but may lack of practical usage.

The items listed above are needed for a measure to be regarded as a good measure of accessibility. Some of the requirements might be in conflict with each other, such as the item of “comprehensive” and “simple”. This makes the work to find a good measure of accessibility much more complicated than expected. On the other hand, in a different context, the requirements would be slightly different. However, in any case, the measure should have the potentiality to explain people’s behavior in a desired and logical way, and to perform well in playing its role in transportation and urban planning. None of the traditional measures could achieve all of these requirements. The activity-based accessibility examined in this analysis satisfies many of the requirements stated above by possessing a number of favorable properties, but it is computationally more complex than the traditional measures. This indicates that the study of a good measure of accessibility still needs a lot of work. This will be made clearer in the later analysis of the ABA and from the comparison between the ABA and the traditional trip-based measures.

### **3.2 Overview**

This chapter presents the framework that is employed to examine the properties and performance of the ABA. Two main pieces of study are presented:

- *Analyze the ABA measure.* With the Portland data and a computer-based micro simulation of the DAS model, the study includes the distribution analysis and sensitivity analysis of the ABA measure. In the distribution analysis, the scale issue of this measure and the difficulty to solve it is discovered, which is resulted from the complex structure of the DAS model. In order to make the ABA comparable across individuals, a simplified method is employed and the distribution of the ABA is thus

analyzed. In the sensitivity analysis, the sensitivities of the ABA to its three important components are examined, including the socioeconomic variables, level-of-service in transportation systems, and the land use patterns both in long-term and short-term behaviors. All these analysis is presented in chapter 4.

- *Compare the ABA with the traditional measures:* In this analysis, the traditional measures of accessibility are grouped according to two ways, first, based on the formulations of the measures, they are classified as isochrone, gravity-based and simple utility-based measures. The ABA is also a utility-based measure but is different from those traditional utility-based measures, in their basis for modeling. The ABA is based on the activities and trips taken by an individual throughout 24 hours, however, the simple utility-based measures are based on separate trips. In fact, all the traditional measures are based on single trips, and the simple utility-based measure is the most advanced measure among all these traditional measures, so the comparison between the simple utility-based measure and the ABA stands for the comparison between the trip-based measures and the activity-based measures. This analysis is conducted in chapter 5.

Before starting the analysis of the ABA from the next chapter, following is the properties that a good measure of accessibility are desired to have. The later analysis will show that the ABA measure satisfies most of these attributes.

## **Chapter 4. Analysis of Activity-Based Accessibility (ABA)**

In this chapter, the properties and performance of ABA are examined both theoretically and empirically. First, the study area and data sets are introduced. Next, the analysis is conducted by examining the distribution of ABA across the population, and its sensitivity to each of the three types of components, which are socioeconomic characteristics, land use patterns and level-of-service of transportation systems. At last, the conclusions derived from the analysis in this chapter are presented.

### ***4.1 Study area and data sets***

All analysis presented in this chapter is performed using the Portland, Oregon data sets and the Portland implementation of the DAS model system, as described in section 1.4.1. In this research, the Portland, Oregon metropolitan area is the geographic region of primary focus. The data used for this study is based on the synthetic population that Portland's Metropolitan Planning Organization (MPO) uses for their planning purposes. The statistics are based on a 10% sample rate of this population. The sampled population consists of 55,000 households, with 105,506 individuals aged over 16 years old. Those younger than 16 are assumed to have constraints on making their own travel decisions and are therefore not considered in this analysis.

### ***4.2 Distribution of Activity-Based Accessibility***

The objective of this section is to examine how accessibility is distributed across the population. The accessibility values are calculated by implementing the ABA measure with Portland data, including information about land use patterns, transportation system and demographics for each individual. A prerequisite for the distribution analysis is that the values of accessibility be comparable across individuals. Due to scaling issues of the DAS model system, the ABA is not directly comparable across individuals. Before a

comparison is made, it is necessary to convert the ABA to a scale that is consistent across individuals. This conversion is described next.

#### 4.2.1 The issue of scale and the ABA

Activity-Based Accessibility belongs to the utility-based measures of accessibility, where accessibility is defined as the expected maximum utility over a choice situation faced by an individual (Ben-Akiva and Lerman, 1985), and it is formulated as

$$Acc_n^* = E(\max_{i \in C_n} U_{in}) = \frac{1}{\mu} \ln \sum_{i \in C_n} \exp(\mu V_{in}). \quad (4-1)$$

Where:  $U_{in} = V_{in} + \varepsilon_{in}$ ,  $i \in C_n$ ,  $C_n$  is the choice set for individual  $n$ ,  $i$  indicates an alternative within this individual's choice set.

$V_{in} = \beta^* X_{in}$ ,  $X_{in}$  is a vector of variables included to explain the utility of alternative  $i$  to individual  $n$ , and  $\beta^*$  is a vector of parameters;

$\text{var}(\varepsilon_{in}) = \pi^2 / 6\mu^2$ ,  $\varepsilon_{in}$  is assumed to be iid Gumbelly distributed.

The formulation in equation 4-1 demonstrates that  $\mu$  defines the scale of the utility and its expected maximum value. For multinomial logit model, it is well known that the  $\mu$  is not identified, and must be normalized (usually to 1). In a nested logit (NL) model, there are multiple scales (one for each nest), and it also requires normalization for identification. The DAS model consists of a complicated system of nested logit equations, in which multiple scales were normalized in the estimation process. The impact that the normalizations have on accessibility is that the scale is not consistent across individuals. Therefore, in order to make comparison and conduct the distribution analysis, the ABA must first be translated to a consistent scale.

#### 4.2.2 The method for ABA unit translation

A standard method of dealing with the inconsistent scale issue is to translate the logsum to a common set of units, such as time or cost. In order to translate the unit of accessibility, the ideal situation is that either time or cost enters the utility linearly and as a generic

variable. Under this condition, the logsum can be translated to minutes or dollars by dividing it with the marginal utility of travel time or travel cost:  $\frac{Acc_n}{\beta_0}$ .

Unfortunately, the DAS model, (the source of the ABA measure) does not satisfy this ideal condition. First, neither travel time nor travel cost is treated as a generic variable, it varies according to modes and income level. Second, they enter the DAS model as a combination of linear, quadratic and cubic formulations of “generalized time”.

Therefore, there is no clear analytical marginal utility to use for the conversion. Instead, a numerical derivative is used and the accessibility in temporal and monetary units are formulated as:

$$Acc'_n = \frac{Acc_n}{\Delta Acc_n / \Delta TT} \quad \text{and} \quad Acc_n^c = \frac{Acc_n}{\Delta Acc_n / \Delta TC} \quad (4-2)$$

First, the numerical derivative of the accessibility value to travel time or travel cost is calculated to approximate the sensitivity of accessibility to travel time or cost. Then the original accessibility value is divided by the sensitivity to obtain its value in temporal or monetary unit.

The specification of the DAS is such that travel time enters each mode’s utility. However, travel cost is not considered in the walk and bicycle. From this point of view, the time variable is preferred. Therefore, the majority of this analysis focuses on temporal units. The monetary accessibility is briefly examined for comparison.

## 4.2.3 Distribution plots

### 4.2.3.1 Temporal units

The methodology presented above is implemented and the distribution of the consistently scaled accessibility is shown in Figure 2. In this calculation, travel time of every possible trip is increased by one minute, the resulted decrease in accessibility value is thus

approximated as the numerical derivative, and this is used to divide the original accessibility value.

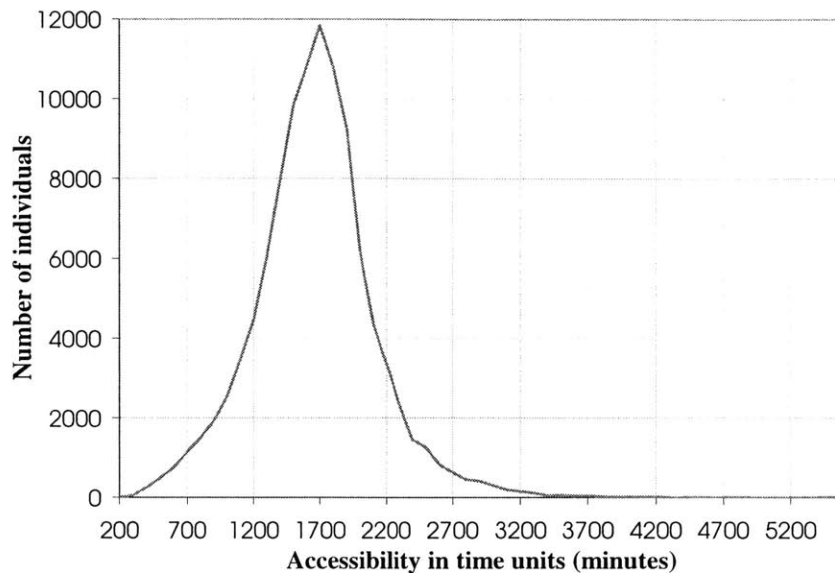


Figure 2 Distribution of accessibility in temporal unit

The distribution is normally distributed, which is not surprising. For comparison, the distribution using the pre-scaled accessibility values is shown in Figure 3, where a bi-modal distribution is presented. The two modes in the bi-model distribution are formulated by employed people and unemployed people. However, the normal distribution shown in Figure 2 indicates this is actually resulted from the scale issue.

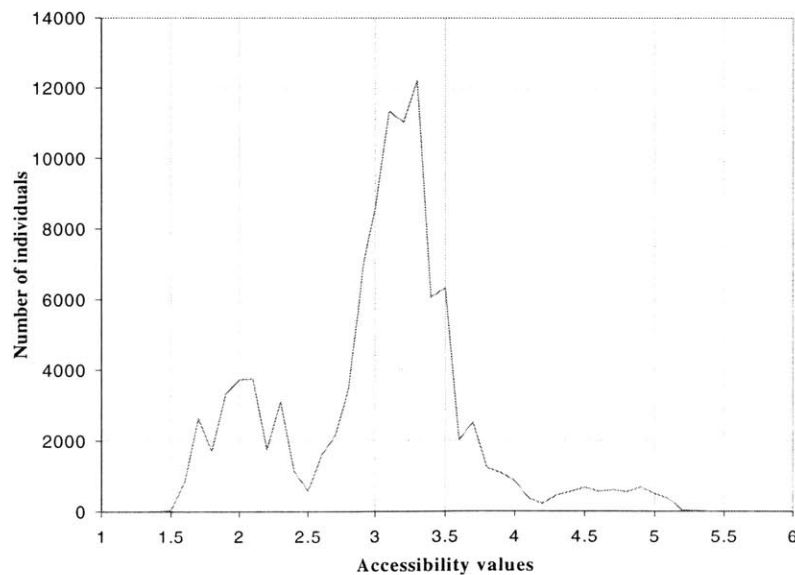


Figure 3 Accessibility values before transforming the units

It must be noted that the minutes shown in Figure 2 really do not mean anything related with time. According to the random utility theory, the utility is ordinal, instead of cardinal. So the values are only meaningful during comparison, but meaningless when considered separately.

The values of the accessibility in temporal units, it is found that they are ranged from 278 minutes to 5531 minutes. Most people have an accessibility under 3800 minutes, only 90 out of the 105,506 persons have values over 3800 minutes. The analysis above has shown that the temporal values of accessibility formulate a very nice normal distribution, with mean 1658 minutes and a standard deviation of 445 minutes. Why, then, do these 90 persons have much higher accessibility values? Examination of these 90 individuals shows that they have higher percentages of elderly, low-income people and females than in the entire population, as shown in Table 2. Furthermore, they have among the highest probabilities of staying at home for most of the day. Because they take fewer trips than others, the one-minute change in travel time of each trip thus has less impact on their accessibility values. This means that the numerical derivative of their accessibility with respect to travel time is much lower than others, and therefore their calculated temporal accessibility values are much higher. And in the subsequent analysis, only people with accessibility values lower than 3800 minutes are considered.

	Among people w/ accessibility values higher than 3800 minutes	Among the whole population
Age over 65	73.3%	14.0%
Low income	72.2%	35.3%
Female	77.8%	52.2%
Average probability of primary activity is at home	2.4%	1.1%

Table 2 Characteristics of people with accessibility higher than 3800 minutes

This section transforms the accessibility values into temporal units. Another common approach is to translate the units into monetary unit, which is conducted in the next section.

#### 4.2.3.2 Accessibility in monetary units

It is often desirable to translate to monetary units so that individual's "willingness to pay" for a particular change to the transportation system can be calculated.



The distribution of the monetary accessibility is shown in Figure 4, which looks quite different from the distribution in temporal unit. In monetary units, the distribution of accessibility is a bimodal distribution, with two peaks occurring at \$300 and \$450 respectively. To investigate the source of the segmentation, the distributions of accessibility for three income levels are drawn in the same figure. It shows that the higher mode is formulated primarily by high-income people, and the lower mode is formulated by low and medium income people.

The weakness of the method to transform to monetary unit results from the nature of the DAS model system. Because in the utility functions for walk and bicycling, no travel cost variable is included, which means that the changes in travel cost would not affect the utility of these two modes at all. However, while the travel cost is changed, it does result in a different utility for other modes, and thus a different accessibility value. The ideal situation for employing this simple method, as stated in section 4.2.2, requires that travel time/cost be a generic variable. The travel cost variable seems further away from this requirement than travel time variable, so the transformation into temporal unit is preferred, and the subsequent analysis is based on the temporal utility values.

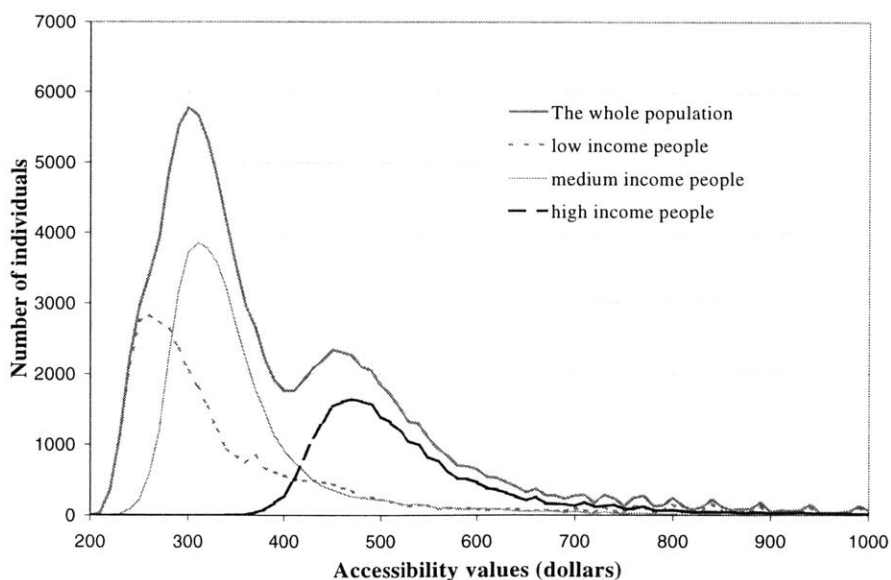


Figure 4 Distribution of accessibility in monetary units

### 4.3 Sensitivity to socioeconomic status

This section studies the sensitivity of this measure of accessibility to social and economic variables by examining the difference in the distributions of accessibility for different market segments. In each subsection, market segments are defined by one variable, the distributions of accessibility for each market segment are plotted and compared.

#### 4.3.1 Market segments defined by income

In this section, the population is segmented by household income level. People with household income less than \$30K are defined as *Low-income* people; between \$30K and \$60K are *Medium-income*; and over \$60k are *High-income* class.

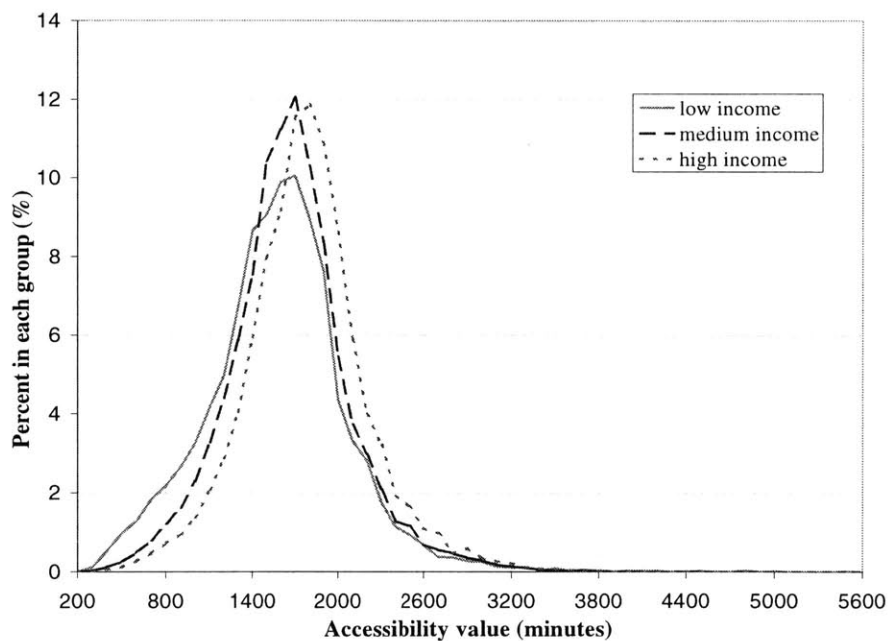


Figure 5 Distributions of accessibility for market segments defined by income levels

The distributions of accessibility over each of these three market segments are shown together in Figure 5. The Y-axis shows the percentage of people within each segment with the corresponding accessibility values. It shows that the income levels have only slight impact on people's accessibility. People with high income have slightly higher accessibility values, and people with lower income have slightly lower accessibility values.

Note that this is very different from the impact of income levels on the monetary accessibility #. So the method of translation could have important consequences when the logsum is used for analysis. This warrants further investigation, and is an important area of future research.

### 4.3.2 Market segments defined by car ownership

In this section, the population is grouped into two market segments, “people without cars” and “people with cars”. For households with no cars, they do not have the choice of “driving by car” when they want to access some activities. Therefore, they have a smaller set of alternatives for mode choices.

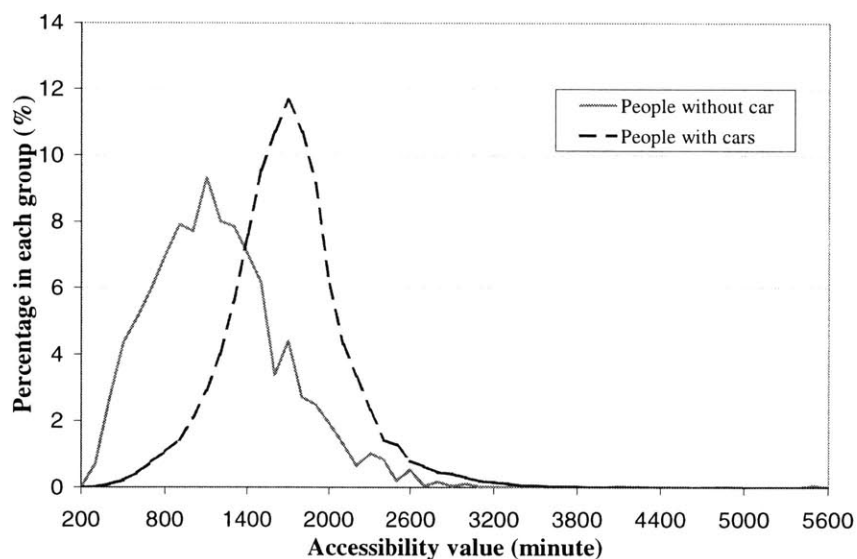


Figure 6 Distributions of accessibility for market segments defined by auto ownership

The distribution of accessibility for two segments are shown together in Figure 6. This figure shows that people without cars have lower accessibility values than those with cars, which is expected.

However, some households without cars still have a very high accessibility. An examination of the residential locations of zero auto households accessibility higher than

2000 minutes<sup>2</sup>, it shows that most of them live in the zones with good services of transit. Even though they don't own a car, they can take the advantage of the transit service to access activities.

### 4.3.3 Market segments defined by employment status

This analysis is focused on comparing the accessibility values of employed versus unemployed people. Similar to the previous discussion, the distributions of accessibility for these two groups are displayed in Figure 7, which implies that unemployed people have slightly lower accessibility than those who are employed. The difference between these two distributions is not very significant, because people's accessibility values are impacted by a lot of factors, such as income, gender. However, the slight difference reflects that the employment status is one of the impacts on people's accessibility, and employed status is favorable in terms of obtaining higher accessibility.

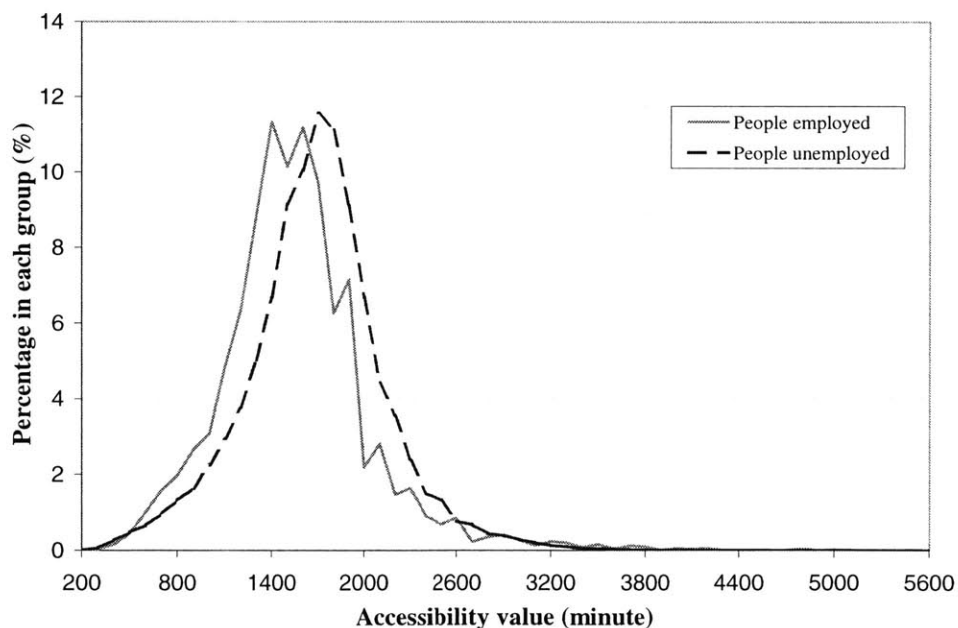


Figure 7 Distributions of accessibility for market segments defined by employment status

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<sup>2</sup> For reasons discussed in section 4.2.3, individuals with accessibility over 3800 minutes were removed from the analysis.

Comparing this chart with the one shown in Figure 3 depicting the distribution of the accessibility in its original units shows that the difference in the accessibility values for employed and unemployed people is exaggerated due to the scale issue discussed in section 4.2.1.

The analysis in this section, which compared the accessibility values across different market segments, verifies that this measure of accessibility possess reasonable sensitivity to the decision-maker's socioeconomic status. Although it does not show the expected obvious difference among market segmentations, but only slight differences are shown from the plots, it reflects the fact that people's accessibilities are impacted by a lot of factors.

#### ***4.4 Sensitivity to level-of-service of the transportation systems***

Since accessibility is mainly employed to represent the interrelationship between transportation and land use, one of the important properties that a measure of accessibility should have is to be reasonably sensitive to the level-of-service (LOS) of the transportation system. This section studies the sensitivity of ABA to transportation systems by examining the changes in individual's accessibility values caused by changes in the transportation system. For this analysis, individual's working locations are assumed unknown, which represents a long-term analysis.

Two changes in the transportation system are artificially created, and the variations in accessibility values are presented and discussed. In the first scenario, a \$0.5/mile peak hour toll is imposed for auto traveling during 7am-8am and 4pm-5pm. In the second scenario, both the travel costs of car and bus are increased by \$1 for every trip, during all time periods throughout the day. The shifts in accessibility values are shown in Figure 8, with the X-axis representing the changes in accessibility values, and the Y-axis showing the number of individuals experiencing the corresponding shift in accessibility. The plots demonstrate that the results from the two scenarios are very different. In the first one, when a peak hour toll is imposed, the changes in the time value are widely spread out, with a

range from 0 to 101 minutes. And for the second scenario, the distribution is much more concentrated around the changes of 0 to 10 minutes.

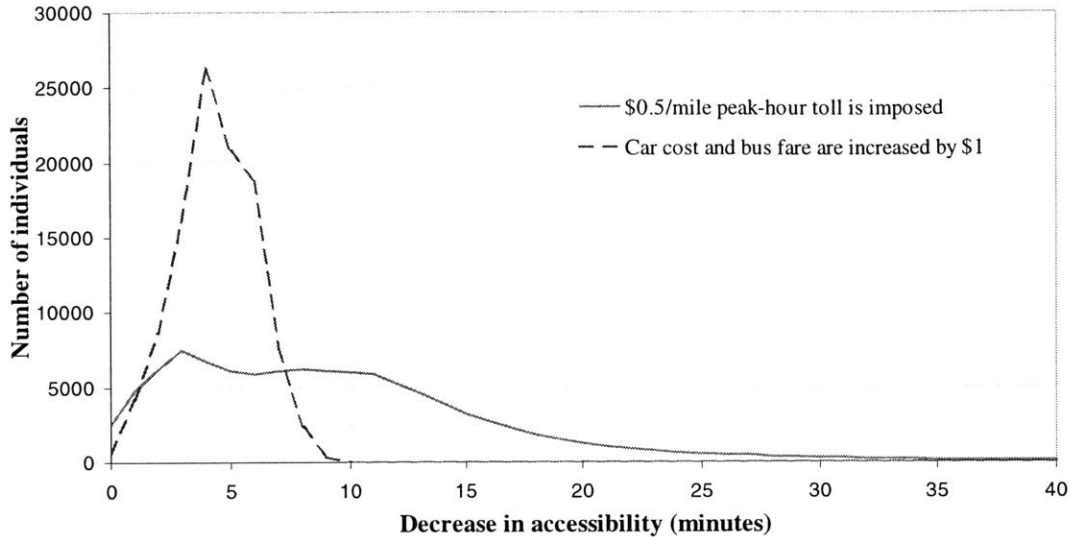


Figure 8 Changes in accessibility values as a result of transportation pricing policies

There are two reasons for the significant difference shown in this figure. First is because of the way the policies impact travel and activity pattern. With the \$1 travel cost increase, no trip escapes the policy, and no trip is heavily penalized. Thus a huge peak with slightly worse accessibility is obtained. However, the peak period toll impacts workers more than nonworkers, and it impacts them roughly in proportion to the length of their commute, which has a wide variation across individuals.

The second reason is that the potential responses to the two scenarios are different. In the first case, where only the auto cost during the peak hours is increased, people would still have a lot of possible choices to avoid the imposed toll. For unemployed people, their activities involved are mostly non-work related, and usually they do not have to follow a very strict schedule. So they can switch their travel schedule to off-peak hours. For employed people. Possible alternatives include switching (a) activity pattern: if possible, some of them might switch their daily activity pattern from work on tour to work at home; (b) travel schedule: if they have flexible work hours, they could travel to work during non-peak hours; (c) travel mode: if they have a convenient access from where they live to where they work, some of the commuters may change to travel by transit,; and (d) others: if it is

almost late for an important appointment, they may prefer to paying the toll in order to save their time. All these possible choices result in a wide range in the changes in accessibility values, as shown in the plot; the less flexible the individual, the higher the shift in accessibility.

Figure 8 also shows that after imposing the peak hour toll, a small number of the individuals experience a decrease in accessibility of more than 10 minutes. Table 3 shows the comparison of these people with the whole population by examining some of the characteristics at the aggregated level. It indicates that among these people, a much higher percentage of them are employed and a much lower percentage of them have no cars compared with the general population. Also those experiencing very high changes in their accessibility values have a lower probability of staying at home than the whole population. Finally, more people in this group have cars and are employed. All these are the reason for these people to have more constraints when seeking a way to avoid the peak hour toll. Therefore, their accessibility values are more sensitive to this toll.

	Percentage among people with changes over 10 minutes	Percentage among the whole population
Full time worker	83.88%	64.08%
No car	0.12%	6.06%
Unemployed	1.72%	18.5%
Probability of staying at home	0.79%	1.10%

Table 3 Characteristics of people with higher sensitivity as a result of a peak hour toll

In the second scenario, the increase in both car and bus cost does not leave travelers with many possible alternatives. In terms of mode choices, this pricing policy impacts both auto and transit, so a shift in motorized mode does not help. In terms of travel schedules, it impacts all the periods and all the trips, so shifting time periods does not help either. Direct ways of responding to this general increase in travel cost are to avoid travelling, or switch to non-motorized modes. So the reduction in accessibility values would be very similar among each other across the population, and thus the distribution of the changes is very concentrated, with the values ranged from 0 to 10 minutes.

So far, the sensitivity analysis has been conducted for both socioeconomic variables and transportation variables. Another important component of accessibility is the land use patterns, which are usually accounted for by the zonal variables. So the next section studies the sensitivity of ABA to residential locations.

#### ***4.5 Sensitivity to residential locations***

The objective of this section is to examine the impact of one's residential location on accessibility. For this analysis, accessibility values are plotted geographically using GIS. Each value plotted represents the accessibility of an individual (or a group) would experience if he (they) lived in the zones.

In each map, five levels of accessibility values are displayed, the darkest color represents the highest level of accessibility, the lightest color the lowest, and the others in between. The color pattern essentially represents the preference, in terms of accessibility, to each of the zones. The number of zones in each category is the same.

This section consists of two parts, first, the analysis is performed with a particular individual. Then the analysis is performed by looking at groups of individuals.

##### **4.5.1 Sensitivity to residential locations at individual level**

This section examines the variations of accessibility over residential locations for an individual. In this analysis, an individual is randomly selected and his accessibility values are calculated for each residential zone. The result is shown by a GIS map. Next, some of his socioeconomic characteristics are changed one at a time, with all other variables kept constant, and the values of accessibility are recalculated and plotted. In this way, the impact of socioeconomic characteristics on accessibility patterns over residential locations are examined. Both long-term and short-term analysis are conducted. The long-term analysis examines the person's expected preference in a long run, say 10 years; and the short-term analysis focuses on the possible changes in this person's behavior in several days. The assumption of working location determines whether the analysis is short or long-term.



#### 4.5.1.1 Long-term analysis

In the long-term analysis, the person's working location is assumed to be unknown. In this way, it can simulate the reality that when people make a long-term decision on where to live, such as where to buy a house, they actually don't know definitely where they will go to work.

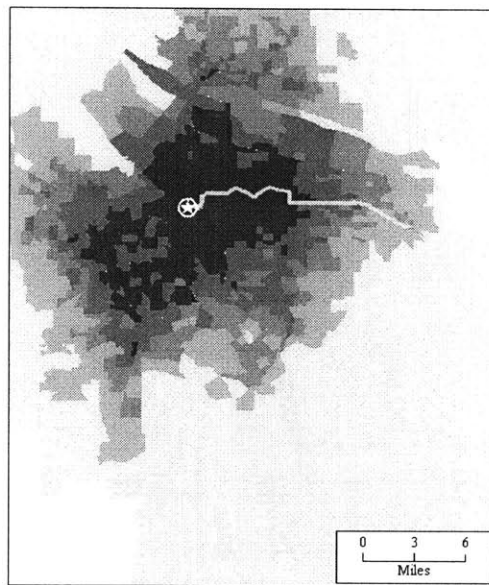
##### ***In the base case***

The base case is defined by observing the accessibility values of a randomly selected person from the population in this study. The person chosen is a 25-year-old male. He lives with his 26-year-old wife. He has a full time job, and his wife doesn't have a job. They have 2 cars, no children, and an annual income of \$50,000. They both have driver's licenses. His accessibility values while living in each of the zones are shown in the map *a* in Figure 9.

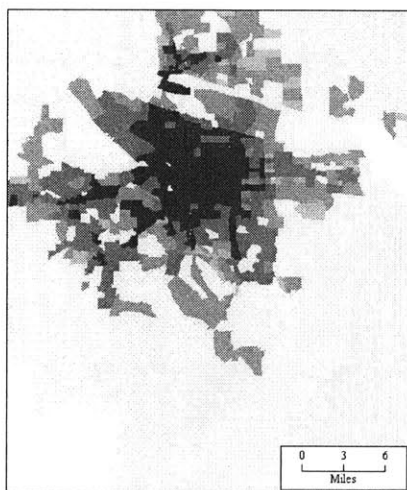
The white star in map *a* of Figure 9 indicates the location of the central business district (CBD) of Portland, and the line starting from the CBD extends to the east is the metropolitan area express (MAX), the light rail system in Portland. This person would obtain the highest accessibility when living around the CBD and along MAX, and also around activity centers.

Map *b* presents total employment within 30 minutes ride of transit for each zone and it is colored in the same way as map *a*, where five categories are displayed, with the darkest color corresponding to the highest level, and the lightest color representing the lowest level. By comparing these two maps *a* and *b*, it can be observed some similarity in their color patterns. The best transit service is concentrated around the CBD. Similarly, this person obtains his highest accessibility values while living in this area, as shown in map *a*. Map *c* displays the total employment within 1 mile from each centroid. This map shows the areas around the CBD and the vicinities of the two activity centers provide a high density of employment, which are also shown in map *a* as a high accessible areas for this individual. This comparison between the map *a* about the base case and the land use

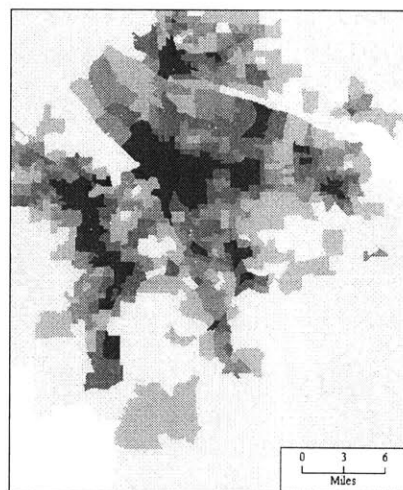
variables indicates the importance of availability of transit services, employment opportunities, and activities to accessibility values.



a. Accessibility values in the long run, base case



b. Total employment within 30 minutes ride of transit



c. Total employment within 1 mile from centroid

Figure 9 Accessibility and land use plots

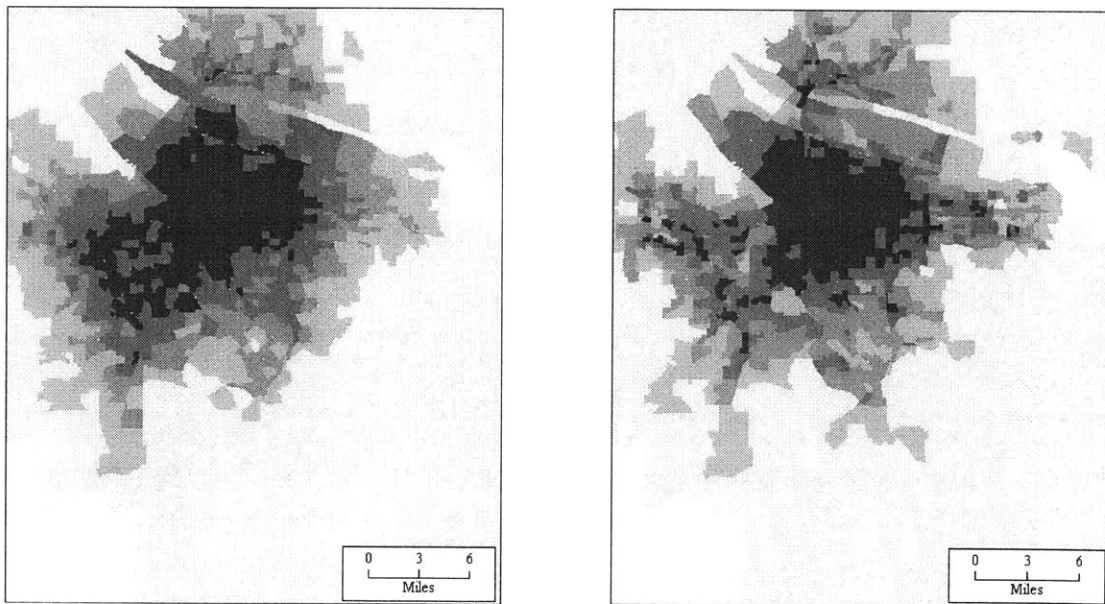
His accessibility values are reduced when living further away from the downtown, because there are fewer local activity opportunities and so he must travel farther to get to activities.

The next step is to investigate the impact of socioeconomic activities on the accessibility pattern. The socioeconomic characteristics of this individual will be altered one at a time, and the new pattern of accessibility will be examined and compared with the base case. The artificial changes include car-ownership and employment status, and the analysis follows.

### ***Car ownership***

In the base case, the individual has two cars available in his household. For comparison, the accessibility plot based on zero case is displayed in Figure 10 *b*. The two car plot is reprinted in map *a*.

Comparing these two maps, with Figure 9, it seems that the zero car plot is similar to the plot displaying the total employment opportunities within 30 minutes of transit. This is not surprising, as it reflects the importance of transit for those not owning a car to access activities.



a. with two cars (base case)

b. with no car

Figure 10 Accessibility plots as a function of car ownership

When he has a car, as shown in map a, the two activity centers located to the southwest of the CBD area are very attractive, even though it doesn't show higher transit services. Since he and his wife have two cars, they don't depend heavily on transit.

Besides the above difference between these two cases, the values of this person's accessibility experience a significant drop, from the average of 4.25<sup>3</sup> when he has car to 2.56 when he doesn't have a car. This is not surprising, since the auto provides a great deal of access.

The analysis in this section shows that when auto ownership of an individual is changed, both his accessibility values and his preference of where to live change. The general decrease in his accessibility values results from the loss of auto mode in his mode choice set and the difference in his preference of where to live results from the taste variations according to his socioeconomic characteristics.

### ***Employment status changed***

This section examines the changes in this person's accessibility values due to a change in employment status. His accessibility values for all the zones are shown in Figure 11, map a exhibits the results calculated from the base case (employed), map b shows the results for the unemployed case.

The difference of employment status results in significant changes in the distribution of accessibility values. The most obvious difference is around the two activity centers. Southwest of the CBO. As mentioned above, the two activity centers are not in the CBD, but they are more populated and provide more employment than other zones in their vicinity (see Figure 9). The deficiency of these two activity centers are that people living here have to travel a longer distance and take more time or cost to get to the CBD. In this long-term analysis, as this person's working location is unknown and more employment exists in CBD, he has a better chance to work around the downtown area. So when he is employed, he would prefer to living close to CBD to avoid much travel. When he is not

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<sup>3</sup> Values are reported in the original (i.e. not translated) logsum units.

employed, travelling to CBD becomes less important, and thus the attractiveness of the activity centers becomes more obvious by providing more activity opportunities with a higher employment and household density.

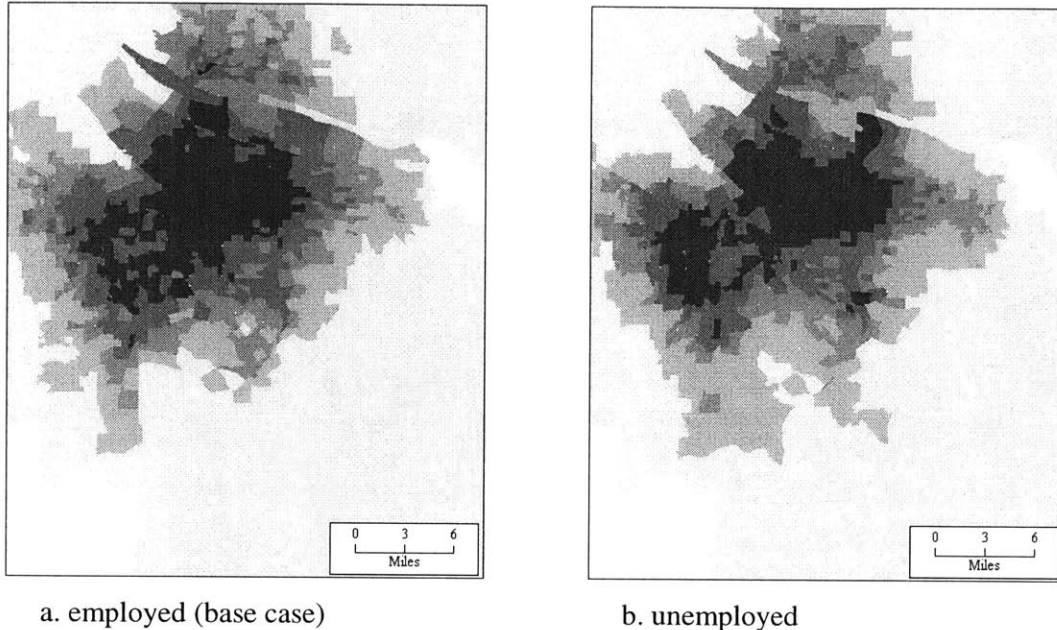


Figure 11 Accessibility plots as a function of employment status

Additional studies were conducted by changing other characteristic, such as income, number of children and age. However, these adjustments did not result in significant deviations from the base case. This indicates that in the long run these changes are not very important in terms of influencing his preference on where to live.

#### 4.5.1.2 The short-term analysis

The short-term analysis investigates the same individual's accessibility in each zone when his work location is known and fixed. As with the long-term analysis, first the base case is considered, and then the impact of adjustments in socioeconomic variables is examined. In this analysis, the same individual is used as in the long-term analysis.

##### The base case

The base case for the short-term analysis is shown in Figure 12 a, and the highlighted zone is where he goes to work. The white star indicates the location of the CBD. This map is

very different from map *b.*, which is the base case from the long-term analysis. Now, the CBD loses its attractiveness to this person, as he goes to work in a zone far from the CBD. As work related activities are usually the most important activities that people would pursue during the whole day. It is reasonable that people would like to live close to where he goes to work everyday.

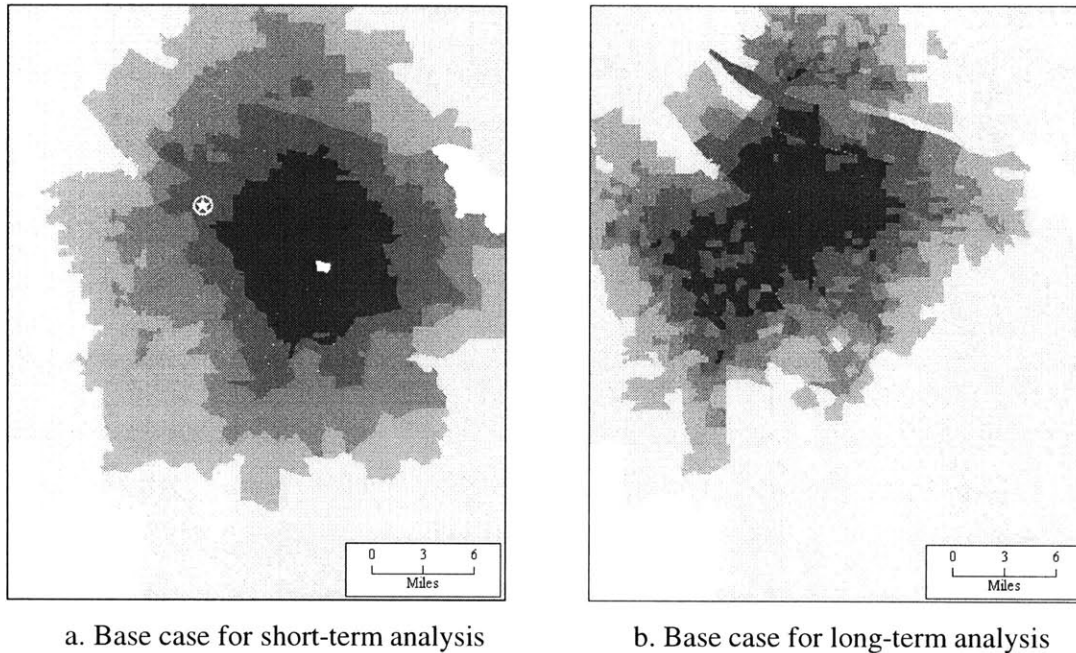


Figure 12 Base cases for short-term and long-term analysis

After analysis of the base case, his socioeconomic variables are changed one at a time to check for sensitivity. The same variables are examined as in the long-term analysis. The results do not show much change in the accessibility. This reflects the fact that when people make short run decisions access to work is the primary factor influencing overall accessibility.

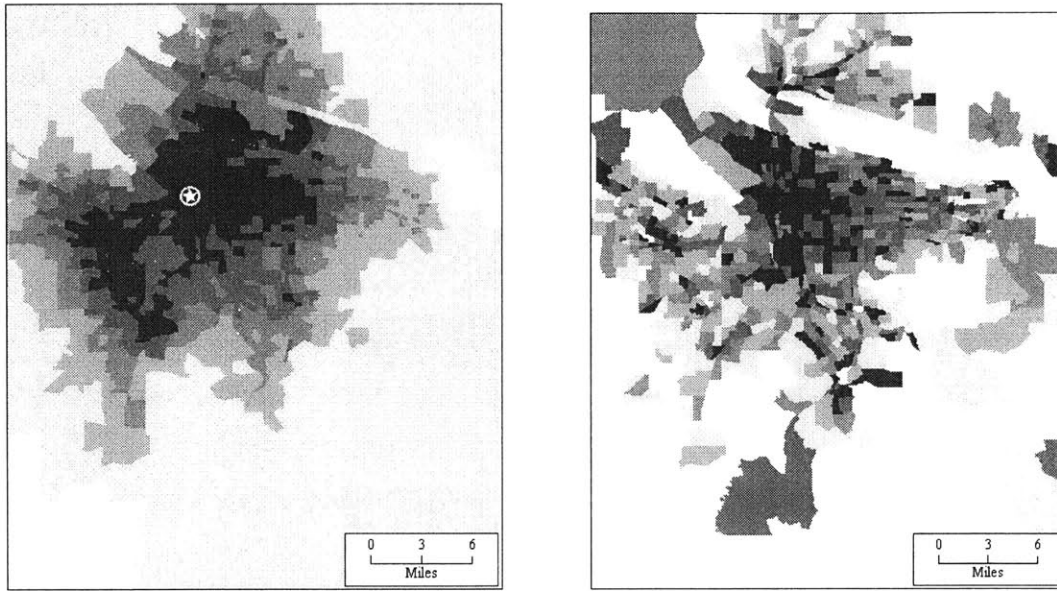
#### 4.5.2 Sensitivity to residential locations at market segments level

In the previous section, the sensitivity of accessibility to the zones is conducted at the individual level. To serve the objectives in policy making, it is also important to examine aggregate results. This section focuses on the analysis at aggregate level, by first studying

a group of people randomly selected from the population, and then studying market segments defined by demographic variables.

#### 4.5.2.1 The whole population

Because of the computational constraints, only 100 persons are randomly selected from the total population and their average accessibilities are presented in Figure 13a.



a. Average accessibility over the whole population      b. Average walk time from home to transit (minutes)

Figure 13 Average accessibility of the whole population and walk time from home to transit

The white star indicates the location of CBD. The darkest color displays the zones with the highest average values of accessibility, which represents the preference of the population in general. This category consists of two areas. The first one is around the CBD with some extension to the east. This area with a band shape provides the highest level of public transportation services, as shown in Figure 13 *b*, which is about the average walk time from home to centroid. The second high access area is around the two activity centers to the southwest of the CBD. These two activity centers, provide more activity opportunities than other zones. There is a big park and a huge shopping mall over there. It is logical that people would receive higher accessibility when living in these areas.

The analysis over the whole population gives a general picture of the sensitivity of accessibility over different residential locations. In the following sections, the population is



classified into market segments, and their zonal preference is illustrated in the same way. The idea to examine the sensitivity to locations for different market segments is based on the assumption that people with different socioeconomic backgrounds will have different preferences regarding accessibilities. The average accessibility values for the sampled group is presented in the GIS maps, illustrate the capability of the ABA to reflect the taste variations.

#### 4.5.2.2 Income levels

In this part, three market segments are defined by annual household income levels with \$30k and \$60k as two thresholds. Their average accessibilities are shown in Figure 14 for the three market segments.

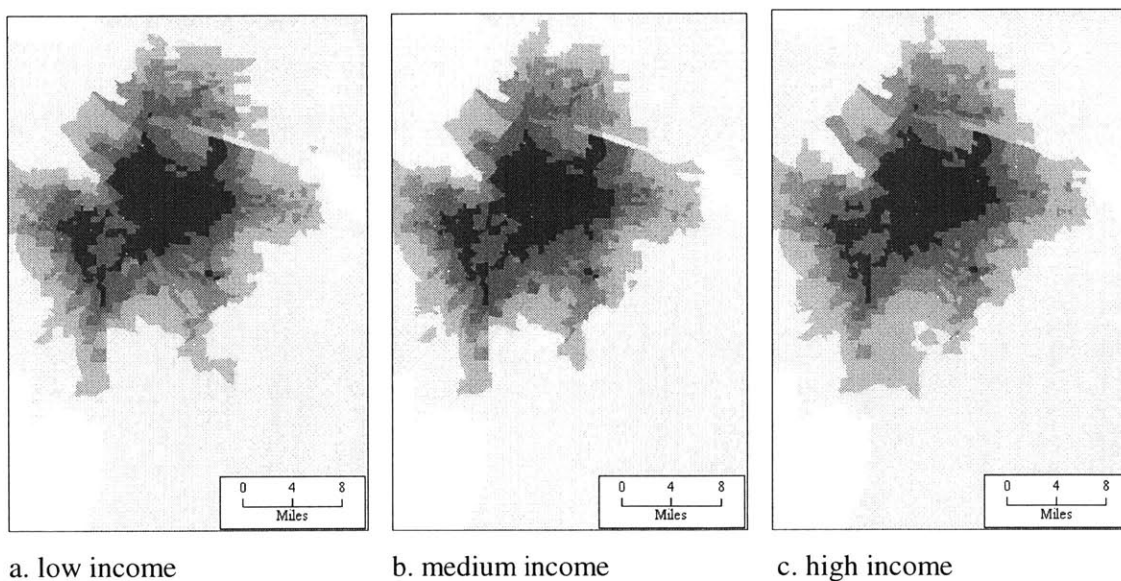


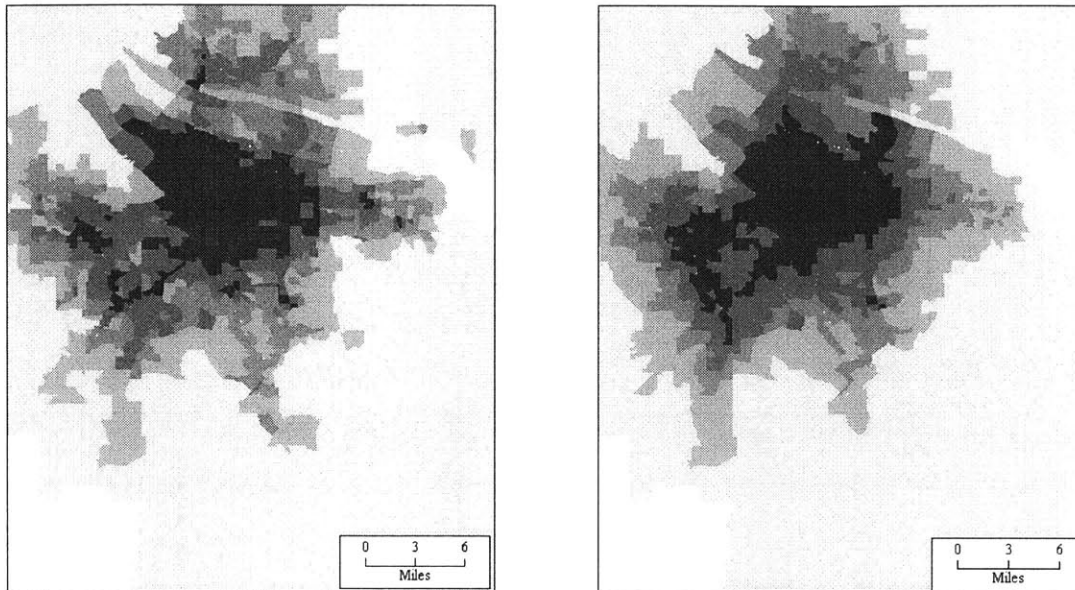
Figure 14 Accessibility plots for market segments defined by income levels

The patterns in these three maps are very similar to each other, which indicates that the impact of land use on accessibility values is identical for different income groups. This is because in the DAS model, no composite variables are formulated to represent impact from both income level and land use variables.



### 4.5.2.3 Car ownership

The two shaded maps shown in Figure 15 refer to market segments defined by auto ownership. Map *a* shows the accessibility values of each zone for people that don't own a car and map *b* is for people with cars.



a. without cars

b. with cars

Figure 15 Accessibility plots for market segments defined by car ownership

In both maps, the CBD is represented by the darkest color, indicating that whether people have a car or not, living in CBD will always provide them with the highest level of accessibility. This is the nature of the CBD which offers more activity opportunities, so that people living here don't need as much travel as when they live in the suburb. The CBD area, also provides higher coverage of public transportation, they have more opportunities in terms of model choice. The most significant difference between these two maps lies in the two activity centers located to the southwest of CBD. For people with cars, these two activity centers are still highly attractive, but not for those without cars.

A more general distinction between these two maps is about the color pattern. The pattern of map *a*. is more scattered and also has some lines with darker colors. These lines indicate more transit services over that area.

The conclusion from this analysis is that accessibility values for those without cars depend more on the distance to CBD and access to public transportation than those with cars do. So a better transit system would favor people with no cars more than those with cars.

**4.5.2.4 Employment status**

Employment status is also regarded as an important demographic variable for policy analysis. The two maps in Figure 15 display the average accessibility values for employed and unemployed people respectively. They have slight difference in their patterns, especially around the two activity-centers, where unemployed people show more preference over there than employed people. This might be because the activity centers provide fewer activity opportunities that can only satisfy the unemployed people who tend to have lower requirement on their activity opportunities than employed people. So the unemployed people are more satisfied at activity centers.

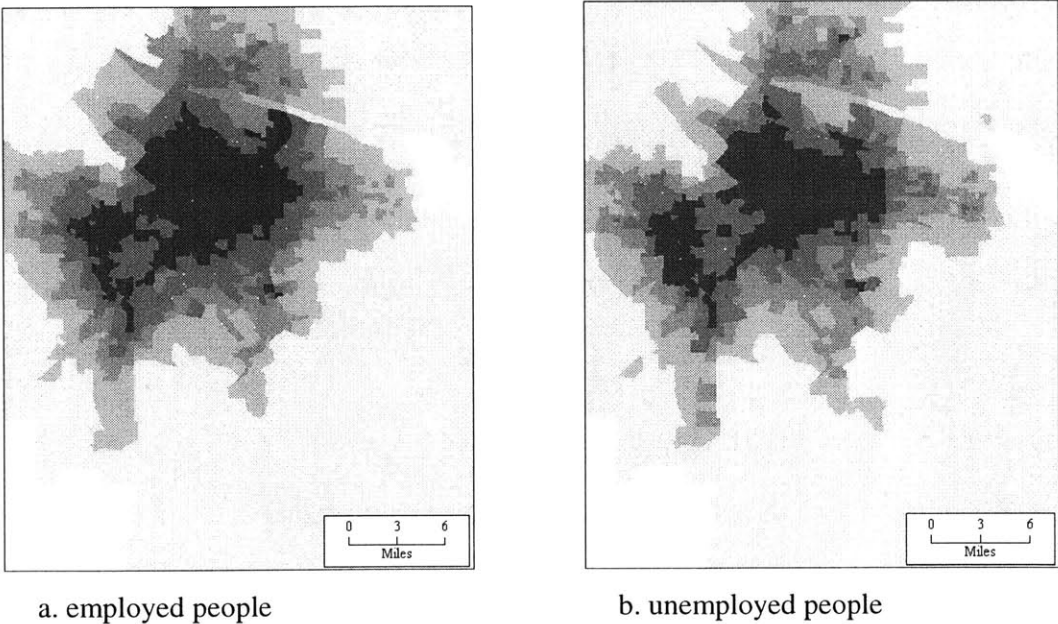


Figure 15 Sensitivity to residential locations for market segments defined by car ownership

The difference between these two maps is not so apparent as that in those two maps with different car ownership. In the DAS model, the variables indicating people’s employment status enter the activity pattern choice model at the top first level, and the time of day model at the second level. In either of these two choices, no land use variables are

considered. So the changes in employment status influence the utilities for activity patterns and time schedules for trips, and these utilities are not sensitive to locations. On the contrary, car ownership directly influences people's travel behavior, in terms of mode and destination choices, which is responsive to the patterns of land use and the travel distance.

## **4.6 Conclusions**

This chapter examines the property and performance of the ABA measure, by studying its distribution across the population and sensitivity analysis for the three important components of ABA measure. The analysis conducted in this chapter indicates that the ABA performs fine in terms of representing the reality and the behavior of individuals. Next chapter is thus focused on comparing ABA with the traditional measures in terms of reflecting the concept of accessibility and the extent to which the ABA measure advances over other measures.

## **Chapter 5. Comparison of ABA with traditional measures**

The last chapter, this study examined the properties and performance of the Activity-Based Accessibility measure. This chapter compares the ABA measure with traditional measures of accessibility by implementing the different measures with the same set of data.

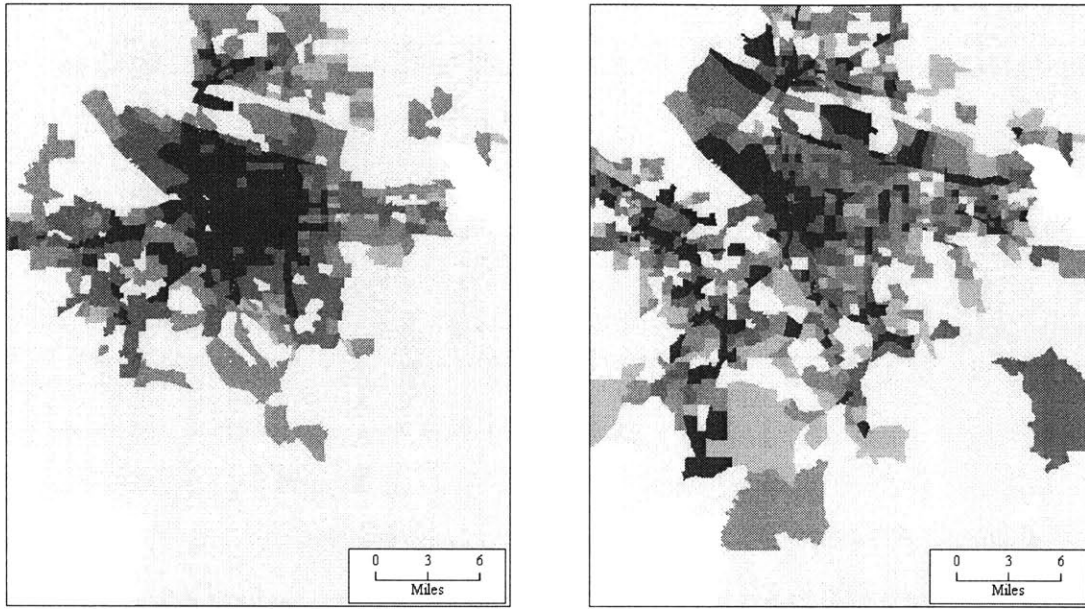
The traditional measures are classified into three categories: isochrone measures, gravity-based measures and simple utility-based measures. These are all “trip-based” measures, which means that they are based on a single trip. The ABA, on the other hand, is significantly different from the traditional measures in that it is based on all the activities and trips people take during a whole day. The ABA measure is also a utility-based measure, it just has a more complex form than the traditional utility-based measures, and their difference in properties and performance are presented later.

### ***5.1 Comparison with isochrone measures***

Isochrone measures, as presented in the literature review chapter, usually evaluate the accessibility of a zone by counting the number of available opportunities within a certain travel time/cost or travel distance from this zone. But the definition of the range beyond which the opportunities should not be counted and the choice of a variable to represent the activity opportunities are both very arbitrary. With different definitions of the isochrone measures, the accessibility pattern of a region will vary substantially. Even though it is a simple measure and easy to understand and implement, the isochrone measures do not effectively describe the concept of accessibility.

Two isochrone measures are implemented to calculate the accessibility of each zone, and the results are shown in Figure 16. Both count the total amount of employment, and the difference lies in their way of defining the “boundary” within which the employment

opportunities are counted. The measure demonstrated in map a. is defined by the “total employment within 30 minutes of transit”. And the other one in map b. is defined by “total employment within 0.25 miles from the centroid of a zone”. The significant difference in these two maps illustrates the sensitivity of the isochrone measures to the definition of the range variable.



a. Total employment within 30min from transit

b. Total employment within 0.25 miles from centroid

Figure 16 Isochrone measures defined by different land use variables

Activity-based accessibility considers both variables in the nested logit model system, even more variables related to the employment opportunities, such as the density of employment opportunities within each zone.

From this analysis, we have seen that isochrone measures are very simple, requiring very few mathematical computations, but they do not perform very well in measuring accessibility values.

## **5.2 Comparison with gravity-based measures**

Hansen (1959) first proposed the gravity-based accessibility more than 30 years ago. Since then, gravity-based measure has been widely used in calculating accessibility values. This

section implements gravity-based measure with the Portland data sets, and the results are shown with GIS maps to compare with the ABA measure.

Gravity-based measures of accessibility, as discussed in the literature review consist of two components:

- Attractiveness: Usually, some land use variables representing the activity opportunities provided by the geographic area, and thus the attractiveness of the zone.
- Impedance: A function of travel time, travel, cost or travel distance, which considers the performance of the transportation system.

By incorporating these two elements, the gravity-based measures account for both the pattern of land use and the property of transportation system, which is an attempt to represent their interrelationship and to illustrate the concept of accessibility.

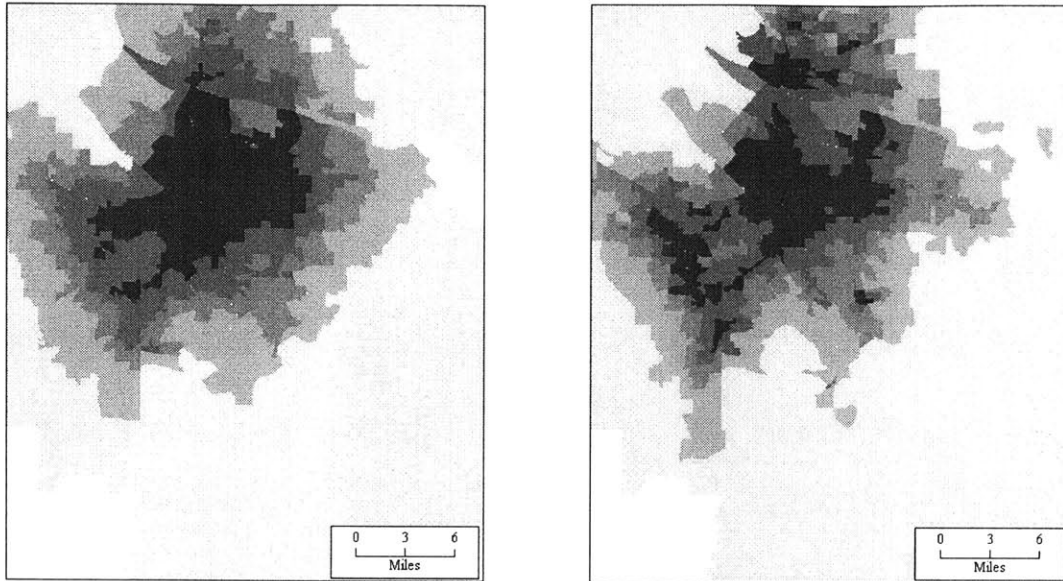
In practice, for different measures in this category, various land use variables or impedance functions could be used. Most of the measures would take one of the three impedance functions, which are

Exponential	$f(c_{ij}) = e^{-c(c_{ij})}$	$c > 0$
Inverse power	$f(c_{ij}) = c_{ij}^{-b}$	$b > 0$
Gamma (combined) function	$f(c_{ij}) = a \cdot c_{ij}^{-b} \cdot e^{-c(c_{ij})}$	$a > 0, c \geq 0$

Among them, a, b and c are parameters that are specific to trip purposes and are predefined. There are multiple ways to obtain their values. In this analysis, the gamma function is used and the parameter values are obtained as the suggested values from (NCHRP365, 1995). The parameters for home-based work trips and home-based other trips are:

HBW	$a=28507$	$b=0.020$	$c=0.123$
HBO	$a=139173$	$b=1.285$	$c=0.094$

In the calculation of gravity-based accessibility values, the employment density in each zone is used to represent activity opportunities. The results are shown in Figure 17.



a. Gravity-based measure for home-based work trip    b. Gravity-based measure for home-based other trip

Figure 17 Gravity-based measures for different trip purposes

The significant difference between the patterns of these two maps indicates the sensitivity of this measure of accessibility to trip purpose. Usually, people take multiple trips for different purposes, and even the sequential trips would have variations in their purposes. So the sensitivity of this accessibility measure to trip purposes implies that the gravity-based measure is applicable to only separate trips, but not sequences of trips. This weakness constrains this measure from possessing enough behavioral explanation.

Furthermore, the gravity-based measure is an aggregate measure. Consequently, everyone living in the same zone would have the same value of accessibility, which is to say that a retired old man has the same value of accessibility as his grandson, who is a teenager and a college student, only if they are living together. This is another weakness of the gravity-based measures. Previous analysis on the sensitivity over the different market segments has demonstrated the significance of the heterogeneity across market segments in terms of causing variations in people's accessibility across zones. This should be a very important consideration for policy-decisions, but it is neglected by the gravity-based accessibility.

The last point addressed here is that if the impedance function is defined as a step function, in which the impedance function equals 1 for those within a certain threshold value of

travel time/cost or travel distance, otherwise it equals to 0, then it becomes the isochrone measure. So the isochrone measure can be regarded as a special case of the Gravity-based measure.

### 5.3 Comparison with Simple Utility-based measures

Utility-based measures refer to those accessibility measures based on random utility theory, in which utility of each alternative is calculated to represent people’s judgement for each option. Accessibility is defined as the expected maximum utility for an individual given a choice situation. This type of measures is also called “logsum”, because it uses the log of the sum over the exponential utility across the whole choice set as the measure of accessibility (see equation 2-3). The ABA measure belongs to this category, as well as some of the traditional measures. Since those traditional measures falling in this group consider only one single trip, and they are simpler both in theory and in practice, they are classified as “simple utility-based measures”.

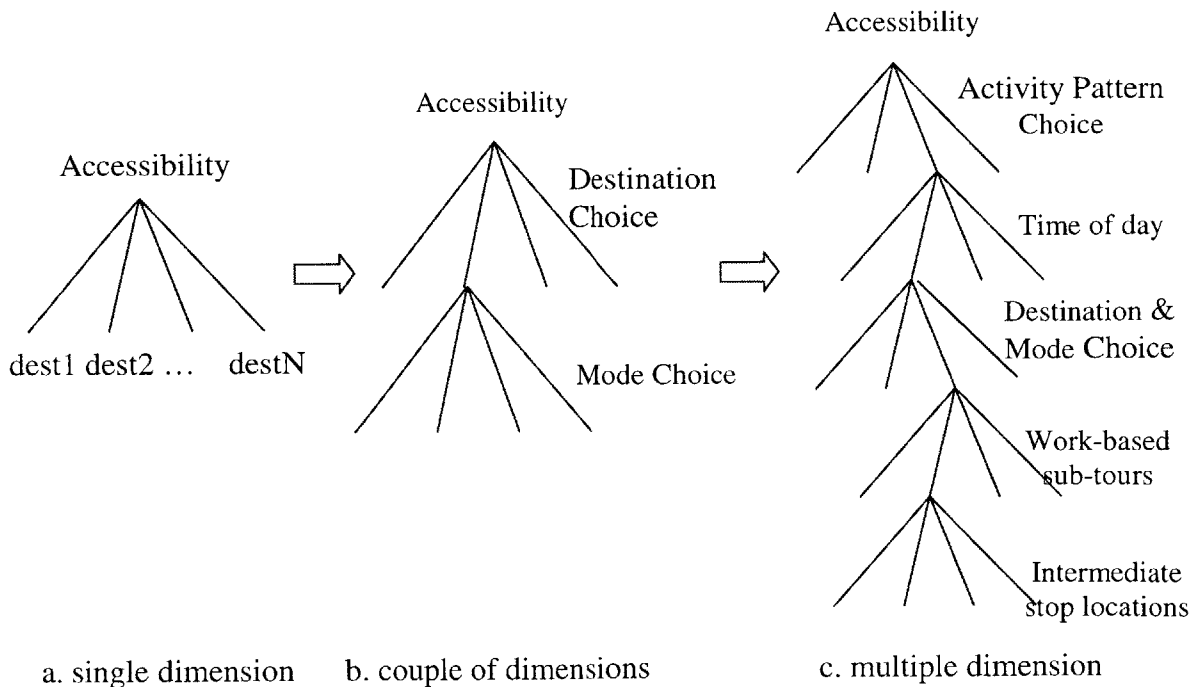


Figure 18 Utility-based measures of accessibility



As shown in Figure 18, the complexity of utility-based measure ranges from a single choice dimension to multiple choice levels. The simplest form of a utility-based measure is the structure shown in *a*, where only choices of destinations are considered. While the model develops vertically, a more complicated model is formulated with both choices of mode and destinations. These two models represented by *a* and *b* are called “simple utility-based” measures. These are trip-based models in that they account for only destination choice or the combination of both mode and destination choice for a specific trip.

Figure 18 c shows the DAS model, which incorporates more choice dimensions than the traditional measures. In the DAS model, the elemental concept is switched from single trip to activities taken within a whole day schedule, and therefore it is a “activity-based” model.

Among the traditional measures, the simple utility-based measures are the most advanced measures, because they can represent more complex choices (e.g. mode) and can be defined at the individual level to take into account the taste variations among people. Within the simple utility-based measures, the measure covering two levels of choices (mode + destination) is superior to those considering only one choice dimension (destination), in terms of the behavioral basis of the models. In reality, even for a single trip, people would have to make decisions on various aspects of the trip, including mode, destination, time, etc. In order to examine the advancement of the ABA measure over the traditional trip-based measures, the mode-destination logsum measure (Figure 18 b) is used for comparison as it is the most advanced of the trip-based logsums. Accessibility values calculated with these measures are presented in Figure 19.

When implementing the two measures, identical input data of land use patterns and transportation systems are used. The same group of 100 people is simulated for the two implementations, and their average values of accessibility while living in each zone are shown in Figure 19. In computing the accessibility with simple logsum measure, the similar microsimulation for implementing ABA is used. Because of the dependence between mode and destination choices, in the DAS model, the choices over these two dimensions are combined together by formulating one level of choice. In calculating the

simple logsums, the higher level of choice “time of day” model is also included. So the simple logsum presented in this analysis is actually calculated from a nested logit model with two nests, and it is therefore the expected maximum utility over the choices of travel schedules, modes and destinations for a home based work trip. The ABA measure is calculated based on all the activities and trips taken during the whole day, and it is the expected maximum utility over the choices of activity patterns.

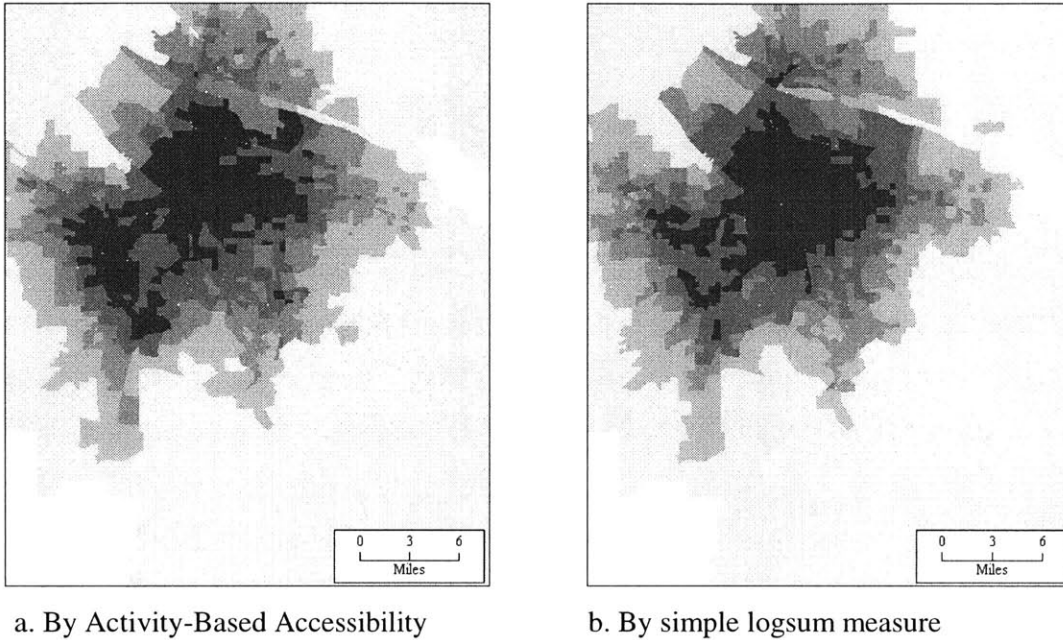


Figure 19 Comparison between ABA and simple logsum measure

These two maps only have some slight differences in terms of the accessibility patterns, in that map *a* displays a stronger accessibility arising from the two activity centers located to the southwest of CBD. Comparing these two maps with Figure 9 *b* and *c*, it shows that result from simple logsum in map *b* is more like the plot in Figure 9 *c*, which is about the “total employment within 30 minutes drive from centroid”; and the result from ABA in map *a* is more similar to Figure 9 *c*, which shows “total employment within one mile from centroid”. This makes sense, because in Portland, most of the trips taken by transit are work trips. The logsum measures cover only this type of trips. And also, employment opportunities is usually an indicator about the number of activity opportunities, and the

ABA measure is calculated based on all the activities and trips taken during a whole day, therefore, the patterns of ABA is very similar to those about the employment opportunities.

## **5.4 Conclusion**

The difficulty in finding a good measure of accessibility results from the difficulty of describing simultaneously the land use patterns, the transportation system, and, most importantly, their interrelationship. This difficulty arises from the numerous variables that impact these components. The isochrone measure is the simplest in terms of formulation and calculation. However, it could not reflect the complexity in people's behavior and choices. The gravity-based measure is improved by incorporating both the activity opportunities and the impedance resulted from travelling. In this way it represent a simple relationship between the land use and transportation system, which is the higher the cost to access an activity opportunity, the less the opportunity impacts the accessibility value. The analysis in this chapter shows that this measure is very sensitive to the mode of travelling and insensitive to the characteristics of the decision-makers. The simple utility-based measure takes into account of the taste variations among the population and it is the most advanced measure among the traditional trip-based measures. The constraint of this measure to only a single trip without considering the context of the trip make it still not desirable in terms of reflecting people's behaviors. The ABA takes activities as the elemental consideration, trips are regarded as the necessity to connect people with different activities, and it treats a whole day schedule as the basis, by which all the activities and trips taken during the whole day is considered in calculating the accessibility value. Since all the trips and activities with different purposes taken during different time schedules are related with transportation systems and land use pattern, their interrelationship thus could be better represented by considering multiple trips, instead of single trips. This is the basic reason that the ABA measure behaves better in the empirical analysis.

This chapter compared the ABA measure with traditional measures of accessibility. The conclusion from this analysis is that the ABA is advanced among all the current accessibility measures.

## Chapter 6. Summary and future research

### 6.1 Summary

The analysis throughout this study demonstrates a number of favorable features of the ABA by implementing this measure with the data from Portland, Oregon. It is a disaggregated measure by describing each individual's behavior, and it is an advanced measure by covering all the activities and trips taken during an entire day. The features and supporting evidence is summarized as follows:

#### 6.1.1.1 Comprehensive considerations

The Activity-Based Accessibility considers both the patterns of land use and the properties of the transportation systems, as well as the variables describing the interrelationship between them. The ABA also takes into account the taste variations among people by incorporating the socioeconomic characteristics of each decision-maker. In this way, the ABA could reflect the variations in people's perception of the interrelationship between land use and transportation systems. This is illustrated from sensitivity analysis from three points of views:

- *Socioeconomic characteristics of an individual*: The analysis presented in this thesis shows that people with different income levels, car ownership or employment status would have slight difference in their distributions of accessibility. The differences between the market segments are not substantial, because the ABA is decided by multifarious considerations.
- *Patterns of land use*: The ABA of an individual is higher when the number of activity opportunities is higher and the transportation system services are better. However, the patterns of accessibility across locations are not identical across individuals or market segments. And it also reflects the difference in long-term decisions and short-term decisions.

- *Level-of-service of transportation systems:* From an analysis on people's accessibility shifts resulted from two pricing policies, it illustrates the capacity of ABA to reflect people's response differences influenced by their flexibility while making travel decisions.

#### **6.1.1.2 Intelligent framework**

The DAS model is developed based on the idea that people's demand of travelling is derived from their demand of getting to activities. By originating the concept of activity pattern, the DAS model formulates an "activity-trip" network, in which the "nodes" are the activities to relate the sequences of trips, and the "links" are the trips to connect the activities. So the ABA can represent all the relationships between the trips and the schedules of the activities. From the analysis and the comparison between the ABA with the traditional trip-based measures, it shows that the ABA advances the traditional trip-based measures by covering multiple trips, with multiple purposes, schedules, modes and destinations.

The contribution of this study is to examine this new Activity-Based Accessibility by studying its properties and advantages over the traditional measures of accessibility. Some future study topics are also recommended from this analysis.

## **6.2 Future research**

- *More on the comparisons with traditional measures.*

In this analysis, the comparison is conducted only at the aggregated levels by examining the GIS plots. When comparing with the trip-based measures, for which the simple logsum measures are used as a representative, it would be helpful to explore more on the properties of the trip-based measures with more analysis. For example, it would be useful to also study the distribution of the trip-based measure and its sensitivities to individuals, transportation systems and the land use patterns for the. The scale issue would not be that difficult for the trip-based measures, because of the simplicity in the model structure, and thus the distribution analysis could be easier than the ABA measure. The results from the

sensitivity analysis could present more similarities between the logsum measures and the activity based measures.

- *More on the sensitivity analysis of the ABA*

During the sensitivity analysis of the ABA, three components of the ABA are examined, including the sensitivity to socioeconomic variables, level-of-service of the transportation systems and the patterns of land use. All of these three analyses have spaces for improvement. First, the sensitivity analysis to the socioeconomic variables is conducted at market segments that are classified by single variables. More studies on the market segments defined by two or more demographic variables might be useful to explore the taste variations across the population. Second, in terms of the level-of-service of the transportation systems, only two different pricing policies were implemented and compared in this study. More analysis on the response in accessibilities resulted from the changes in transportation systems might be helpful in investigating more about the performance of ABA. Finally, in the sensitivity analysis of the ABA to the land use patterns, only one individual's accessibility values are studied with the GIS plots. More persons with different backgrounds might be useful to fully examine this property of the ABA.

- *Improvement in the DAS model specification.*

All the analysis conducted in this thesis is based on an early implementation of the Day Activity Schedule model system with the Portland data. The improvement of the DAS model would result in the improvement in the ABA measure. For example, Bowman (1998) had already worked on the pattern specification in his dissertation (he introduced more socio-economic and lifestyle variables to better explain the preferences of the pattern types). Also, for ABA, the activities are very important to the equation, but the current model represents them incredibly coarsely (retail, non-retail, etc.). These models also tend to focus on auto and transit, and important issues for walking and biking (e.g., bike lanes, pedestrian friendliness, etc.) are not in the models. Both of the latter issues are actually relics of the "mobility-based" analysis in which the activities themselves were not very important and non-motorized modes were also not emphasized.

- *More on the scale analysis of the ABA measure.*

Since the DAS model is formulated by a complex system of logit models, its complicated estimation procedures result in an inconsistent scale for the Activity-Based Accessibility measure. Therefore, the ABA values are not comparable across the population. In this study, a simplified method is employed to transfer the unit of ABA. Even though the empirical results turn out to perform well from this analysis, this method is not developed with a robust mathematical or economic principle and the implication and potential solutions should be investigated.

- *Accessibility measure of household.*

As mentioned at the beginning, accessibility is very important in residential choices. In reality, when people make decisions on where to live, they also consider the needs of other members in the same household, with various weights, according to each member's role in the household. In the current ABA measure, there is no consideration of this issue, accessibility value is calculated individually, with little inclusion of interactions between members in the same household. In order to be better served as a critical input to the residential choice models, an accessibility measure defined at the household level would be necessary in residential choice modeling.

- *Accessibility measures with the existence of information technology.*

With the emergence and dramatic development in human society, information technology becomes more and more important in people's everyday life, and thus impacts people's behavior in many ways. Teleworking, teleshopping, teleconference, and many other telecommunication methods are becoming increasingly popular. People's behavior with the existence of the newly developed information technology will be better to be described by the activity-based model than the trip-based models. This is because, as mentioned in a previous chapter, the fundamental concept of the activity-based model is that people's desire to travel comes from their need to pursue activities. The telecommunication network is similar to the transportation network, in that it also serves to link people to activities.

The structure of the activity-based model can readily be expanded to include the telecommunications network.



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