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New Methods to Measure Urban Environments for Consumer Behavior Research: Individual Access Corridor Analysis of Environmentally Sustainable Travel to Rapid Transit

by

Bruce Sidney Appleyard

A dissertation submitted in partial satisfaction of the requirements for the degree of Doctor of Philosophy

in

City and Regional Planning in the Graduate Division of the University of California, Berkeley

Committee in charge:

Professor Robert Cervero, Chair Professor Michael Southworth Professor Elizabeth Deakin Professor Joan Walker Professor Steven Raphael

Fall 2010

New Methods to Measure Urban Environments for Consumer Behavior Research: Individual Access Corridor Analysis of Environmentally Sustainable Travel to Rapid Transit

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Bruce Sidney Appleyard

#### Abstract New Methods to Measure Urban Environments for Consumer Behavior Research: Individual Access Corridor Analysis of Environmentally Sustainable Travel to Rapid Transit

by

#### Bruce Sidney Appleyard

#### Doctor of Philosophy in City and Regional Planning University of California, Berkeley

#### Professor Robert Cervero, Chair

Until recently, data, technology, and practice have limited travel behavior research in its ability to uniquely capture individual-level details of urban environments. While previous studies have relied primarily on aggregate, zonal averages homogeneously attributed to unique individuals, this dissertation presents methods to more closely align measures of the urban environment with the individual as the unit of analysis—in short, disaggregated data for disaggregated analyses.

Furthermore, previous studies have often focused on the immediate areas (1/4- to 1/2-mile radii) around trip origins and destinations, while little focus has been paid to the unique characteristics of the urban environment in between. In response, this research pioneers the use of a new spatial unit of analysis, the "individual access corridor" (IAC), to better understand how people may be influenced by certain urban design, land use, or transport characteristics experienced along their journey to a certain destination (e.g., stores, mixed use developments, schools, and transit stations).

The primary goal of this research is to develop and test new methods to measure the urban environment. Three core principles (*resolution, respondent, replicability*) comprise the central evaluative framework guiding the exploration and development of these new methods. They are introduced in this dissertation as the "3R principles of methodological development." They guide the use of the IAC to capture high-*resolution* information about the urban environment (*land use activity, transport access*, and *traveler perceptions*) that can be uniquely attributed to each individual survey *respondent* in a *replicable* manner. This information, in turn, can support reliable and valid analyses of the influence of the urban environment on consumer behavior that are meaningful, rigorous, and generalizable.

The secondary goal of this research is to test these new measures as inputs for travel behavior analyses of a relatively standard intercept travel survey—the 2008 Station Profile Survey for the San Francisco Bay Area Rapid Transit (BART) system. Improving measures for these analyses is important because substantial effort and money is currently being spent on influencing traveler behavior in suburban/non-CBD areas, and for trips to transit. As most morning commuters across the U.S. drive to rapid transit stations, and over relatively short distances, substantial sustainability benefits could be realized by coaxing even a small fraction of these drivers to use "green" non-motorized travel (NMT)

modes of bicycling and walking. As well as providing useful insights into designs and policies that support NMT, this study of rapid transit access behavior serves as a "proof of concept" for the development and application of the new methods to measure the urban environment explored in this research.

In terms of its primary goal, this research shows that capturing high-*resolution* information of the urban environment can be uniquely attributed to each individual survey *respondent* in a *replicable* manner to support both reliable and valid analyses of consumer behavior. *Reliability* of these new methods and measures is determined by: 1) their ability to objectively and uniformly capture and calculate factors of interest; and 2) their provision of similar results through repeated experiments. *Validity* is established via: 1) a thorough in-depth review of empirical research, literature, and urban theory to identify particular aspects of the urban environment they represent; and 2) an examination of the findings emerging from numerous models, with respect to interpretability, sensibility and usefulness.

Specific achievements include the following:

- This research supports the use of the IAC to examine the unique intermediate area of a trip between its origin and destination, especially when examining NMT behavior (bicycling and walking).
- This research enriches our understanding of how to measure and analyze land use activity, beyond the currently used measures of "diversity", where entropy indices have been widely used as a proxy for land use mixture. Specifically, this research tests the best methods for managing vast amounts of complicated land use information, classified at the parcel-level, to be meaningfully applied to analyses of consumer behavior.
- This research complements the current body of literature on travel behavior and the built environment by more formally recognizing and including measures of the functional/operational qualities of urban environments, as well as measures of physical infrastructure, urban form, and "perceptual qualities" (Ewing et al., 2006; Ewing & Handy, 2009).
- This research provides valuable insight on transportation policies and urban design practices that will help communities and regions move more deliberately toward sustainability objectives, such as reducing auto use, GHG emissions, and congestion, while simultaneously improving air quality, street livability, the building of social capital, and enhancing opportunities for physical activity.

In terms of the second goal of this research—testing the relationship of these new measures of the urban environment to rapid transit access travel behavior—they are proven to support *reliable* and *valid* findings that provide useful, nuanced insight into the influence of the urban environment on rapid transit access mode choice. Specifically, the findings suggest that certain policies and design characteristics of the individual access corridors (IACs) to rapid transit could increase the likelihood that one will either walk or bicycle (thus supporting the achievement of sustainability benefits) if:

- Access corridors are composed of buildings that are at a *human scale*, are located close to the street (giving them a stronger sense of *enclosure*), and have distinct, "visually rich" urban form characteristics that express both *complexity* and *imageabilty*.
  - This is supported by the finding of a strong negative relationship between the use of an NMT mode to access rapid transit and the presence of larger ("big box") parcels, and auto-supporting land uses, such as parking lots and road & freeway rights-of-way (ROW), along a commuter's IAC.
- Communities are designed with narrower, well connected streets and/or more direct walking and bicycling paths.
  - This is supported by the finding of a strong positive association between the use of an NMT mode, and more direct routes accessing rapid transit. It is also supported by strong negative relationship between NMT rapid transit access and the amount of land in auto-supporting land uses, such as parking lots and road & freeway rights-of-way (ROW), along a commuter's IAC.
- Small, personal service retail opportunities are provided.
  - This supported by the finding of a strong positive relationship between NMT access and the presence of small retail/mixed uses along a commuter's IAC.

Finally, the methods and measurements explored and developed in this dissertation can be applied in a wide range of urban settings and toward a better understanding of the influence of important characteristics of the urban environment on consumer behavior as it relates to a broad array of sustainability objectives.

### Dedication

For my mother, Sheila, my siblings, Rustin, Moana, and Ian. And to my father, Donald, who advised me to always work towards "making the world a better place" and who—along with all of his grandchildren, Shea and Jason Donald (J.D.), Analisa, Kian and Riyan—give me passion and purpose to at least try to do so every day of my life.

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On the face of it, this may appear to be a predominately technical dissertation that could have been developed in isolation. But underlying this work is a lengthy tale of social networking and knowledge sharing. People from BART, MTC, Google, ABAG and ESRI generously donated invaluable data and/or software. But More importantly, they graciously shared their knowledge to help me develop the necessary methods to measure the urban environment to further our understanding of its relationship to environmentally beneficial behavior. Without them, these methods and measures would otherwise remain unrealized abstract notions. Effective and relevant innovation occurs because people reach out, communicate and collaborate. At its core, the gracious sharing of knowledge is an exceptionally admirable human quality. And there are many people I have to thank for this.

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## PART I FOUNDATIONS

### **Chapter 1: Introduction**

Given that transportation choices are personal, they need to be understood from the perspective of the individual. As they make trips, people think about what things along the way look like, how these things make them feel, and real and perceived notions, ranging from distance to danger. They are likely not thinking about traffic analysis zones (TAZs), census tracts, or whether they are exactly a <sup>1</sup>/<sub>4</sub> or <sup>1</sup>/<sub>2</sub> mile from their destination. So if we are trying to better understand the influence of certain urban environmental factors on shaping a person's travel choices, we need to measure things that are at a closer scale to his or her interaction with the context through which they travel. However, in order to conduct meaningful analyses of consumer behavior that can be generalizable to a larger population, these measures must be captured in an objective and resourcepermissive fashion for a large enough group of people. At the same time, the measures must be valid indicators for guiding policy and design decisions.

Until recently, data, technology, and practice have limited travel behavior research in its ability to uniquely capture individual-level details of the urban environment<sup>1</sup> (categorized in this research into the components of *land use activity, transport access* and *traveler perceptions*). While previous studies have relied on aggregate, zonal averages, homogeneously attributed to unique individuals, this dissertation presents methods to more closely align measures of the urban environment with the individual as the unit of analysis. This research partially overcomes these problems via the use of a new spatial unit of analysis, the "individual access corridor" (IAC),<sup>2</sup> to better understand how people may be influenced by policies and infrastructure experienced along their journey to a certain destination (whether it be to stores, mixed use developments, schools, or transit stations).

Using zonal aggregations is an understandable approach, as until now 1) data used in travel behavior and built environment research is readily available at zonal levels, 2) technology has not made it easy to capture more detailed measures of the built environment, and 3) the academic community has widely accepted the practice of using zonal levels of aggregation of the built environment for studies on travel behavior.

<sup>&</sup>lt;sup>1</sup> The term "urban environment" (UE) is used in this dissertation to distinguish the new measures presented herein from the current body of literature on the built environment's influence on travel behavior. As well as the physical components of the built environment, the notion of the urban environment used in this dissertation more formally includes the operational aspects, as well as the "perceptual." In short, the "software" as well as the "hardware" of cities and regions that may influence environmentally beneficial travel behavior.

 $<sup>^{2}</sup>$  Previous studies have often focused on the immediate areas (1/4 to half mile radii) around trip origins and destinations, while little focus has been paid to the unique urban environments in between.

Zonal levels of aggregation may still provide sufficient data for understanding the choices drivers make because it is reasonable to think that one travelling inside a vehicle is insulated and cognitively desensitized from the interstitial space between their trip ends (origin and destination). This effect is shown in Figure 1-1, drawn by a 10-year-old child who was driven everywhere. The figure illustrates how a child views the world from the back seat or window of a car—as virtually a series of unlinked paths.<sup>3</sup>



Figure 1-1: View of travel routes by a 10-year-old child who is mostly driven in a car.

Source: Appleyard, B. (1997).

People traveling in cars are likely to be cognitively disconnected to subtle contextual characteristics of the community in between their origin and destination. Conversely, people walking and bicycling (out-of-vehicle travelers) may be relatively more aware and sensitive to key characteristics of the immediate areas around their



origins and destinations, than the space between. This effect is shown in Figure 1-2, which illustrates the origins of the individual access corridor concept.

Figure 1-2: Origins of the Individual Access Corridor Concept. This conceptual diagram illustrates how people traveling by different modes *motorized* (car and bus) vs. *Nonmotorized* (walking and bicycling) – may view, and in turn, may be influenced by the urban environment in different ways.

Source: Diagram by Cervero (2010). Interpretation and annotation by Appleyard, B. (2010).

<sup>&</sup>lt;sup>3</sup> In technical terms this is an "archipelagic spatial activity pattern" effect as coined by Karsten, L., & van Vliet, W. (2006, p. 152)

Assigning each individual driver the average value associated with a census tract or traffic analysis zone (TAZ) may miss subtle, but still influential characteristics of the neighborhood origin and/or station destination, let alone the space between. Furthermore, as people travel outside the protective envelope of a car or bus, they experience things along their journey with a greater sensitivity, as shown in Figure 1-3.<sup>4</sup> Zonal levels of aggregation therefore hinder our understanding of how the urban environmental factors influence walking and bicycling rates.



Figure 1-3: A 10-year-old who is able to walk and bicycle everywhere is much more cognitively connected with key urban environmental elements of their community.<sup>5</sup>

Source: Appleyard, B. (1997).

<sup>&</sup>lt;sup>4</sup> Drawn by a student from the same school as the child who drew Figure 1.1. This child walked and bicycled everywhere (and was given the same instructions and same amount of time as the child whose map is showing in Figure 1.1 who was driven most of the time).

<sup>&</sup>lt;sup>5</sup> This map and accompanying testimonial statement expresses how out-of-vehicle travelers (bicyclists and pedestrians) are acutely sensitive to the qualities of the urban environment. It also underscores how aggregated average values of the urban environment may hide important qualities along an individual's journey that may influence their travel behavior.

#### 1.1 New Spatial Unit of Analysis: Individual Access Corridor

A main focus of this dissertation is to find better ways to measure and understand the urban environment for consumer research. In doing so, this research explores a new spatial unit of analysis to capture such measures. The individual access corridor (IAC) introduces an alternative to the conventional practice of applying zonal averages to a group, by allowing urban environment measures to be uniquely attributed to each individual survey respondent. Additionally, this research employs these IACs to capture a much finer *resolution* of data (such as parcel land use or specific business and place based activities). Therefore, in sum, the IAC offers new capabilities to capture high *resolution* data, uniquely attributed to each individual *respondent*. One of the most important capabilities of the IAC is that it can do all this in a *replicable* manner for thousands of survey respondents, as illustrated in Figures 1-4 & 1-5.

Figure 1-4: This map illustrates the individual access corridor (IAC) concept focussing on a particular station. In this case, these are a sample of individual access routes to the Pleasanton/Dublin Station of the San Franscisco Bay Area Rapid Transit System.



Figure 1-5: This map illustrates the individual access corridor (IAC) concept from a synoptic view of the San Franscisco Bay Area



Figure 1-6 illustrates the use of the IAC in capturing detailed, parcel-level land use information along each individual respondent's likely route to a transit station.



Figure 1-6: In these examples a 200-foot buffer is used to select proportions of each parcel, summing a total land area for all specific land use categories and then calculating a proportion of that particular land use along each IAC for the thousands of respondents to the 2008 BART Station Profile Survey.

#### **1.2 Problem Statement**

Applying variables at zonal levels of aggregation may miss critical details of a person's experience along his or her journey to a rapid transit station. On the other hand, employing methods that capture too much irrelevant data are not only onerously resource intensive (in time, cost, and labor), but can inject too much "noise" into the models, hampering statistical robustness, methodological objectivity, and *replicability*.

In response to these issues, there are two specific goals of this research:

- To develop new methods and refine current measures of the urban environment that could simultaneously provide reliable and valid inputs to the analysis of consumer behavior.
- To test the relationship of these new methods and measures to rapid transit access travel behavior. This exercise serves two purposes:
  - 1. As a proving ground for the development of these new methods and measures, thus serving as a "proof of the concept;" and
  - 2. To provide useful insight into policies and design practices that supports the use of non-motorized rapid transit access modes specifically, and more environmentally beneficial travel behavior in general.

#### Goal 1: Develop and Refine New Methods to Measure the Urban Environment

The development of any new procedures or methods needs an evaluative framework with guiding principles. Given that the objective is to support statistically rigorous, meaningful and generalizable analyses of the influence of the urban environment on consumer behavior, the new methods developed and refined in this research strive to capture high-*resolution*, detailed measures of the urban environment. These measures are captured through resource permissive, objective, *replicable* methods, which can then be applied uniquely to each individual travel survey *respondent* for a group that is large enough to support statistically meaningful models. Thus, the principles of the central evaluative framework of this research are *resolution, respondent, replicability*, otherwise known as the "3R principles of methodological development" (or more simply, the "3R principles").

Emerging from this endeavor is the use of detailed geospatial datasets (such as parcel-level land use classifications, street networks, and lot sizes) coupled with the employment of the "individual access corridor" (IAC) which enables the unique geospatial buffer selection (*respondent principle*) for detailed analyses of urban environment (*resolution principle*) for a significant number (thousands) of surveyed individuals (*replicability principle*). Thus, the overarching hypothesis by which these new methods and measures are tested is as follows:

Following the 3R principles of methodological development, the new individual access corridor (IAC) components of the urban environment—*land use activity, transport access,* and *traveler perceptions*—are reliable and valid for use in consumer behavior research.

#### Goal 2: Test the Relationship of the New Methods and Measures to Rapid Transit Access Travel Behavior

The second goal of this research is to ground the development of these new methods and measures by applying them to a real-world problem: How does the urban environment influence the probability that commuters will adopt more environmentally sustainable behavior when accessing rapid transit stations? As most morning commuters across the U.S. drive their cars to rapid transit stations, and over relatively short distances, substantial sustainability benefits could be realized by coaxing even a small fraction of these drivers to "green" non-motorized travel (NMT) modes. The operative hypothesis to test the practical application of these new measures of urban environments, and hence test the overall hypothesis stated above, is as follows:

During a person's morning commute to work via a non-CBD rapid transit station, components of the urban environment (land use activity, transport access, and traveler perceptions) significantly influence rapid transit access travel behavior.

This operative hypothesis is referred to herein as the Urban Environment/Transit Access (UETA) hypothesis. The development and testing of these new methods to measure the urban environment pivots on the use of a relatively standard intercept travel survey— the 2008 Station Profile Survey for the San Francisco Bay Area Rapid Transit (BART) system—and develops a new array of geospatial methods to measure and create both *reliable* and *valid* urban environmental variables for meaningful and generalizable analyses of their influence on environmentally beneficial travel behavior.

#### **1.3 Structure of this Dissertation**

This dissertation has three main parts, as follows:

#### **PART I: FOUNDATIONS**

**Chapter 1** introduces the problem that this dissertation will address: the need for better measurements of the role urban environment in travel behavior. **Chapter 2** reviews how researchers have been measuring the urban environment including a) the relationship of the "perceptual qualities of the urban environment" (Ewing et al., 2006; Ewing & Handy, 2009) with travel behavior, and b) how urban environment factors influence bicycling, as well as walking. This chapter also situates this dissertation in the field, as well as its place along a methodological progression of urban environment measures from aggregate (zonal) to disaggregated individual access corridor (IAC). Overall this work builds on the vast and rigorous literature on travel behavior and the built environment conducted ever since Cervero and Kockelmann (1997) pioneered the D-Variable framework in the mid-1990s, and refined through the seminal syntheses of the travel behavior and built environment literature conducted by Ewing & Cervero in 2001, and in 2010.

Part I also introduces and illustrates the central evaluative framework guiding the exploration and development of these new methods: the 3R principles of methodological development, *resolution, respondents,* and *replicability*. Finally, the new spatial unit of analysis, the individual access corridor (IAC), is more formally discussed for its benefits towards broadening our currently used zonal D-Variable measures by enabling a much higher resolution of data gathering that can then be attributed to each individual survey respondent.

#### **PART II: KEYSTONE**

Throughout Part II, both the 3R principles and the real-world issue framework of rapid transit station access are applied toward the evaluation of both current methods to measure the urban environment and the new methods explored in this dissertation. **Chapter 3** bridges the vast body of previous research and the method development presented in this dissertation, establishing the *reliability* of the captured and calculated measures as well as their *validity* in meaning. **Chapter 4** tests the relationship of these new methods to measure the urban environment toward their relationship with environmentally beneficial rapid transit access travel behavior, as well directly testing the model performance of the final set of new IAC measures of the urban environment against a standard set of zonal D-Variable measures.

#### PART III: BRIDGE TO THE FUTURE

**Chapters 5 and 6** contain conclusions, policy/design guidance and reflections regarding the new methods to measure the urban environment presented in this dissertation. In particular, how these findings help guide planning and design practices to more effectively support more environmentally sustainable rapid transit access behavior. An overarching goal of Part III is to help guide both future travel behavior research/modeling efforts and the evaluation of current and future designs and plans for their ability to lower auto use and GHG emissions, and provide a host of additional benefits for the enduring health, wealth, and equity of our communities.

#### **1.4 Overview of Contributions**

This research bridges a key methodological divide in the travel behavior literature. Until now, GIS programming and other data limitations have restricted our ability to capture higher resolution urban environment variables for individual respondents through methods that can be objective, resource permissive, and replicably applied to large enough numbers of individuals for meaningful analyses. While improving our understanding of how urban environmental factors influence bicycling and walking, this dissertation examines ways to combine urban design literature's findings and insights about the "perceptual qualities of the built environment" (Ewing et al., 2006; Ewing & Handy, 2009) with travel behavior research methods in ways that allow for both the richness of urban design approaches and the cost-effectiveness of readily available data.

Further achievements of this research include the following:

- It pioneers methods to capture, at the scale of the individual, both reliable and valid measures of the urban environment, potentially benefiting both conventional and micro-simulation and activity-based travel demand analyses.
- It uniquely examines the intermediate area between the origin and destination of a trip via the use of a new spatial unit of analysis, the individual access corridor (IAC).
- It enriches our understanding of how to measure and analyze land use activity, beyond the commonly used measures of entropy as a proxy for a mixture of land uses. Specifically, this research tests the best methods for managing vast amounts of land use information, classified at the parcel-level, and then uniquely attribute this information to individual respondents in order to render meaningful results in predictive models of consumer behavior.
- It complements the current literature on travel behavior and the built environment by broadening the scope to more formally include the functional/operational qualities of transport access, as well as the influence of physical infrastructure.

Considering that the predominant means of accessing suburban rail stations throughout the United States is by private car, changes in rail transit access behavior presents potentially large payoffs towards weaning our society from automobile dependence and hence reducing greenhouse gas emissions, reliance on foreign oil, and the need to chase congestion with new infrastructure. But to do so the urban environment between riders and their rail transit stations need to be much more accommodating for pedestrians and bicyclists. By retrofitting existing transit stations and building future ones so they provide effective, livable, and safe access, this research could help draw drivers out of their cars, as oftentimes these trips are relatively short and thereby substitutable by either walking or bicycling. The methods explored and developed in this dissertation show promise toward gaining a more comprehensive and nuanced understanding of the urban environment's influence on rapid transit access travel behavior and, by extension, how to achieve a broad array of sustainability benefits.

### **Chapter 2: Previous Research and Framing the Issues**

This chapter reviews the relevant literature regarding measuring the urban environment for travel behavior research, highlighting the ways this dissertation lies along a methodological continuum from aggregate to disaggregate measures of the urban environment, covering issues associated with the need to gather more precise measures, captured and modeled at the individual level. More broadly, this chapter examines ways to bring the urban design literature's findings and insights into travel behavior modeling in ways that allow for both the richness of urban design approaches and the costeffectiveness of readily available data. It focuses on the particular problem of accessing non-CBD rail transit stations with parking, and sheds new light on how to improve the use of "green" NMT modes. Furthermore, it highlights the need to look more precisely at the influence of the "perceptual qualities" of the urban environment (Ewing et al., 2006; Ewing & Handy, 2009), along with the need to better understand how urban environmental factors influence bicycling and walking. Finally, this chapter discusses how the emergence of a new spatial unit of analysis, the individual access corridor (IAC), by allowing for much finer resolution of data gathered for each individual survey respondent, offers opportunities to refine current practice.

# **2.1 Review of Literature on the Influence of the Built Environment on Travel Behavior**

Early interest on how land use and design policies could influence travel behavior focused on the connection between residential densities and transit use. A 1977 study by Pushkarev & Zupan (1977) suggests that transit use can be increased through policies that increase densities. Since the early 1990s, such studies have appeared with increasing frequency. First, inspired by the 1997 Cervero and Kockelman study titled "Travel Behavior and the 3Ds: Density, Diversity, and Design," research on travel behavior and the built environment has involved the creation of a handful of *dimensions* (referred from here on as "D-Variable" dimensions) of the built environment and travel behavior research. This research concluded that the complementary existence and interaction of density, diversity, and design could yield modest, yet significant, travel reduction benefits. Ever since, travel behavior research associated with the built environment has generated multiple dimensions, or "Ds".

#### 2.1.1 Research Challenges

#### Complexity of the Relationship between the Urban Environment and Travel Behavior

The relationship between the physical urban environment and travel behavior has proven itself to be complex and in need of being more fully understood. For example, Boarnet & Sarmiento (1998) and Crane & Crepeau (1998) found contradictory results, while Downs (2004) concludes that even with an extensive rail system, the clustering of housing near stations would produce only a small reduction in auto traffic congestion, compared to the transportation needs of a metropolitan region. The latest meta-analysis by Ewing & Cervero (2010) shows that many aspects of the urban environment, as they have been measured until now, have a significant, although sometimes limited, association with travel behavior. Arguably, these studies have been conducted under a paradigm of under-priced driving in more than a half-century of planning predominantly around the automobile, enabling the development of travel behavior habits that are hard to break. Few would argue, however, that many forces of the prevailing paradigm may change, and that the price of travel is more volatile and can change much more quickly (days, weeks) than can the urban environment (years, decades).<sup>6,7</sup>

## The Criteria for Causality: The Missing Link between Travel Behavior and Built Environment Research

A continuing challenge in this area of research is that *correlation* does not automatically mean *causality*. Yet in order to make informed policy decisions (and avoid costly mistakes), we really need to accurately understand causality (Susan Handy, Cao, & Mokhtarian, 2005).

#### 2.1.2 Research Solutions: Measuring "The Right Things in the Right Way"<sup>8</sup>

Handy (2006a) summarized the state of the research on the relationships between the built environment and rates of walking and bicycling by saying:

"Relationships between the built environment and physical activity shown in the studies reviewed here are perhaps not as strong or consistent as many readers would expect" (p. 43).

She offers the following explanations:

1) "the relationships really aren't strong or consistent;" or

2) "we haven't been studying them in the right way" (p. 43).

Assuming greater salience for Handy's second point, based on the above discussion of the literature, a central question of this research is: How can we better measure the urban environment?

Up until now, most disaggregate studies of transit access mode choice have included urban environmental measures aggregate at zonal levels (TAZs, census tracts, or the "rule of thumb" of  $a^{1/2}-^{1/4}$ -mile circle around a transit station), potentially missing key

<sup>&</sup>lt;sup>6</sup> An illustration of why we should care about the built environment in terms of consumer behavior is illustrated in the following example: In March 2008, National Public Radio reported that even as General Motors (GM) was asking for more taxpayer "bailout" money, one perk GM refused to give up was a company car and company-paid gas for about 8,000\_white-collar employees. While GM has discussed ending the program, a spokesman said killing the program now would be "extremely" disruptive because "Employees have built their lives around it. It allows many to live far from their offices and commute at little expense." Changing the cost of transportation is quicker and easier than transforming the built environment, but we need to be forward thinking to create environments that can free people from being reliant on automobiles and fuel prices.

<sup>&</sup>lt;sup>7</sup> And therefore we should care about how we plan our areas to take advantage of as many transportation options as possible.

<sup>&</sup>lt;sup>8</sup> This section on the built environment's influence on travel behavior has been informed by discussions with several of the leading academic experts in the field, in particular Professors Cervero, Ewing, Handy, Deakin, Southworth, and Frank. All of whom enriched my understanding of the subtleties and nuances of this complex relationship between these dimensions of the built environment and how they truly affect travel behavior.

details of a person's interaction with their environment. To be sure, detailing all that an individual faces on their journey to transit would be time-consuming, expensive and, perhaps more importantly, hard to replicate while maintaining objectivity, but improvements are possible.

#### The Importance of the Distance to a Local Destination (or the Perception of it)

According to Handy,<sup>9</sup> the distance to local destinations, both real and perceived, has the strongest, most direct influence on whether one decides to walk. It is important to note that distance is probably more directly affected by access to destinations (land use mix or diversity) than by density. This makes sense, as these factors are key determinants of the quality of a person's interaction and experience with their environment. The importance of distance or, more to the point, the perception of it, to encourage walking (as well as the distances a person is willing to walk) is supported by the findings of several urban design studies (Bosselmann, 2008; Isaacs, 2001; Park, 2008). These findings suggest that the influence of the other D-Variables on the choice to walk, as well bicycle, may operate through their influence on the perception of distance. Figure 2-1: How the D-Variables may operate on an individual's perception of distance and the choice to walk (or bicycle), is based on a review of relevant studies and through numerous discussions with Dr. Susan Handy<sup>10</sup> and members of my dissertation committee.



Figure 2-1: How the D-Variables may operate on an individual's perception of distance and the choice to walk (or bicycle).

<sup>&</sup>lt;sup>9</sup> Based on a lengthy, ongoing discussions with Dr. Susan Handy, beginning at the 2006 ACSP Conference at Ft. Worth, TX (and continuing via subsequent emails, phone calls and in-person conversations).

<sup>&</sup>lt;sup>10</sup> Ibid.

To address these issues, this dissertation examines ways to combine the findings of urban design literature and insights with travel behavior research methods, bringing together the richness of urban design approaches with cost-effective practices of using of readily available data. This effort is grounded by pragmatically applying and testing these new methods to measure to the specific problem of NMT access to suburban rail transit stations. Figure 2-2 shows the key gaps in the research literature on travel behavior and the built environment that this dissertation is trying to bridge (indicated in the figure by question marks "?"). These are:

- A better understanding of how travel behavior is influenced by the "perceptual qualities of the built environment."<sup>11</sup>
- A better understanding of what factors influence the decision to bicycle, as well as whether or not to or walk.



Figure 2-2: Conceptual Diagram of Influence of D-Variables on Distance (and the perception of the duration of time) on selecting "Green" NMT (Walking and Bicycling) modes.

<sup>&</sup>lt;sup>11</sup> (Ewing et al., 2006; Ewing & Handy, 2009)

#### Seminal Syntheses of the Built Environment "D-Variables" and Travel Behavior

Two seminal meta-analyses by Ewing and Cervero, reviewing more than 50 empirical studies in 2001 and 200 studies in 2010, further refined these D-Variable "dimensions" of the built environment shown to influence travel behavior into the following: Local Density, Local Diversity, Local Design, and Regional Accessibility (Ewing & Cervero, 2001, 2010).<sup>12</sup> The following are some of their main conclusions:

- **Trip frequencies** appear to be primarily a function of the socioeconomic characteristics of travellers and secondarily a function of the built environment.<sup>13</sup>
- **Trip lengths** are primarily a function of the built environment and secondarily a function of socioeconomic characteristics.<sup>14</sup>
- **Mode choices** depend on both, though probably more on socioeconomic characteristics.
- Vehicle Miles Travelled (VMT)—the outcome of the combination of trip lengths, trip frequencies, and mode split—are more significantly associated with characteristics of the built environment.

As in the 2001study, in 2010 Ewing and Cervero find *regional accessibility* to still have the highest, inverse association (negative elasticity) with VMT. In both 2001 and 2010, a 10-percent increase in regional accessibility was still correlated with a 2-percent decline in VMT (Ewing & Cervero, 2001, 2010).

A powerful and elegant quality of the original D-Variables (density, diversity, and design) has been that they simultaneously communicate to researchers and modelers, as well as practitioners and policymakers (the latter group being important as they ultimately decide what, where, and how things get built). In sum, the 3-D message has been something like this: "Thoughtfully design developments at higher densities with a diverse mixture of uses to make them more walkable." The trouble has been where practitioners have lost sight of the 4th and 5th "Ds" (*destination* accessibility and *distance* to transit),<sup>15</sup> sometimes designing great 3-D communities that are far apart and inaccessible to important regional activity *destinations* (work, school, etc.) by anything

<sup>&</sup>lt;sup>12</sup> Also referred to as "Destinations." Later "Distance to Transit" was added.

<sup>&</sup>lt;sup>13</sup> Since the testing of the new measures in this dissertation looks primarily at transit access mode choice, this research pays close attention to socioeconomic factors, in alignment with these findings.

<sup>&</sup>lt;sup>14</sup> As people walking and bicycling may be more sensitive than in-vehicle travelers to aspects of the urban environment, this suggest a stronger influence the built environment may have on the distances people may be willing to walk bicycle.

<sup>&</sup>lt;sup>15</sup> Working as a consultant evaluating various development projects in California's Central Valley for their ability to lower GHG emissions, my colleagues and I have found that while many of the proposals are much better designed for walking and bicycling than in the past, and likely see some Drive to NMT substitution for discretionary trips, much of the environmental benefits are negated, if even a small portion of work trips (say, 15%) have to leave the development and drive significant distances (e.g., 30 Miles) to the nearest employment center.

but an automobile. As Ewing and Cervero state in their most recent 2010 meta-analysis, regional accessibility matters most toward lowering vehicle use and, by extension, presents the best hope for lowering greenhouse gas emissions, increasing opportunities for physical activity, and achieving a host of sustainability objectives.<sup>16</sup> Nevertheless, designing these communities to support walking, even if just for discretionary trips, is still important (Ewing & Cervero, 2010).

#### Conventional Spatial Units of Analysis: Zonal Aggregations

As in 2001, Ewing and Cervero's 2010 meta-analysis of the literature on travel behavior and the built environment predominantly chose studies that had enough observations to meaningfully guide policy. Some studies (and the constituent data) were excluded because they characterized the built environment "subjectively rather than objectively, that is, in terms of qualities perceived and reported by travelers rather than variables measured in a standardized way by researchers" (Ewing & Cervero, 2010), that is, by objective, *replicable* methods. This meant that of the 200 studies, practically all the built environment measures data was aggregated to zonal levels: 1/2-mile buffers around stations, census tracts, traffic analysis zones (TAZs), etc. This method homogenously applies the zonal averages (violating the *resolution* principle) of these zonal aerial units of measure to all individuals (violating the *respondent* principle) with origins and/or destinations within these zones. Of the selected disaggregated studies of individual behavior, only a handful had measures of the built environment that were sub-zonal or more closely aligned to the scale at which a person interacts with the urban environment—in other words, a human scale. Again, this is understandable, as up until now, technology has made it difficult and expensive to *replicably* gather such high *resolution* (human-scale) information for each travel survey *respondent* that can provide reliable and valid inputs into statistically significant models of consumer behavior. But the human scale of the urban environment matters to our understanding of the urban environment's influence on travel behavior.

#### Human Scale Matters: Critical Review of the Influence of Built Environment Dimensions on Travel Behavior

According to Handy (2006b), one of the weaknesses of the travel behavior and the built environment literature is that we need to better understand the scale at which these various dimensions influence travel. For example, the local neighborhood dimensions of Distance, Density, Diversity, and Design have a bigger effect on walking than on driving. Handy also notes these other limitations of the built environment currently used in travel behavior research:

- These dimensions do not carry equal influence on travel behavior.
- They do, however, influence travel behavior through their synergistic relationship with each other.
- They carry influence on different modes and at different scales (e.g., neighborhood vs. regional/subregional).

<sup>&</sup>lt;sup>16</sup> Up until now, most of the built environment and travel behavior research has focused on what factors *lower* auto use, rather than on what factors *increase* walking and bicycling.

#### The Built Environment's Influence on Walking

In the past, there has been considerable disagreement in the literature about the role of the built environment on pedestrian mode choice and travel characteristics. A 1996 study by Cervero and Radisch compared traditional (grid street pattern) neighborhoods with more recent, suburban (circuitous street pattern) neighborhoods and found that residents of a traditional neighborhood, around the Rockridge BART Station, averaged around a 10-percent higher share of non-work trips by non-automobile modes than did residents of a suburban neighborhood around the Lafayette BART Station (Cervero & Radisch, 1996). On the other hand, a 1998 study by Crane & Crepeau (1998) using household travel diary and GIS data for San Diego, CA, found that there was little role for land use in explaining travel behavior and no evidence that the street network pattern affected either short or long non-work travel decisions.

According to Ewing & Cervero (2010), most of the studies reviewed in their 2001 synthesis of travel behavior and the built environment research focused on auto-use outcome measures (VMT, auto- ownership, etc.) and did not include much research directly addressing walking, transit use or bicycling. In their 2010 meta-analysis, walking trips are found to be most strongly associated with the functional aspects of design (intersection density) and measures of land use activity mixture (identified as *diversity*), jobs-housing balance, and distance to stores.<sup>17</sup>

#### Limited Understanding of the Built Environment's Influence on Bicycling Behavior

Currently, there is also very limited research on the built environment's influence on bicycling behavior and very little statistical understanding about bicycle travel to any destination, let alone to transit stations. Much more research is needed. Studies to date have been hampered by small sample sizes, wide variances in trip lengths, and a failure to take into account distinct community characteristics and individual attitudes—although the 2001 National Household Travel Survey did find that the average bicycle commuteto-work distance is about three miles.<sup>18</sup> It should be noted that Ewing and Cervero's 2010 meta-analysis did not include studies on the relationship between bicycling and the influence of the built environment—another key focus of this dissertation—"due to a dearth of solid research" (Ewing & Cervero, 2010). Some elusive questions are as follows: How far are bicyclists willing to travel? And, how do perceptions of distance, as affected by the urban environment, influence a person's decision to bicycle?

<sup>&</sup>lt;sup>17</sup> They also found walking to be most strongly related to measures of land use diversity, intersection density, and the number of destinations within walking distance, and bus and train use equally related to proximity to transit and street network design variables, with land use diversity a secondary factor.

<sup>&</sup>lt;sup>18</sup> United States Department of Transportation, Federal Highway Administration. National Household Travel Survey, 2001. Data available online at: http://nhts.ornl.gov/download.shtml. This study was based on a sample of only 71 bicycle-work commute trips reported by respondents. The average distance for all bicycle trips, of those surveyed was about 2 miles (sample of 1,851 total trips).

#### Limited Understanding of the Influence of "Perceptual Qualities" of the Urban Environment on Travel Behavior

A question probed in this dissertation is whether the current methods and measures effectively capture how the built environment influences walking and bicycling, as those travelers experience urban spaces at the scale of the sidewalks (including and cracks), building frontages, block lengths, difficulty crossing intersections, etc. The limitations of the body of research on the aesthetic qualities of the urban environment's influence on travel behavior are perhaps best described by (Ewing et al., 2006)<sup>19</sup> where they say in the first sentence of their abstract:

In active living research, measures used to characterize the built environment have been mostly **gross** [emphasis mine] qualities such as neighborhood density and park access.

They go on to say in the third sentence of their introduction:

Audit instruments have proliferated for assessing the walkability and bikeability of environments, but these too have characterized the built environment with **crude measures** [emphasis mine] such as number of travel lanes and presence of marked crosswalks.

In the fourth sentence, they go on to support the need to better understand what is referred in this research as *traveler perceptions*, when they say:

Urban designers point to subtler qualities that may influence choices about active travel and active leisure time. These are sometimes referred to as perceptual qualities of the urban environment or, alternately, just urban design qualities.<sup>20</sup>

And while recognizing that "perceptions are important," Ewing & Cervero (2010) also point out that perceptions "differ from objective measures of the built environment and are arguably more difficult for planners and public policymakers to influence" — an important balance this dissertation is trying to strike — to find objective measures (albeit proxies) of these "perceptual qualities of the urban environment" that matter to people wishing to walk or bicycle that can *replicably* be collected for a large enough group of people to support statistically significant analyses to more fully inform policy decisions.<sup>21</sup>

<sup>&</sup>lt;sup>19</sup> Using aggregate measures of built environment factors at the scale of the census tract or traffic analysis zone (TAZ) have provided effective understanding of travel behavior at the scale and perspective of a driver making a trip.

<sup>&</sup>lt;sup>20</sup> Referring to this also as "urban design" suggests that urban designers only work on issues related to the "perceptions" or urban form, while they are often involved in functional/operational aspects of how a city works, from how streets networks are designed to how traffic and transit systems operate.

<sup>&</sup>lt;sup>21</sup> As discussed later in this dissertation, parcel geometry seems to promise an objective measure, albeit a proxy, for these important, but not yet replicably captured "perceptual" measures of the urban environment.

In response to these concerns, urban design researchers have undertaken detailed studies of the built environment to determine which aspects actually encourage riding transit, walking, and bicycling and which do not (Bosselmann, 2008; Isaacs, 2001; Park, 2008). Their approaches often involve gathering detailed data, documenting the quality of the built environment and the experience of walking along a path from an origin to a destination. While such studies have revealed a better understanding of the perceptual factors that are in fact supportive of walking and possibly bicycling, the resource-intensive nature of gathering such high-resolution data hampers the ability to gather enough observations to support statistically significant models. While such studies rank high on the *resolution* and *respondent* principles used to evaluate methods in this dissertation, they do not rate as high with regard to the *replicability* principle, as the scale and intensity of the methods applied are often heavily subjective, data intensive, and expensive. Nevertheless, there is an argument to be made that there is a need to better understand people's perceptions of the urban environment and how their perceptions influence travel behavior.

# **2.2 Illustrative Application of 3R Principles in Evaluating Methods to Measure Urban Environments**

In response, this research seeks new methods to measure urban environments. Development of new methods requires a central evaluative framework with guiding principles. The following is an example of how the 3R principles of *resolution*, *respondent*, and *replicability* are applied to guide the methodological development of measures of the urban environment, in the specific context of their influence on access to rapid transit. In brief, these new methods are applied to research on non-motorized transport (NMT). To ground the development of these new methods, a real-world problem and dataset is used: rapid transit access travel behavior.

## **2.2.1** Previous Research on the Built Environment's Influence on Walking to Transit

#### Previous Research on Access to Transit by Walking

Several researchers pioneered studies on the distances individuals are willing to walk to a transit station. Early work suggests that <sup>1</sup>/<sub>4</sub> mile (1,320 feet) was the optimal catchment area (Demetsky & Perfater, 1975). Several researchers pioneered studies on the distances individuals are willing to walk to a transit station. Later, Stringham (1982), observed people willing to walk up to 4000 feet from transit stations, and Untermann (1984), who found approximately 10 minutes or 2300 feet (almost <sup>1</sup>/<sub>2</sub> mile) to be the maximum distance most people in the U.S. were willing to walk to reach transit. Both Stringham (1982) and Untermann (1984) found that walking distances can be extended by upgrading streetscapes. Untermann further found that transit passengers become less sensitive to walking distances as transit service frequency increases. Agrawal, Schlossberg, & Irvin (2008) surveyed pedestrians about their walking behavior in Portland, Oregon, and the San Francisco Bay Area, while capturing details of the built environment with handheld GPS units. Their findings further confirmed that a <sup>1</sup>/<sub>2</sub>-mile catchment area may be more common than the previously held standard of <sup>1</sup>/<sub>4</sub> mile. Furthermore, Cervero (2007) found that <sup>1</sup>/<sub>2</sub>-mile catchments areas appear to be

"indifference zones" in the sense that residents within those areas generally ride transit regardless of local urban design attributes. A study of travel behavior at 40 TODs situated along nine different heavy, light, or commuter rail lines in California found that residents living within ½ mile of transit stations are almost four times more likely to use transit than those who live ½ to 3 miles away (Lund, R. Cervero, & Willson, 2004).

As testing the new methods explored in this dissertation uses NMT access to rapid transit, a 2x2 matrix is provided to map a sample of studies in this field, representing the spectrum of the 3R principles of methodological development. As shown in Figure 2-3, the horizontal axis is a continuum of measurements of built environment variables from low to high resolution. The vertical axis is a continuum from low to high methodological replicability. The studies located within this matrix are discussed further below.



Figure 2-3: Matrix of a Sample of Disaggregate Studies of NMT Access to Rapid Transit and how they perform in relation to the *3R principles of methodolical development*.

#### 2.2.2 High-Resolution/Low-Replicability Research on Transit Access Mode Choice

For its detailing of the urban environment, Park's 2008 doctoral dissertation should be considered alongside Agrawal et al.'s (2008) study. Park included detailed surveys of 249 routes near transit stations in mostly older suburbs in the San Francisco Bay Area and found that four significant path walkability factors—*sidewalk amenities, low traffic impacts, street scale and enclosure, and landscaping elements*—increased the likelihood of transit users walking rather than driving to the station. However, the resource-intensive nature of the data gathering presented challenges for these researchers and likely for future research using these same methods.<sup>22</sup> Table 2-1 shows the 3R principles evaluation of the Park (2008) and Agrawal et al. (2008) methods.

Principle	Rating	Discussion
Resolution	High	
Respondent	High	
Replicability	Low	Costly to collect data

Table 2-1: 3R Principles Evaluation of Park and (Agrawal et al., 2008) Methods.

#### 2.2.3 Low-Resolution/High-Replicability Research on Transit Access Mode Choice

Studies by Loutzenheiser (1997) and Cervero (2001) used

individual/disaggregate-level research on transit access mode choice. Both employed methods with higher levels of replicability and robust modeling than Agrawal et al. (2008) or Park (2008). However, largely due to technological and data limitations at the time, they had to rely on lower-resolution measures of the urban environment aggregated at zonal levels (TAZs).

These two studies show that while aggregate approaches are useful, as the data on which they rely on are readily available and thus support the *replicability* principle, they rate lower on both the *resolution* or *respondent* principles. Table 2-2 shows the 3R principles evaluation of the Cervero and Loutzenheiser methods.

Principle	Rating	Discussion
Resolution	Moderate to Low	Zonal aggregation
Respondent	Moderate to Low	Zonal average is uniformly applied
Replicability	High	Data readily available

Table 2-2: 3R Principles Evaluation of Cervero and Loutzenheiser Methods.

Some of their specific findings, important to guiding this dissertation's exploration of NMT rapid transit access, are as follows:

• The Loutzenheiser (1997) study finds that substantial parking availability at the transit station is associated with decreased walking rates, while the presence of retail businesses around the station is positively associated with increased walking rates, after controlling for socioeconomic variables.

<sup>&</sup>lt;sup>22</sup> As supported by conversations with Schlossberg (coauthor alongside Agrawal), October 2007, and Park, Fall 2009.

• The Cervero (2001) study used aggregated (although detailed) TAZ calculations of built environment characteristics of transit access trips to Washington, DC, Metrorail stations by residents of Montgomery County, Maryland. Finding that urban design factors, particularly sidewalk amenities, have a significantly positive association with walking to access rapid transit.

### 2.3 The Fourth "R": *Refining* Measurements of the Urban Environment under the New IAC Analysis Paradigm

This section discusses in more detail how the IAC offers an opportunity to transforms the current way we measure and understand the urban environment, by allowing much finer *resolution* of data gathering (such as parcel land-use, or specific business and place based activities) that can be uniquely attributed to each individual survey *respondent*. As the D-Variable framework is the current standard for measuring physical aspects of the urban environment, the new measures should be considered as extensions of this as in many ways they embody the characteristics of the dimensions of the D-Variables. Therefore, the distinction between the new measures are based on their spatial unit of analysis (whether they are based on the new IAC, or on zonal aggregations). Thus this research will sometimes refer to the measures of the urban environment as either the "IAC" or "Zonal" D-Variables. The following section discusses the rationale for refining the Zonal D-Variables and parts of their attendant dimensions, in light of the new techniques and capabilities presented within this dissertation.

#### Case for Refining our Use and Understanding of Density Dimension for IAC Analyses

While density is one of the easier measurements to gather and apply across communities, its influence on lowering vehicle miles traveled (VMT) is actually quite small, once other factors of the built environment are controlled, according to Ewing & Cervero (2010), who say:

"Surprisingly, we find population and job densities to be only weakly associated with travel behavior once these other variables are controlled."

This is likely due to the fact that high-density downtowns are associated with many other factors influencing travel behavior, such as the presence of sidewalks, frequent bus service, parking scarcity, and so on. With the ability to independently capture urban environmental features along an individual's access corridor enables our the refining how we understand and measure density for use in travel behavior research.

## Case for Refining our Use and Understanding of Diversity Dimension for IAC Analyses

At its core, diversity is a measure of land use activity. Early thinking on the importance of mixing land uses make our urban environments more walkable and livable (and arguably more sustainable), can be traced at least back to the Jacobs & Appleyard (1987) article, *Toward an Urban Design Manifesto*, when it discusses the need for "integration of activities."

Until recently, measuring land use activity at the zonal level has been has been limited to measuring dissimilarity or entropy as proxies for land use activity mixture. One solution, developed by Cervero & Kockelman (1997) was to use an "entropy index" as a proxy for the mixture of land use activities (*Diversity* D-Variable dimension). And these measures of entropy are useful for regional-level travel behavior research, given the data and technology readily available. But they can belie key activity characteristics (e.g., number of jobs vs. number of residents), as illustrated in the following example:

Consider this formula for calculating a standard, zonal (1/2-mile radius around a station destination) jobs-to-housing, mixed-use entropy index:

Jobs-to-Housing/Mixed-Use Entropy =  $\{-\Sigma k [ (pi) (ln pi)]\}/(ln k),$ 

where:

pi = proportion of total land-use activities in category i within a half mile (straight-line distance) of the station;

i categories are households (# of single family units; and # of multifamily units), and employment (retail and non-retail jobs); and

k = 4 (number of land-use categories).

Station areas with heterogeneous mixes of housing and jobs scored high on these factors (based on the 0–1 entropy index, where 1 represents maximum heterogeneity).

Figure 2-3 illustrates how entropy indices can hide key activity characteristics. In this example, similar "entropy" scores are calculated for a downtown San Francisco BART stations (Montgomery) and the overwhelmingly suburban residential station, North Concord. As shown in the inset bar chart showing employment (red) and population (blue) for these three stations, similar entropy scores are calculated because both areas have one predominant land use—downtowns are mostly employment, while bedroom communities are mostly residential.



Figure 2-3: Mixed-Use Entropy Index of BART Stations, 2008.

#### Case for Refining our Use and Understanding of Design Dimension for IAC Analyses

The IAC allows us to capture detailed characteristic of the environment (*resolution*), which then can be applied to each individual (*respondent*). Both of these characteristics improve our ability to probe the subtle complexities of the urban environment's influence on travel behavior.

While not often distinguished in the current body of travel behavior research, there are really two aspects of design that are referred to, but not consistently addressed. They are as follows: a) Functional/operational characteristics and b) Form, perhaps more commonly understood in the literature as an operant on our travel behavior as the "perceptual qualities of the urban environment or *urban design*" (Ewing et al., 2006; Ewing & Handy, 2009). In their 2010 meta-analysis of travel behavior and the built environment, Ewing and Cervero focus exclusively on the *functional* aspects of design, mostly dealing with "street network design characteristics within an area"- a large scale for understanding human interaction with the environment.

Arguably there is a need to more directly identify an "operational" element as a component of the urban environment. For example, when designing and planning communities, practitioners have to think about how things are going to work. Asking such questions as: How frequently are the buses going to operate? Where is the parking going to be located? How much will it cost? How will the traffic signal timing work to balance the needs of drivers with those of people trying to cross the street? And even how are rapid-response tow-trucks going to work to free up congestion?<sup>23,24</sup> And this functional/operational design aspect should not be seen as acting mutually exclusive of a traveler's perceptions.<sup>25</sup>

<sup>&</sup>lt;sup>23</sup> Downs, A. (2004). *Still Stuck in Traffic*, recognizes this as one of the most cost-effective and politically palatable methods to relieve congestion.

<sup>&</sup>lt;sup>24</sup> Building on the "Network Society" notions of Webber and Castell's, we should consider the flow of information under this idea functional/operational design. A good example of this is illustrated in the use of the Google Transit website which provides almost instantaneous information about where, when and how long, it will take to ride the bus.

<sup>&</sup>lt;sup>25</sup> How a transit system operates likely shapes perceptions of the urban environment. For example, the operation of Curitiba's or Bogota's BRT systems likely gives people a stronger cognitive connection with the respective downtowns of these cities.
# **2.3.1 Refining Measures of the Urban Environment for IAC Analysis: Land Use Activity, Transport Access, and Traveler Perceptions**

As the IAC gives us an entirely new capacity to measure the urban environment, we need some overarching principles and theory to guide us in refining how we measure and understand the characteristics of the urban environment.<sup>26</sup> Inspired by both Lynch's (1981) book, *A Theory of Good City Form*, and the insights of Jacobs & Appleyard (1987) *Toward an Urban Design Manifesto*, this research uses the urban environment components of land use *activity*, transport *access* and traveler *perceptions* as the guiding urban environmental *dimensions of performance*. These components and their relationship are illustrated in Figure 2-4 below.



Figure 2-4: Individual Access Corridor (IAC) Components of the Urban Environment (UE).

The following is an itemized discussion of each of these new components:

# Land Use Activity

Now that we can measure land use activity in entirely new ways—classified at the parcel level—at the very least the concept of "activity" should be more clearly identified as a component of the urban environment, reflecting our ability to now look more deeply at specific land use synergies (e.g., the interplay between stores, schools, parks), rather than solely at an overall measure of land use mixture, or "entropy" per se.

<sup>&</sup>lt;sup>26</sup> As well as a better understanding of how people use urban spaces.

## **Transport** Access

Transport access is the broadest of these components, and includes the physical aspects of modal amenities (hardware), as well as the operation, management, and the ability of people to have the means of using such amenities (software). For example, is a car available and is there access to cheap parking? Or, is one allowed to bring a bicycle on a BART train at all times or do you have to get picked up in a car at the other end?<sup>27</sup>

## **Traveler Perceptions**

The article, *Measuring the Unmeasurable: Urban Design Qualities Related to Walkability* (Ewing & Handy, 2009), recognizes the importance of perceptual qualities emanating from the urban environment and the need to better measure them and better understand their influence on travel behavior, especially walking. And although these qualities have been perhaps the hardest dimension to uniformly quantify, Ewing and Handy (2009), working with a team of sixteen urban design experts, applied a rigorous analysis to identify qualities they believed would be proven highly correlated with walkability.<sup>28</sup>

Their focused list of urban form qualities important to walking is as follows:

- **Imageability** is the quality of a place that makes it distinct, recognizable, and memorable.
- **Enclosure** is the degree to which streets and other public spaces are visually defined by buildings, walls, trees, and other vertical elements.
- **Human scale** is about size, texture, and articulation of physical elements that match the size and proportions of humans and, equally important, correspond to the speed at which humans walk.
- **Transparency** is the degree to which people can see or perceive what lies beyond the edge of a street or other public space, particularly human activity.
- **Tidiness** is the importance of operations and maintenance of a place and making sure that community members feel responsible for their property and community.
- Complexity is the visual richness of a place.

This component should also include measures recognizing the importance of perceptions of distance (see Isaacs, 2001) and the other measures of vitality, livability, and sense of place (see Bosselmann, 2008, Chapter 3).

<sup>&</sup>lt;sup>27</sup> For the purposes of this research, these physical and functional subcomponents of the modal amenities are referred to as "transport access." Nevertheless, the concept of *access* also includes the importance of social equity, or *access to opportunity*. It is thus important to consider the personal attributes of the survey respondents as well, so that access includes measures of income, race, educational attainment, gender, etc.

<sup>&</sup>lt;sup>28</sup> These measures are currently being evaluated in the field, and focus only on commercial streets.

## 2.4 Summary, Conclusions and Next Steps

Considering the new opportunities presented by the IAC spatial unit of analysis to capture the richness and complexity of the physical aspects of the urban environment and its relationship to travel behavior, the next chapter applies the 3R principles of methodological development to evaluate both current and new measures of the urban environment.

In sum, combining the new IAC method with richer, more detailed geo-spatial datasets (parcel-level land use data, street networks, and lot sizes) allow us to better capture and then analyze subtle yet influential qualities of the urban environment. In the case of this dissertation, these capabilities are applied toward helping us better understand what urban environmental factors encouraging people to access transit stations through more sustainable modes and practices.<sup>29</sup>

<sup>&</sup>lt;sup>29</sup> This including driving practices, such as encouraging peopled to drive to the closest station, as well as keeping them from bypassing the transit system altogether.

# PART II KEYSTONE

# **Chapter 3: Developing and Refining Methods to Measure Urban Environments for Individual Access Corridor Analysis of Environmentally Sustainable Travel to Rapid Transit**

## 3.1 Chapter Overview

This chapter is the keystone of this dissertation. Building on an in-depth discussion of the literature, it delves into the exploration of new methods to measure the urban environment. Until now data and technology have mostly limited measures of the urban environment in travel behavior modeling to zonal aggregations. The new capabilities explored in this research opens the door for the refining our fundamental approaches to how such things as land use activity, parcel geometry, and route directness can be incorporated into future travel behavior research.

Building on the vast body of body of previous work in this area, this chapter incorporates the 3R principles of methodological development as the central evaluative framework toward developing new methods to measure the urban environment.

The discussion in this chapter shows how the new spatial unit of analysis, the individual access corridor (IAC)—a unique geospatial buffer selection of key components of the urban environment for each of thousands of surveyed individuals — primarily satisfies the *respondents* principle. The ability to work with more highly detailed data (e.g., land use activities classified at the parcel-level) primarily satisfies the *resolution* principle. The ability to gather this detailed data and attribute it uniquely to thousands of survey respondents, while maintaining uniformity and objectivity, satisfies the *replicability* principle. Chapter 4 presents the testing and further refinement of these new measures based on their iterative application in predictive models of consumer behavior.

## 3.2 Methodological Overview

The new methods to measure urban environments in this research balances the following oftentimes competing principles: 1) they capture high-*resolution* information of the urban environment for each individual survey *respondent*, in a *replicable* (objective, resource permissive) manner so a large enough sample of information about individuals can be modeled to support both reliable and valid analyses of consumer behavior, that are generalizable to a broader population.

The overarching operational hypothesis by which these new methods and measures are tested is as follows:

Following the 3R principles of methodological development, the new individual access corridor (IAC) components of the urban environment—land use activity, transport access, and traveler perceptions—are reliable and valid for use in consumer behavior research.

This research explores the *reliability* and *validity* of these new methods and measures by pragmatically applying them toward the analysis of a real-world problem: access to rapid transit. Reliability is established by examining the objective, resource-permissive nature by which the measurements can be gathered.<sup>30</sup> Validity—a much trickier issue to address—is established through an in-depth, theoretical discussion of each measure's meaning and relevancy toward what is meant to be measured, as well as their usefulness toward testing a specified research hypothesis.

The operative hypothesis to test the practical application of these new measures toward the issue of transit access travel behavior is as follows:

During a person's morning commute to work via a non-CBD rapid transit station, components of the urban environment (land use activity, transport access, and traveler perceptions) significantly influence rapid transit access travel behavior.

This hypothesis is referred to herein as the Urban Environment/Transit Access (UETA) hypothesis, and this chapter discusses the gathering and preparation of measures to be used as inputs in multinomial logit (MNL) models of consumer choice—essentially testing the utility individuals may place on these new measures of the urban environment (specific land use activities, transport access amenities, and perceptual qualities of the urban environment encountered along their access corridors to rapid transit). While providing a proof of concept for these new measures, this study's analysis of rapid transit station access is also an important issue to address on its own merits, as most U.S. commuters who use rapid transit get to and from their stations by car.<sup>31</sup>

<sup>&</sup>lt;sup>30</sup> In the next chapter, reliability is established by evaluating the performance of these new measures via numerous multinomial logit (MNL) model runs, testing to see whether fairly similar results are obtained when a relatively experiment or analysis is repeated.

<sup>&</sup>lt;sup>31</sup> This is exemplified in BART's case where, according to the 1998 and 2008 BART Station Profile Surveys used in this dissertation, in both 1998 and 2008, 50% of the people drove from their homes to access the Bay Area Rapid Transit (BART) system.

## 3.2.1 Key Datasets

Information for this research has come from many sources, including a unique collaboration with Google Transit to calculate travel times, as well as this researcher's own geospatial calculations. But the most important data comes from the 2008 Station Profile Surveys of the Bay Area Rapid Transit (BART) system. Most importantly, this survey provided information on the mode, home origin, station destination, as well as the time an individual of arrived at a particular station.<sup>32</sup>

Another critical dataset used in this research is the street network geographic information system (GIS), granted for use by the San Francisco Bay Area's Metropolitan Transportation Commission (MTC). While tremendously useful to this paper, this GIS-based street network needed to be inspected thoroughly and corrected so that all the various modes could be appropriately routed (e.g., bicyclists would not have their estimated routes to transits going on freeways. An additional advantage of the using the BART Station Profile Survey data for this dissertation is that it captured travel behavior and other information for a significant number of bicyclists.

## **3.2.2** Characteristics of the Sample Population and Stations (Destinations)

### **Characteristics of the Sample Population**

To test the operative hypothesis, the sample of respondents to the 2008 BART Station Profile Survey focuses on morning commuters <sup>33</sup> travelling between home and the respective BART station who:

- Travelled no more than 5 miles (network distance) to reach a station, as this distance is reasonably reached by bicycling as well as motorized modes;
- Accessed non-CBD, BART stations with parking.

<sup>&</sup>lt;sup>32</sup> For the purposes of this research, the ESRI ArcInfo geographic information system (GIS) was tailored via Python and Visual Basic programming to do tasks ranging from making sure that bicycle routes to BART were not on freeways to capturing detailed parcel-level geospatial and land use information for thousands of survey respondents.

<sup>&</sup>lt;sup>33</sup> Morning commute trips were intentionally used for this analysis as these are purposeful and timesensitive, supporting the rationale of geo-coding the shortest estimated route between respondents' homes and their respective transit stations. During the morning commute, people walking and cycling may take a relatively direct route to transit, which can be corrected to a certain extent by increasing the buffer around these routes. However, driver's may be prone to greater deviations, as they likely have a greater ability to drop-off a child a school, partner at work ,etc. on the way to the station.

# Characteristics of the Stations: Stations with Parking and Outside of Central Business Districts

As shown in the map in Figure 1, this research focuses on stations and urban environments in the inner portion of the Eastern San Francisco Bay Area that met the following two criteria: 1) motor vehicle parking was provided on station property; and 2) they are located outside central business districts (which, in the case of BART, were stations with parking).

These two criteria were used for the following reasons:

- These stations and surrounding areas presented the greatest potential for conflicts between nonmotorized and motorized modes of access;
- Focusing on stations that are highly convenient for automobile drivers intentionally targets this analysis to more clearly uncover the challenges of transforming auto-oriented stations into bike- and pedestrian-friendly ones;
- All 420 All
- The park-and-ride lots of these stations represent important transformable, grey-banked redevelopment Figure 3-1: BART Stations in Eastern San Francisco Bay Area. Source: Author and BART

opportunities for transit-oriented development.

# 3.2.3 Information and Preparation and Prototype of New Method

# Information Preparation

While standard software is used in this research, virtually none of the processes and methods explored and developed in this study are a part of any standard practice. Their development first required grounding in theory, and then an exploration of new ways to make the processes and software work to obtain the intended measure. This required constant, diligent consultation with technical practitioners, as well as the software developers themselves.<sup>34</sup>

<sup>&</sup>lt;sup>34</sup> These interactions have led to several direct improvements to the next version of ESRI's ArcMap software (v. 10). For instance, this work has been directly recognized for finding a "bug" in the program for calculating direct distances, which was addressed in a Service Pack update sent out to the thousands of ESRI ArcInfo software users.

## Prototypical 3R, Individual Access Corridor (IAC) Geo-Spatial Method to Measure Key Urban Environmental Components

Although there were many different geo-statistical methods explored and employed to measure the urban environment in new ways, Figure 3-2 represents a prototypical example of how this research tailors a geographic information system (GIS) through the use of a new spatial unit of analysis, the individual access corridor (IAC). In brief, via Python and Visual Basic programming of ESRI's ArcMap GIS, the IACs capture detailed information for thousands of survey respondents, as follows:

- First, the home origins of respondents to the 2008 BART Station Profile surveys are geo-coded;
- Second, the shortest appropriate route (e.g., bicycles and pedestrians are not routed on freeways) are estimated for each individual to the rapid transit station specified in their survey response.
- Third, a 200-foot, IAC buffer<sup>35</sup> is created to capture and calculate such things as the average size of the parcels, specific land uses, network measures of distance and route directness, etc.<sup>36</sup>



Figure 3-2: The individual access corridor (IAC) in action.

<sup>35</sup> This research uses 200 feet, but the methods are designed so one could expand this (e.g., to 400 feet).
<sup>36</sup> All methods to measure the urban environment presented in this dissertation attempt to have built-in ways to correct for any inaccurate route estimates. Consider the example of calculating the IAC average parcel size (discussed further below). The IAC buffer around an estimated route could be scaled to cast a wider net to capture adjacent streets, thus increasing the chances that a respondent's actual route capture, if different from the estimated route. Furthermore, by programming the GIS software to then calculate the average size of the parcels within this buffer, the APS measure would theoretically only modestly change as the IAC buffer area around the estimated path increased. This was one of the reasons APS was chosen as the preferred measure of parcel geometry.

## **3.2.4 Dependent/Outcome Variables**

The outcome units of measure—the dependent variables or, for multinomial logit models, the choice set—are: 1] walk (person walking), 2] bicycle (bicyclist), 3] ride bus (bus-rider), 4] drive alone (solo-driver), and 5] get driven to station and dropped-off.

# **3.3 Independent Variables: Land Use Activity, Transport Access, Traveler Perceptions**

# 3.3.1 Organization

This section presents the development of new methods and refinement of current ones to measure the urban environment. Where appropriate, this research evaluates these methods according to how well they meet the 3R principles, rating them high, moderate, or low.

Where it makes sense to do so, this examination includes the following:

- Background of the literature, including a discussion of previous research, theory, and approaches;
- A discussion of the approaches in this research toward developing methods to capture intended measures.<sup>37</sup>
- Where possible, recommendations for improving research and/or practice;
- And finally, in all cases there is a discussion and articulation of the validity and meaning of the measure.

# Establishing Validity of the Measures

To establish the validity and meaning of these measures, a key question to ask is whether the variables honor the testing of operative research hypothesis? In this case it is the urban environment/transit access (UETA) hypothesis stated above. To address this question, a detailed inquiry is provided throughout this chapter, theorizing which of these measures may influence transit access mode choice. Specifically asking, "what urban form characteristics add utility (positively or negatively) to an individual's selection of a particular mode for a particular trip purpose? An important consideration along this line of inquiry is that people walking and bicycling to the station have different needs than those traveling via a car or bus and will be influenced by different things. As they are more exposed to the environment of their *IAC*, people walking and bicycling likely care more about the way buildings and the street environment make them feel. In-vehicle travelers (solo drivers, transit riders, and car passengers being dropped-off) are likely to be more influenced by the characteristics of the immediate areas around their origins and destinations. In contrast, out-of-vehicle travelers (people walking or bicycling) are relatively more sensitive to contextual characteristics of the access corridor itself - the space between the origins and destinations.

<sup>&</sup>lt;sup>37</sup> These ratings are relative to the body of literature current at the time of the writing of this paper, based on the work of Ewing and Cervero (2010), which covers research through 2009.

# **3.3.2 Land Use Activity: Dealing with Specific, Parcel-Level Land Use Classifications in Predictive Models of Consumer Behavior**

Until now data, technology, and methods have limited the measurement of land use activity to zonal indices of land use entropy as proxy for land use mixture.<sup>38</sup> The use of parcel-level data and the individual access corridor (IAC) access buffer—specifically, the ability to capture and examine land use activities classified at the parcel-level, and then apply them uniquely to the estimated routes of thousands of survey respondents—opens the door for *refining* current approaches to incorporate land use activity into predictive models of consumer behavior. Land use information analyzed at the parcel level likely provides a more appropriate ecological unit of analysis to examine the influence of particular land uses, and the synergies of a collection of land uses, on walking and bicycling. This research tests the best methods for dealing with specific, parcel-level land use classes that can be uniquely attributed to individual respondents in predictive models of consumer behavior.

These new capabilities open the door for methodological improvements along many dimensions, including analyses of real estate/economic development, social equity, locations of criminal activity, among others. Finally, parcel-level land use information capture shows promise toward supporting more in-depth analyses of the influence of land use synergies on travel behavior.

- 2. GIS files with land use district information was obtained from ABAG, the San Francisco Bay Area's regional Council of Governments (COG). The land use districts (not yet cross-referenced and disaggregated to the parcel level) were coded using ABAG's 72 land use categories.
- 3. Using a series of geo-spatial techniques, ABAG's land use district information was uniquely attributed to each of the thousands of individual parcels in Alameda and Contra Costa counties.

<sup>40</sup>Maintaining *Manageability* and *Meaning*: As one would expect from any efforts to aggregate land use categories for a large number of individual jurisdictions (in this case over 100), ABAG had to combine the multitude of land use classes into a uniform classification system. The main challenge is to take parcellevel land use data for multiple land use categories (in this case 72) and try to strike a balance between creating a more *manageable* dataset, while maintain its *meaning*.

While it makes sense to simplify a group of land use categories from 72 to a more *manageable* number (in this case 14), it is equally important to maintain the integrity and identity of land use categories, as well as maintaining the distinction between them – important to yielding *meaningful* policy direction from model results.

<sup>&</sup>lt;sup>38</sup> *Diversity* D-Variable dimension.

<sup>&</sup>lt;sup>39</sup> The following steps were taken to create the parcel-level land use GIS files necessary for this analysis:

<sup>1.</sup> GIS files with parcel geometries were obtained from the Assessor's Offices of Alameda and Contra Costa counties.



Figure 3-3: Calculating proportions of each land use category along a sample of each survey respondent's estimated route to the Fruitvale BART Station.

After testing numerous methods, Figure 3-3 provides an illustrative example of how this research ultimately captures detailed IAC land use activity information along each respondent's likely route to their respective rapid transit station (in this case, the Fruitvale BART Station).

Out of this new method to measure emerges three ways to calculate land use variables to serve as inputs in analyses of consumer behavior, as follows:

- Land Use Proportion (LUP): The proportion of a certain land use category along an individual's access corridor.
- Land Use Distance (LUD): The absolute distance of a certain land use category along an individual's access corridor.
- Land Use Dummy Variables: A measure representing the presence of an activity, rather than the overall number of that activity along an IAC.

Choosing which of these land use activity measures depends on 1) the utility that a land use activity may serve for the traveler, and 2) whether the land use itself represents a building form that presents a significant added influence a *traveler's perceptions*. The key question to ask when determining which of these measures to use is:

Given the characteristics of the access corridor, the destination station, and the home origin, in what way might a specific land use activities serve a certain *personal service utility* for an individual? (Which may then influence an individual's decision to select a particular mode, for a particular trip purpose.)

Consider the example of the *personal service utility* of a coffee shop. A morning commuter may greatly appreciate the opportunity to easily grab a coffee and something to eat on the way to a rapid transit station. If the coffee shop is easy to access via walking (and conversely hard to reach by driving because of congestion, lack of parking, etc.), this would positively influence the selection of walking over driving to the station, all else considered equal. Arguably an individual needs only one (perhaps two) coffee shops to satisfy their personal service utility needs. And while they may pass several along their journey to access the rapid transit station, they are likely indifferent to whether there are three coffee shops or thirty along their individual access corridor. Therefore it makes sense to code such a land use activity as a dummy variable.

### Traveler Perception: The Land Use Activity Connection

The *utility* of a land use activity likely changes throughout the course of a day and for differing trip purposes. And when a land use activity does not directly satisfy an individual's personal service utility, its influence could shift toward shaping an individual traveler's *perceptions* of the urban environment. For example, depending on whether a restaurant specializes in breakfast, lunch, or dinner, its utility would likely change throughout the day. Therefore, for land use categories such as the amount of land in public rights-of-way (ROW), parking lots, and other non-personal service uses, the Land Use Proportions measure (LUP) is used as a person walking would likely cognitively consolidate their *perceptual* sense of these areas.<sup>41</sup>

#### 3.3.3 Quantifying "Perceptual Qualities of the Urban Environment"

# Measuring the "Unmeasurable": <sup>42</sup> Validity and Meaning

"Perceptual qualities of the urban environment" have for a while been believed to matter to the quality and walkability of our street environments (Ewing et al., 2006; Ewing & Handy, 2009). Early work on understanding perceptions, and how they may attract people out of their vehicles, Appleyard (1981) finds auto traffic to be a particularly strong deterrent to empowering non-drivers to fully engage with the environment around streets. He also finds that urban environmental features such as street widths, building setbacks, trees/vegetation, the placement of parking, views, and lighting also affect street life, positing that street livability attract more people to the street environment, thus showing how a positive "perceptual" qualities becomes self-reinforcing. Furthermore Dumbaugh (2005) and Ewing & Dumbaugh (2009), find that "livable streetscape" elements, such as buildings with visually complex facades, buildings located closer to the street (often found in older districts which, in turn, often are composed smaller parcel sizes), and trees planted near the street cause drivers to slow down and drive more carefully, thereby actually *increasing* the street's safety for all users, which theoretically would entice more people out of their cars and possible walk or bicycle. Ultimately, Jacobsen's (2003) research concludes that there is indeed "safety in numbers," finding that collision rates decline as the number of pedestrians and bicyclists present in the street environment increases. Drivers apparently travel with more care when they expect people to be on and around the street, so streets with more people are safer than those devoid of people and activity—again reflecting this self-reinforcing phenomenon of street safety and livability. In sum, this body of research shows how the influence of building form can instill safer driver behavior, and thus emanating a positive perceptual sense of the street environment's safety and livable, which, by extension, likely attracts more people, again both creating and reinforcing its positive perceptual identity.

<sup>&</sup>lt;sup>41</sup> The IAC Land Use Distance (LUD) measure may be a promising alternative when comparing auto and non-auto modes over longer trip distances. Limiting the network distance for this sample to five miles, makes the use of the land use proportions (LUP) measure sensible, as it presents a lower threat of multicolinearity with the *network distance* measure used in the predictive models.

<sup>&</sup>lt;sup>42</sup> Ewing & Handy (2009).

## Background and Previous Approaches

Although capturing the "perceptual qualities of the urban environment, or urban design" that are believed to matter to walkability have been perhaps the hardest dimension to uniformly quantify, focused efforts have been made by (Ewing et al., 2006; Ewing & Handy, 2009) as discussed in Chapter 2.

## Approach in this Dissertation: Use of Parcel Geometry

In the past 10 years, with advances in technology, parcel geometry has become increasingly recognized as a useful measure of urban form (Lee, Moudon, & Courbois, 2006; Hess, Vernez Moudon, & Logsdon, 2001; Owens, 2005). Furthermore, Ewing & Handy (2009) report that urban theorists recognize how narrower buildings, as would be associated with smaller parcels, "define human scale." Using parcel geometry as a measure of the built environment makes sense: smaller parcels are likely to be related to older subdivisions, which: 1) are likely to have older houses and retail stores; 2) are often smaller (giving them a *human scale*); 3) are located closer to the street (giving the street environment more *imageable*); 5) have buildings with detailed fenestration, emanating a sense of *complexity* and "visual richness."

As well as overcoming the problems of subjectivity bias and lack of uniform quantification inherent in measuring urban design elements (Ewing et al., 2006; Ewing & Handy, 2009), parcel geometry can serve as a more objective, replicable measure. From the policy perspective, using parcel geometry as a measure of the urban environment is advantageous, as parcel size can readily be written into zoning and subdivision ordinances, supporting its *validity* for use in consumer behavior research. Finally, it is a measure that can rate respectably high on all 3R methodological development principles.

The following measures of parcel geometry were considered for this research: 1) a distance-to-parcel ratio, 2) the actual number of parcels along a route, and 3) the average parcel size. Average parcel size (APS) was the measure ultimately chosen for this research. When using APS, it is important to base it on land uses that closely align with the massing and scale and location of building form, as illustrated in the example of capturing the parcel for the entire University of California at Berkeley Campus.<sup>43</sup>

<sup>&</sup>lt;sup>43</sup> Using all parcels, regardless of land use type, will prove problematic as large institutional parcels will confound the attainment of the intended measures of building form. In this case, these are the qualities of imageability, enclosure, and complexity would not be reflected.

A solution to this problem is to 1) Combine land use data with the parcel spatial geometry. This required gathering land use data (in this case from ABAG) and combine it with parcel GIS files (in this case from the Alameda and Contra Costa County Assessor's offices); 2) Examine all land use categories selecting the land uses that best reflect building form. In this case, residential and retail parcels were chosen.

The average parcel size (APS) along the respondent's estimated IAC route is calculated as follows:

- 1. Create an IAC buffer of a particular size around the respondent's estimated route.
- 2. Select the parcels within and intersecting with the IAC buffer. This means that the square footages of large parcels were captured, even if just a small portion intersects with the IAC buffer.<sup>44</sup>
- 3. Calculated the combined square footage of all the parcels, and then divide that total by the number of parcels selected, to arrive at the average parcel size (APS) of the IAC.

# Problems Encountered Using Parcel Geometry

Following the calculations for *all* parcels, regardless of land use type, proved problematic. As shown in Figure 3-4, large institutional parcels in Berkeley belonging to the University of California actually confounded the attainment of the intended APS measure. In this case, mostly the qualities of imageability, enclosure, and complexity would not be reflected.



Figure 3-4: Issues Associated with Calculating Average Parcel Size.

The red (darker) lines in this map show the estimated routes of survey respondents who may have travelled near or through the UC Berkeley Campus. The APS calculations for these individuals captured the large parcel size of the campus, skewing the APS measure away from its intention to capture "perceptual" measures of urban environment such as *human scale, enclosure,* and *complexity*.

<sup>&</sup>lt;sup>44</sup> This is justified on the basis that the building form perceived by the individual would be reflected along the edges of a parcel, even if it is only partially within the buffer. The alternative of taking just a portion of the parcel in the buffer would lower the variance in APS from one individual's route to the next, which seems to undermine the purpose of the measure and the intent for it to be representing the unique experience of an individual.

A solution to this problem is to: 1) gather land use data (from ABAG) and combine it with parcel GIS files (from the Alameda and Contra Costa County Assessor's offices); and then 2) to go through all land use categories, selecting the land uses that best reflect the building forms embodying important perceptual measures of urban environment. For this task, residential and retail parcels are used.

Table 3-1 shows the 3R principles evaluation of the average parcel size measure.

Table	3-1:3	R Princip	les Evalua	ition of A	Average I	Parcel Size	Measure.

Principle	Rating	Discussion
Resolution	High	
Respondent	Moderate	Estimate of likely shortest path
Replicability	High	

### Recommendations for Future Studies

A better alternative, had it been available for entire study area, would have been to use digital building footprint information. Inquiries were made about this to several sources, but the data were not yet available for the entire study area. In the future, this is a promising source of information to consider using.

## **3.3.4 Transport Access**

### Distance

Obtaining accurate impedance measures of network distance and/or travel time is important for multinomial logit models, as these models require as much knowledge as possible on the costs associated with travel (in this case distances or travel time) for all *relevant* modal alternatives, and for all respondents, whether they chose that mode or not.

## Previous Approaches

"Distance to Transit" has emerged more recently as an important measure among other D-Variables (Ewing & Cervero, 2010). However, impedance measures of network distance, especially travel time, are often difficult to obtain in a uniform fashion. Many previous studies rely on straight-line distance calculations between different zones of aggregation, either from one traffic analysis zone (TAZ) centroid or, in some cases, one census tract to another.<sup>45</sup>

### Approaches in this Research to Measure Network Distance

As each individual 2008 BART Station Profile Survey provided the location of the intersection nearest their home origin, this research calculated the network distance, using a non-standard batch procedure which included pairing the geo-coded home origins with the station destinations and then using ESRI's Network Analyst's "Route Solver". Geo-locating the routes for these thousands of survey respondents is a key step in this research — supporting the measurement of other urban form characteristics through the tailored use of a variety of buffer selection procedures, as outlined earlier.

## Limitation of Network Distance Measure

In exploring and testing these new methods, an assumption is made that people would take the shortest possible route to get to a transit station. As this research is looking at time-sensitive morning commutes to work, this assumption seems reasonable. Follow-up telephone or email surveys to respondents can be useful in achieving greater accuracy in route estimates.

Principle	Rating	Discussion
Resolution	High	
Respondent	Moderate	An estimate of likely path assuming shortest route.
Replicability	High	

Table 3-2: 3R Principles Evaluation of Network Distance Measure.

<sup>&</sup>lt;sup>45</sup> When estimating routes on any geospatial network, thoughtful accommodation of the specific needs of each mode is needed. This research avoided these problems by conducting an extensive review, correction, and then programming of the entire network to keep erroneous route estimates from occurring (e.g., estimating routes for bicyclists and pedestrians onto freeways, or estimating motor vehicles onto dedicated bicycled/pedestrian paths).

## Recommendations for Future Studies

In order to more accurately estimate the likely path respondents use to access transit, which could have linked trips along their way (such as dropping off kids at school or partners at work, or just stopping at a coffee shop), future BART station profile surveys may want to consider questions to capture this information with geo-coded locations of these linked trips.

## Calculation of Bus Travel Paths and Times

For years, transportation modelers in travel behavior research have faced challenges in capturing accurate bus transit travel time measures. This research approached this problem from a completely new angle by tapping into digital databases of transit schedules, working in coordination with the leading computer scientist directing the development of Google Transit.

To arrive at these estimates, this research took advantage of knowing the time a BART Station Profile Survey respondent was surveyed to have arrived at the BART station. Working through a dynamic connection to the schedules (via Google Transit), a "back-casting" calculation was made determining where and when that person would have had to take a bus to get from their home origin to the destination station. As well as providing schedule based estimates of in-vehicle bus-times, this method also estimated the time it would take a person to walk from their home origin to the bus stop itself—a measure rarely, if ever capture in conventional transportation demand modeling. Key missing pieces of information are: 1) the time a person would likely wait for the bus to arrive; and 2) what mode they actually used to access the bus stop . Table 3-3 shows the 3R principles evaluation of these electronic schedule bus travel time estimates.

Principle	Rating	Discussion
Resolution	Moderate	Requires capturing arrival time at station. Does not include time waiting, or bus access mode.
Respondent	Moderate to High	
Replicability	High	

Table 3-3: 3R Principles Evaluation of Electronic Schedule Bus Travel Time Estimates

## Recommendations for Future Research

For electronic schedule estimates of bus travel time, it is important to make sure that the time captured in the survey matched the actual time the survey respondent arrived. Furthermore, key missing pieces of information are: 1) the time a person waits at the stop for the bus to arrive; and 2) the actual mode a person uses to access the bus stop. Future survey protocols could be designed accordingly.

### Walkability and Route Directness

Neighborhoods designed with curvilinear streets and cul-de-sacs that lack direct walking paths have low route directness, whereas areas with straight streets and shorter walking distances have high route directness and are more pedestrian friendly.<sup>46</sup> Furthermore, Ewing & Cervero (2010) find walking trips to most strongly associated with intersection density (as well as land use mixture, jobs-housing balance, and distance to stores). Table 3-4 shows the 3R principles evaluation of standard zonal measures of intersection density.

Principle	Rating	Discussion
Resolution	Moderate to Low	Zonal aggregation
Respondent	Moderate to Low	Zonal average is uniformly applied
Replicability	High	Data readily available

Table 3-4: 3R Principles Evaluation of Intersection Density Measures.

<sup>&</sup>lt;sup>46</sup> Ewing & Handy (2009) also find "long sight lines" associated with gridded streets to be one of the most significant elements defining "human scale."

# Approaches in this Research to Measure Route Directness: Straight-Line to Network Distance ratio (SL2ND)

Dill (2003) determines that one of the best individual measures to capture route directness is the ratio of the network distance to the straight-line distance.<sup>47</sup> This dissertation, however, determined through trial and error that it would be best to divide the straight-line distance by the network distance, creating a 0-1 measure of route directness.<sup>48</sup> The closer to 1, the more closely aligned are the network and the path distances, and thus the route between home origin and station destination is more direct. A sample of how these calculations are made for stations in Oakland, CA, is shown in Figure 3-5 below.



Figure 3-5: Straight-Line to Network Distance Distance Ratio Table 3-5 shows the 3R principles evaluation of the route directness measure.

Principle	Rating	Discussion
Resolution	Moderate to High	
Respondent	Moderate to High	Based on respondent's statement of nearest intersection and estimate of network route
Replicability	High	

Table 3-5: 3R Principles Evaluation of the Route Directness Measure.

<sup>&</sup>lt;sup>47</sup> Another major study using a similar route directness measure, a 0-1 scale measuring shortest street distance/straight-line distance, is Cervero et al. (2009a).

<sup>&</sup>lt;sup>48</sup> This ratio was calculated using the following steps:

<sup>1.</sup> Each individual respondent to the 1998 and 2008 BART Station Profile Surveys provided the location of their home intersection nearest the transit station.

<sup>2.</sup> ESRIs Network Analyst was used to calculate the network distance, through a non-standard batch procedure which including pairing the geo-coded home origins with the station destinations.

<sup>3.</sup> Building on the above procedure, the straight-line distance was calculated.

# **3.4 Independent Variables**

Building on the above discussion, the final set of new measures to be examined for their influence on rapid transit access travel behavior is presented in Table 3-6 below.

UE Component	Variable/Measure (for AM Commuters to Transit)	Measure (for AM Commuters to Transit)	Expected influence bicycling (b), walking (w), and/or bus (bus)	
	1 = Parking Fees at Station	Car parking payment	+ (b,w)	
S S S S S S S S S S S S S S S S S S S	1= Parking saturation at Station (and within ½ mile a) saturates during AM Commute	Parking availability	- (b,w)	
Acce	Number of Bike Parking Spaces	Bicycle amenities	+ (b)	
ansport	# of parking spaces at station and within $\frac{1}{2}$ mile around station	Car amenities	- (b,w,bus)	
Ĕ	Est. Travel Time of Bus Trip (minutes)	Travel cost (bus)	- (bus)	
	Network Distance (miles)	Travel cost (distance)	- (b,w)	
tions	Straight Line to Route Network Distance Ratio	Route Directness/Connectivity	+ (b,w)	
Percep	Average Parcel Size (sq. ft.) Human Scale, Enclosure, Complexity, and Development Intensity		- (b,w)	
	Proportion Retail/Wholesale	Personal Service Utility	- (b,w)	
ity	1= Res/Comm Mixed Use/ Small Retail	Personal Service Utility	+ (b,w)	
Activ	Proportion Educational/Religious/ Community Instit.	Personal Service Utility	+ (b,w)	
	Proportion Employment Centers	Personal Service Utility	+ (b,w)	
ity/ tions	Proportion Parking Lot	Perceptual Utility	- (b,w)	
Activi	Proportion ROW	Perceptual Utility	- (b,w)	
Pe _	Proportion Urban Park	Perceptual Utility	- (b,w)	
unity/ tes	1= High Income (over 75K)	Income	- (b,w)	
portu	1= Low Income (less than 25K)	Income	+ (b,w)	
o Op ial At	1 = Male	Gender	+ (b,w)	
ess tu irson	Number in HH	Household Size	+ (b,w)	
Acce	1 = "Car Available for Trip Today"	Car availability	- (b,w)	

Table 3-6: Independent Variables of Final Model

# **3.5 Summary and Conclusions**

This chapter addresses the primary goal of this research: to develop and test new methods to capture high-*resolution* information of the urban environment that can be uniquely attributed to each individual survey *respondent* in a *replicable* manner that, in turn, supports valid, rigorous and generalizable analyses of the influence of the urban environment on consumer behavior. The central evaluative framework, based on the 3R principles of *resolution, respondent*, and *replicability*, is used throughout to evaluate new and old methods to measure the urban environment. The development and testing of these new methods and measures is grounded by the real-world problem presented within the secondary goal of this research: to test the relationship of these new measures toward understanding their influence on rapid transit access travel behavior, using a relatively standard intercept travel survey, the 2008 Station Profile Survey for the San Francisco Bay Area Rapid Transit (BART) system.

This chapter shows it is possible to capture high-*resolution* information of the urban environment that can then be uniquely attributed to each individual survey *respondent* in a *replicable* manner. Specific achievements related to the primary goal of this research include the following:

- This research uniquely examines the intermediate area of a trip between its origin and destination, the IAC.
- This research enriches our understanding of how to measure and analyze land use activity, beyond the currently used measure of entropy as a proxy for mixture of land uses. Specifically, this research tests the best methods for managing vast amounts of specific, parcel-level land use information toward meaningful analyses of consumer behavior.

In closing, this new capacity to capture high-*resolution* information of the urban environment for each individual survey *respondent* in a *replicable* manner opens the door to greater research possibilities, as explored in the next chapter, where the usefulness of these new measures are applied to a predictive model of travel behavior. This exercise tests and further refines the usefulness of these new measures for consumer behavior research, as well as to gain insight into design and policies that support environmentally beneficial rapid transit access.

# **Chapter 4: Testing the New Measures: Individual Access Corridor Analysis of Rapid Transit Stations**

The main objectives of this chapter are twofold: 1) to further explore the usefulness (*reliability* and *validity*)<sup>49</sup> of these final candidate variables by pragmatically applying and testing them in multinomial logit (MNL) predictive models of rapid transit access mode choice, refining and selecting a final set; and 2) to use them to further our understanding of how the urban environment itself may shape environmentally beneficial rapid transit access travel behavior.

The achievement of these two objectives is facilitated by the process of testing the following operational hypothesis, referred herein as the *urban environment/transit access* (UETA) hypothesis:

During a person's morning commute via a non-CBD rapid transit station, components of the urban environment (land use activity, transport access and traveler perceptions) significantly influence rapid transit access travel behavior, controlling for personal socioeconomic attributes.

While many different geospatial datasets are used, as discussed in Chapter 3, this analysis pivots primarily on information from a relatively standard intercept travel survey — the 2008 Station Profile Survey for San Francisco Bay Area Rapid Transit (BART) system. Most importantly, these data provide information on the mode, home origin, station destination, as well as the time an individual of arrived at a particular station.

<sup>&</sup>lt;sup>49</sup> In this chapter, measurement *reliability* is established by evaluating the performance of these new measures via numerous multinomial logit (MNL) model runs, testing to see whether fairly comparable results are obtained when relatively similar experiments are repeated. *Validity* is addressed by an in-depth examination of the results to test whether they are sensible and usefulness toward testing a specified research hypothesis.

## 4.1.1 Descriptive Statistics: Characteristics of the Sample Stations and Population

To test the urban environment/transit access (UETA) hypothesis of this research, and in turn the usefulness of the new IAC measures, careful thought was put into selecting the sample of station destinations, as discussed in Chapter 3, which in turn determined the sample population. First, to support a fair comparison between the choice of an auto or non-auto rapid transit access mode, the sample of 2008 BART Station Profile Survey respondents was limited to individuals who traveled no more than 5 miles (network distance) to reach a station. This distance was selected to balance the need to have as many respondents as possible, while maintaining a reasonable distance that could be traveled by a bus or bicycle (representing a "green" transportation mode option). Secondly, to test the effectiveness of the online Google Transit schedules, the sample was limited to those areas where transit providers made that information readily available. In the end 18 stations were chosen, located in the inner (western) portions of San Francisco East Bay Area counties (Alameda and Contra Costa).

As parking at the station is one of the key criteria for inclusion, the following is a breakdown of the number of parking spaces on, and surrounding the transit station:

- The median number of parking spaces at these stations was 892.
- The median number of parking spaces within a 1/2-mile radius of these stations was 1,242.
- The median total of parking spaces within a 1/2-mile radius of the stations in this sample (including spaces owned by the transit system) was 2,336.

Table 4-1 below shows the breakdown of the distances survey respondents walked to their respective stations.

Entry Station	08 Walk Median	08 Walk Count	08 Bike Median	08 Bike Count
Union City	0.73	88	2.03	3
Fremont	0.70	208	2.19	5
Castro Valley	0.70	38	1.54	4
Coliseum	0.68	69	N/A	N/A
South Hayward	0.67	49	2.68	4
Richmond	0.63	171	2.50	2
North Berkeley	0.60	420	0.94	42
Bay Fair	0.60	90	1.27	2
El Cerrito Plaza	0.56	387	1.01	33
San Leandro	0.55	159	1.27	6
Fruitvale	0.54	146	1.91	29
MacArthur	0.53	307	0.87	28
El Cerrito Del Norte	0.52	112	1.05	11
Hayward	0.50	133	3.25	2
Rockridge	0.47	448	0.65	22
Ashby	0.46	439	0.83	44
West Oakland	0.45	121	1.82	21
Lake Merritt	0.27	716	1.29	24

Table 4-1: Distances 2008 Survey Respondents Walked or Bicycled to Inner San Francisco East Bay BART Stations.

The sample population for the final model included 6,122 respondents<sup>50</sup>, 943 (15%) of whom identified themselves as either Black or Hispanic/Latino and not White.

The following is a list of key descriptive statistics for the final sample:

- The median entry time was 8:15 AM, near the middle of the morning peak.
- The median average parcel size (APS) encountered along a respondent's individual access corridor (IAC) was 13,331 square feet, slightly more than a quarter-acre lot, thus reflecting the suburban nature of many of these access corridors.
- The median straight-line-to-network-distance ratio is 0.790839 (1 equals a straighter, more direct route to the station), reflecting that the street networks associated with these IACs provide relatively direct paths and connectivity.

Table 4-2 shows the Number of individuals in the sample, by mode and percentage of total. As these are commuters traveling to stations with parking, it is expected that there would be relatively fewer people who accessed the system by bus.

Mode	Count by Mode	Percentage of Total
WALK	2,157	35.23%
BIKE	492	8.04%
BUS	116	1.89%
CAR	2,848	46.52%
CARDO	509	8.31%
Grand Total	6,122	100.00%

Table 4-2: Number of individuals in the sample, by mode and percentage of total.

Table 4-3 shows the median, minimum, and maximum distances people were surveyed to travel to all BART stations, during their morning commute to work. Distances are based individual geo-spatial street network estimates , between a respondent's home origin and the station where they were surveyed. This table shows that the bicycles are well represented in the sample of the final model. This is important As one of the main goals of this research is to better understand UE influences on bicycle behavior. Of interest is that the median distances for bus riding (1.45) or bicycling (1.13) to access transit are roughly equivalent, indicated the opportunity for substitution between these modes. Furthermore, the fact that the maximum distance observed for a bicyclist traveling to a BART station is almost 5 miles supports its use of the outer limits of the sample population.

Stationio								
Mode	Median	Minimum	Maximum	Count				
WALK	0.52	0.02	2.98	3931				
BIKE	1.13	0.04	4.88	530				
BUS	1.45	0.04	4.99	1409				
CAR	2.06	0.03	5.00	3750				
CARDO	1.53	0.03	4.99	1067				

Table 4-3: 2008 AM Commute Distances (miles), by mode (under 5 miles) for all BART Stations

<sup>&</sup>lt;sup>50</sup> The final model used information for 5,694 of these respondents.

## 4.1 MNL Modeling

Multinomial logit (MNL) modeling is used in this research to estimate the likelihood of an individual choosing a specific rapid transit access mode out of a set of five choices: walk (*WALK*), bicycle (*BIKE*), ride a bus (*BUS*), drive a car alone (*CAR*), or be driven and dropped off (*CARDO*). MNL models are based on the basic theory that each traveler *n* is assumed to have a set of travel mode choices, each with its own utility  $U_{in}$  which is the utility of the *i*th mode for the *n*th traveler (Ben-Akiva & Lerman, 1985; Train, 2003). Furthermore, each traveler's utility is assumed to consist of an observed component  $V_{in}$  plus an unobserved component  $\varepsilon_{in}$ . Error terms are assumed to be independently, identically distributed (i.i.d.) Extreme Value. The observed component *V* is a function of the constant for the *i*th mode, the beta parameter estimates, the unique urban environmental (UE) factors (land use activity, transport access, and perceptions), and the personal attribute variables (PATs) for the *n*th traveler (e.g., gender, income, race, etc.). Below is a representation of the MNL model used in this research to determine the probability of a person choosing to drive a car alone (CAR) to access rapid transit.

$$P(CAR_n) = \frac{e^{V_{CARn}}}{e^{V_{WALKn}} + e^{V_{BIKEn}} + e^{V_{BUSn}} + e^{V_{CARn}} + e^{V_{CARDON}}}$$

where:

 $V_{in} = \text{Constant}_i + \beta_1' UE_{in} + \beta_2' PAT_n$ 

i = mode;

n = decision maker;

 $\beta_i' =$  a row vector for the unknown parameters of the urban environment (*UE*) variables;  $\beta_2' =$  a row vector for the unknown parameters of the personal attribute (*PAT*) variables;  $UE_{in} =$  a column vector for the urban environment variables (land use activity, transport access and traveler perceptions) for each alternative mode *i* and each decision maker *n*;  $PAT_n =$  a column vector for the personal attribute variables of each decision maker *n* (gender, income, race, etc.).

#### 4.1.2 Model Results

Using BioGeme<sup>51</sup> software, about 100 MNL models were run with varying combinations of variables. This process provided insight into what might be the best practices for dealing with the measures developed in this research. The final model (which included 5,694 survey respondents, and achieved an adjusted rho-squared of 0.558) is shown in the Table 4-4 below.<sup>52,53</sup>

<sup>&</sup>lt;sup>51</sup> Bierlaire, M. (2003). BIOGEME: A free package for the estimation of discrete choice models, Proceedings of the 3rd Swiss Transportation Research Conference, Ascona, Switzerland. For more information also see the Biogeme tutorial, Bierlaire, M. (2008). An introduction to BIOGEME Version 1.6, biogeme.epfl.ch

<sup>&</sup>lt;sup>52</sup> Please note all "P-Values" reported in this dissertation are *robust* P-values.

<sup>&</sup>lt;sup>53</sup> Considering the results of about 100 model runs, results of the final model specification stayed relatively consistent (reliable), withstanding changes to the number of observations, varying variable and parameter combinations, etc., indicating robust model qualities.

		BIK	E	BUS	S	CAR	2	CAR	00	WA	LK
UE Component	Variables	Parameter	Robust P-value	Paramotor	Robust P-value	Parameter	Robust P-value	Parameter	Robust P-value	Parameter	Robust P-value
Component	Constant	3.00	0.00**	-6.32	0.00*	Base	1 -value	0.845	0.18**	6.93	0.00**
	1 - Darking Ecco at Station					-0.507	0.00**	-0.260	0.14*		
	I - Parking rees at Station					0.007	0.00	0.200	0.11		
	1 = Parking Fills AM Commute					0.812	0.00**	-0.200	0.46		
Transport	# Bike Parking Spaces	0.00474	0.00**								
Access	# Parking Spaces at and ½ mile around Station					0.000862	0.00**	0.000446	0.00**		
	Est. Travel Time of Bus Trip (min.)			-0.00105	0.96						
	Network Distance (miles)	-1.06	0.00**					0.0879	0.09**	-4.01	0.00**
Trans. Acc. (Design)	Straight-Line-to-Network-Distance Ratio (closer to 1 = more direct)	0.443	0.27	5.68	0.00**			-0.234	0.57	3.68	0.00**
Perception (Density)	Average Parcel Size (10,000 sq. ft.)	180	0.01**	.0313	0.33			0218	0.32	109	0.00**
	Retail/Wholesale	0.583	0.45	6.60	0.00**			1.42	0.06**	0.501	0.42
Activity	1 = Res/Mixed Use/Small Retail	0.627	0.00**	-8.26	0.00**			-0.0982	0.62	0.483	0.00**
(Diversity)	Prop. Ed/Relig./Communty Instit.	-0.305	0.89	-2.67	0.64			-3.35	0.13*	-4.47	0.01**
	Proportion Employment Centers	-2.10	0.21	-0.600	0.86			-0.389	0.74	1.23	0.37*
	Proportion Parking Lot	-13.7	0.00**	12.6	0.17*			-2.84	0.52	-9.63	0.01**
Activity/	Proportion ROW	0.726	0.20*	3.80	0.06**			0.924	0.07**	-3.42	0.00**
rerection	Proportion Urban Park	2.72	0.32	2.63	0.63			4.04	0.02**	3.13	0.22
	1 = High Income (Over 75K)	-0.466	0.00**	-0.651	0.15**			-0.0904	0.48	-0.315	0.01**
	1 = Low Income (less than 25K)	1.30	0.00**	1.30	0.00**			0.478	0.04**	0.832	0.00**
Access to Opportunity	1 = Male	1.39	0.00**	-0.414	0.31			-0.202	0.10**	0.699	0.00**
	Number of People in Household	0.0115	0.40	0.0540	0.61			0.0256	0.06**	0.0112	0.49
	1 = "Car Available for Trip Today"	-2.23	0.00**	-3.02	0.00**			-1.78	0.00**	-2.35	0.00**
	1 = Black or Non-White Hispanic	-1.28	0.00**	-0.105	0.80			0.0730	0.64	-0.0390	0.81
Number of individuals:     5694     † Robust P-Values: ** < 10%; *10% to 20%       Adjusted rho-square:     0.558											

Table 4.4: Final MNL	Model of 2008BART	Station Access I	Mode Choice
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# 4.2 Discussion of Findings

## 4.2.1 Land Use Activity

## Small Retail/Mixed Use Developments along Individual Access Corridors

The final model results reveal several interesting findings. As shown in Table 4-5 below, the presence of mixed-use/small retail<sup>54</sup> opportunities (which includes coffee shops) has a significant positive association with the likelihood one will use a NMT mode such as walking or bicycling to access a BART rapid transit station. This finding supports the idea that the ability to satisfy a personal service utility as part of the morning commute, such as getting a cup of coffee, matters to walking and bicycling rates, thereby supporting environmentally beneficial behavior.

	BIKE		BUS		CARDO		WALK	
Land Use Activity	Param.	P-value	Param.	P-value	Param.	P-value	Param.	P-value
1 = Mixed Use/Small Retail	0.627	0.00	-8.26	0.00	-0.0982	0.62	0.483	0.00

Table 4-5: Results for Mixed Use/Small Retail along IACs.

Interestingly, there is a significantly negative association between mixed uses/small retail and riding a bus or being dropped off at a station. This makes sense, as travelers would unlikely want to get off and back on a bus, to satisfy a personal service need, especially during the time-sensitive morning commute. The same is true for a driver who would have to go through the process of finding a parking space. And while in downtown settings one would expect the opposite to be true (more bus riding associated with greater mixture of land uses), we need to take a step back and remember that the trips in this study are to non-CBD rapid transit stations with parking.<sup>55</sup>

### Proportion of Employment Centers along Individual Access Corridors

The presence of employment centers has a positive, although somewhat weak, association with the likelihood one will walk to a transit station for the morning commute. Interestingly, there is a weak negative association with the likelihood one will bicycle, and a very weak negative association with the likelihood one will ride a bus or be dropped off at the station. One explanation could be that people having access to communities rich in work opportunities via these modes (bicycling, bus riding or being dropped off) would likely not have to use a rapid transit system to reach their job. A common, unique factor shared by these modes is that they involve vehicles that do not

<sup>&</sup>lt;sup>54</sup> As discussed in Chapter 3, it is sensible to employ land use dummy variables to represent the mere presence of a particular land use opportunity that can fulfill a personal service need.

<sup>&</sup>lt;sup>55</sup> Parking scarcity, congestion, and the like may also be factors associated with mixed use/small retail land uses in non-CBD and CBD stations, further encouraging walking and bicycling.

require car parking spaces, which are often scarcer and more expensive near employment centers.

Furthermore, there is a need to recognize how the classification of the mode a person uses to access rapid transit (or any other destination for that matter) may itself transform as one travels through his or her individual access corridor. For example, a driver could drop another person off at their place of work along the driver's IAC, becoming a solo driver as they move on to the transit station. In future intercept travel surveys, it may be worth asking an additional question regarding this possibility. In the case of walking, these employment land uses may benefit an individual's personal service (or positive perceptual) utility during their morning commute (discussed in Chapter 3).

## Proportion of Retail/Wholesale Businesses along Individual Access Corridors

Retail/wholesale business has a statistically weak, positive association with walking and bicycling, and a statistically strong positive association with drop-offs and riding the bus to access rapid transit, as shown in Table 4-6 below. The fact that bus routes often travel along commercial corridors may explain part of this association. People walking and bicycling may appreciate some utility traveling along retail, commercial corridors, similar to what is found with small retail/mixed use activities. However, this positive association may not be as statistically strong, as this land use category includes auto-oriented retailers and wholesalers who likely provide lower levels of personal service utility to morning commuters and likely much lower levels of positive perceptual utility to people walking or bicycling.

	BIKE		BUS		СА	RDO	WALK	
Land Use Activity	Param.	P-value	Param.	P-value	Param.	P-value	Param.	P-value
Proportion Retail/ Wholesale	0.583	0.45	6.60	0.00	1.42	0.06	0.501	0.42

Table 4-6: Results for Retail/Wholesale Businesses along IACs.

# Proportion of Educational, Community, and Religious Institutions along Individual Access Corridors

Relative to driving, as shown in Table 4-7 below, bus-riding, bicycling and station drop-off s are found to have a negative association with the proportional presence of educational, community, and religious institutions along the access to rapid transit, reflecting a certain disutility these uses serve to people traveling by these modes during the morning commutes. As the habit of walking to school has been replaced over the years by children being chauffeured by their parents, these results may be picking up some of this trend. Because of concerns about threats to their children's safety from traffic and/or stranger danger or simply because of convenience, parents with schoolchildren have a number of additional reasons to drive during the morning commute. After dropping off their children, they may then go on to the transit station as a solo driver (another example of how modes may transform along IACs). The positive, although slightly weak association with the likelihood one will walk to access rapid transit, may reflect a walk-to-school/walk-to-transit connection, supporting policies to colocate schools near transit services. It may also reflect the positive impact that

educational, community, and religious institutions have on the perceptual quality of the walking experience.

	BIKE		BUS		CARDO		WALK	
Land Use Activity	Param.	P-value	Param.	P-value	Param.	P-value	Param.	P-value
Proportion Ed/Religious/ Community Institutions	-2.10	0.21	-0.600	0.86	-0.389	0.74	1.23	0.37

Table 4-7: Results for Educational, Community, and Religious Institutions along IACs.

## 4.2.3 Traveler Perceptions

Many earlier studies of travel behavior and the built environment have found mixed results regarding "micro-design elements," with the body of quantitative, statistical research showing such things as land use mix as more influential (Ewing & Cervero, 2010). Other, more qualitative research (Agrawal et al., 2008; Bosselmann, 2008; Isaacs, 2001; Park, 2008) has found perceptual qualities to still be important, although these studies lacked large enough sample sizes to say this with great confidence.<sup>56</sup> The aim of this research has been to provide measures (albeit proxies) representing perceptual qualities of the urban environment.

# Land Use Activity and Traveler Perceptions

Many of these measures likely overlap between the three components of the urban environment presented in this dissertation (land use activity, transport access and traveler perceptions). If, for example, a certain land use activity doesn't serve a direct personal service utility (during that particular time of travel), then its utility toward influencing mode choice might become more associated with the "perceptual qualities of the urban environment"(Ewing et al., 2006; Ewing & Handy, 2009). When a land use activity clearly cannot clearly serve a personal service utility, for a particular mode during a morning commute (e.g., a parking lot has little positive personal service utility for a person walking or bicycling, and likely has a negative "perceptual" value). Thus, the following findings about IAC land use activities are recognized more for their influence on rapid transit access mode choice through their influence on an individual's perceptions.

<sup>&</sup>lt;sup>56</sup> In an effort to move towards a resolution between these two bodies of research, this study captures land use activity categories that are specified at the parcel-level via a new spatial unit of analysis (individual access corridors) as opposed to zonal (TAZs) circular buffers around the origins and destinations of a person's trip) in an attempt to capture the more detailed and nuanced qualities of land use activity that play an important role in influencing a person's perception of the urban environment, also referred to as "urban design."

## Proportion of Public Rights-of-Way (ROW) along Individual Access Corridors

Public rights-of-way (ROW) include all the land area that is associated with roadway transportation: streets, freeways, interchanges, and adjacent public land. Thus, this variable can possibly serve as a proxy for such things as road width, number of lanes, and by extension, traffic volumes, vehicle speeds, and localized nuisances from noise to pollution, etc. For example, the larger the ROW, the wider the streets, the faster the vehicles travel, the greater the vehicle volumes, the greater the annoyances of noise and air pollution. For these reasons, ROW can also serve as a proxy for street livability (D. Appleyard, 1981). Interestingly while ROW was significantly negatively associated with walking, it was positively, although more weakly, associated with bicycling. This may indicate how bicyclists, as vehicle operators, are more accepting than pedestrians of wider streets, faster traffic, etc.<sup>57</sup> This may be also due to the fact that a large section of the BART right-of-way between the North Berkeley and El Cerrito Del Norte stations accommodates the Ohlone trail, which accommodates bicyclists (and pedestrians) very well. The results for public rights-of-way are shown in Table 4-8.

	BIKE		В	US	CA	RDO	WALK	
Land Use Activity/ Perceptions	Param.	P-value	Param.	P-value	Param.	P-value	Param.	P-value
Proportion ROW	0.726	0.20 *	3.80	0.06 **	0.924	0.07 **	-3.42	0.00
Proportion Parking Lot	-13.7	0.00 **	12.6	0.17 *	-2.84	0.52	-9.63	0.01

Table 4-8: Results for Public Rights-of-Way along IACs.

# Proportion of Parking Lot Land along Individual Access Corridors

Strong negative associations between the likelihood of walking or bicycling along access corridors with large proportions of parking lot land confirms the notion that parking lots create hostile and unfriendly environments to people either walking or bicycling. For pedestrians, the issue could be one of poor perceptual quality and/or low opportunities for servicing personal needs. Bicyclists could have similar issues, but with the added threat posed by drivers entering and exiting driveways – a serious issue to bicycle safety. Furthermore, parking lot land proportions could conceivably serve as proxy measure for the traffic volumes confronted by non-motorized travelers.<sup>58</sup>

## Proportion of Urban Parkland along Individual Access Corridors

As would be expected, the proportion of an IAC that is in urban parkland is positively associated walking and bicycling, although this association is perhaps weaker than one would anticipate. One explanation may be that during this time urban parkland may serve a lower utility than it would at other times of the day and for other trip

<sup>&</sup>lt;sup>57</sup> On the whole this supports the emerging recognition that bicycling and walking have different needs.

<sup>&</sup>lt;sup>58</sup> Assuming these lots are being used by morning commuters, parking lot land use may also serve as a proxy for congestion.

purposes. For example, the *personal recreational utility* of an urban park likely increases for a traveler during the afternoon/evening (as opposed to the morning) commute. Interestingly, there is a strong positive association with the proportion of urban parkland along the access corridors of people who are dropped off at their BART station. In the East Bay Area hills there is a great deal of parkland that may be influencing this finding. More analysis of the home origins of these commuters who are being dropped off at a BART station is needed to determine if this is indeed the case. Table 4-9 shows the results for urban parkland.

	BIKE		BUS		CARDO		WALK	
Land Use Activity/ Perceptions	Param.	P-val	Param.	P-val	Param.	P-value	Param.	P-val
Proportion Urban Parkland	2.72	0.32	2.63	0.63	4.04	0.02	3.13	0.22

Table 4-9: Results for Urban Parkland along IACs.

# Average Parcel Size

The average parcel size measure explored in this dissertation has consistently (through almost 100 model runs)<sup>59</sup> been found to have a strong inverse correlation (significantly negative association) with the likelihood that a person will either walk or bicycle to access rapid transit. These findings confirm the notions posited by several scholars that smaller lot sizes (finer-grained development patterns as opposed to big-box development, for example) help encourage walking (Jacobs & Appleyard, 1987). This study shows, in addition, that there can also be a significant positive association between smaller lot sizes and bicycling. The results for average parcel size are shown in Table 4-10 below.

Table 4-10 Results for Average Parcel Size along IACs.

	BIKE		BUS		CARDO		WALK	
Traveler Perceptions	Param.	P-value	Param.	P-value	Param.	P-value	Param.	P-value
Average Parcel Size (10,000 sq. ft)	180	0.01	.0313	0.33	0218	0.32	109	0.00

# The Meaning and Usefulness of Average Parcel Size

While parcel geometry seems to serve as promising proxy measure for intensity of development (density), it also appears to serve as a decent, objective proxy measure for the "perceptual qualities of the urban environment" that many experts believe to be important to walking rates (Ewing et al., 2006; Ewing & Handy, 2009), but up until now has been elusive to confirm.

<sup>&</sup>lt;sup>59</sup> Supporting the conclusion that APS is a *reliable* measure.

Chapter 3 discusses the literature recognizing the connection between parcel size and the important perceptual qualities of the urban environment that may be associated with encouraging walking(Ewing & Handy, 2009; Ewing et al., 2006; Hess et al., 2001; Lee et al., 2006). In particular it details how smaller parcels are likely associated with buildings that are of a smaller, human scale, are located closer to the street (emanating a stronger sense of enclosure), have distinct characteristics (making them imageable), and have a "visual richness" (emanating a sense of complexity). By extension, the findings of this research confirm these ideas, suggesting that smaller parcels would encourage more walking and now (perhaps for the first time) increases in bicycling rates.

## Future Research on Average Parcel Size

To further understand the connection between parcel size and traveler perceptions, future research should look at the relationship between average parcel size and a sample of the several urban form characteristics, such as:

- Building setbacks as associated with a sense of *enclosure*;
- Building heights as associated with *human scale*, and a sense of *enclosure*;
- Age of buildings as associated with *complexity* and *imageability*;
- Presence of streets trees, furniture.

Many of this could be verified through satellite imagery and Google Street View.

# *Route Directness: Straight-Line-to-Network-Distance Ratio along Individual Access Corridors*

The straight-line-to-network-distance (SL2ND) ratio for this sample was found to have a significant positive association with the likelihood one will walk, bicycle or take a bus to access a rapid transit station, as shown in Table 4-11 below. Although bicycling is positively associated with route directness, it has a weaker association than the likelihood one will choose to walk, reflecting perhaps a bicyclist's greater acceptance (than people walking) of indirect routes (circuitous, with curvilinear streets and networks, long blocks, etc.). For example, indirect bike paths are still attractive options, as they allow bicyclists to avoid busy streets—especially if they are commercial streets with cars pulling in and out of parking lots and street parking spaces, opening doors, etc. And even in communities with curvilinear street patterns, it makes sense for bicyclists to be more accepting than pedestrians of indirect street networks, especially if a bicyclist is simultaneously appreciating a physical activity utility along with the trip.

	BIKE		BUS		CARDO		WALK	
Transport Access/ Design	Param.	P-value	Param.	P-value	Param.	P-value	Param.	P-value
Straight-Line-to- Network-Distance Ratio*	0.443	0.27	5.68	0.00	-0.234	0.57	3.68	0.00

Table 4-11: Route Directness: Straight-Line-to-Network-Distance Ratio	along IACs
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\* A value closer to 1 is more direct.

## **4.2.4 Transport Access**

Beyond just the physical infrastructure of the urban environment, this research includes measures dealing with the functional/operational components of access to transport, such as the presence of car parking fees, number of parking spaces, parking saturation, etc.

## Network Distance/Time

For walking and bicycling likelihoods, the findings regarding the network distance variable makes sense (both significant and negative). For the drop-off mode, as compared to driving alone, it would appear that as the trip gets longer, the more likely it is one would choose to carpool and then get dropped off. Some of this may be explained by the fact that some drivers (and their passengers) benefit from the highway HOV lanes which run parallel to these BART stations on both Interstates 80 and 880. Future intercept survey questions could confirm this.

## Station Car Parking Fees

As one would expect, this study found a significant negative association with fees for parking and driving. What was counter-intuitive was a negative (although weaker) association with charging for parking and the likelihood a person gets dropped off. This may have something to do with the possibility that a transit station that charges for parking may serve as a proxy for a terminal point for the rapid transit system, which would increase its attraction to carpoolers dropping off passengers.

## Estimated Transit Times and Estimated Time to Walk to the Bus

There was a negative, but statistically weak, association with the probability that one would ride a bus as the estimated transit time increased. This result may be weakly significant because bus riders to these non-CBD BART stations in the East Bay may be somewhat captive to riding a bus in order to get access to BART. In future research, additional measures may need to be included for both the amount of time a person may have to wait at the bus stop and the time it takes to get to the bus stop, and by which mode did they used to access the bus-stop (whether by walking, being dropped off, bicycling, etc.).

### Transit Station Bike Parking

There is a statistically significant positive relationship between the likelihood one would bicycle and the number of bike parking spaces at the transit station. As with the number of parking spaces for cars and the positive association with driving, this relationship is possibly circular, but in a slightly different way. That is, more people bicycling to a station has likely prompted BART to increase their provision of bicycle parking spaces.

## 4.2.4 Access to Opportunity: Personal Socioeconomic Attributes (PATs) Component

Consistent with previous research, personal socioeconomic attributes (PATs) of the commuters are still powerful predictors of transit access mode choice in general, and bicycling and walking in particular. Attributes relevant to this research are income level, car availability, gender, race, and number of persons in the commuter's household.

## Income Level

Throughout many model runs, high income has been a strong negative predictor that one would walk, bicycle, ride a bus, or even be dropped off to these stations. Also consistent with previous studies, the opposite is true for a person with an income less than \$25,000.

An interesting finding related to the association between passenger drop-off and low income was that expanding the catchment area from 3 to 5 miles caused the likelihood that one would be driven and dropped off at a station to switch from a negative to a significant positive association. Future studies may want to look further at this distance/passenger drop-off connection.

## Car Availability

Consistent with previous research, the availability of a car for the trip on the day of the survey was a powerful predictor that one would choose to drive over all other modes of access.

## Gender

There was also a strong positive association with being male and the likelihood one would walk or bicycle, whereas for bus riders or passengers being dropped off at the station, there is a stronger association with being female.

### Race

Race plays a significant role only in predicting whether one would ride a bicycle to access rapid transit. Specifically, there is a lower likelihood bicycling to the stations in the study if a person identified himself or herself as either Black or of non-white, Hispanic/Latino heritage. The relationship between race and all other access modes is statistically weak.

## Number of Persons in Household

The number of persons in a commuter's household was strongly associated only with the likelihood a person would be dropped off at the station, while weakly associated only with the likelihood that one would bicycle, walk, or ride a bus there.

# 4.3 Planning and Design Guidance from Model Findings

The findings of the predictive models of consumer behavior presented in this dissertation are consistent with the vast body of previous research. In addition, they enhance our understanding of the complex relationship between the urban environment and travel behavior. As with most studies, personal socioeconomic attributes (PATs) are found to be strong predictors of travel behavior. Nevertheless the new measures developed and refined in this research provide a rich set of reliable and valid results to guide policy and design decisions for transit access toward achieving a greater array of sustainability benefits.

Based on a comprehensive consolidation of the major findings emerging from the many models created and reviewed during the course of this research, the following is a list of specific planning policy and design strategies that should be considered for rapid transit access corridors, toward the goal of increasing more environmentally beneficial and sustainable travel behavior:

- Access corridors should be composed of buildings that are at a human scale, are located closer to the street (emanating a stronger sense of *enclosure*), have distinct characteristics such as front porches (emanating a sense of *imageability*), and providing a "visual richness" (sense of *complexity*).
  - This is supported by the finding of a strong negative relationship between the use of an NMT mode to access rapid transit, and the presence of larger ("big box") parcel sizes, and auto-supporting land uses, such as parking lots, and road & freeway rights-of-way (ROW) along a commuter's IAC.
- Communities should be designed with narrower, well-connected streets and/or more direct walking and bicycling paths.
  - It is also supported by strong negative relationship between NMT and the amount of land in auto-supporting land uses such as parking lots, and road & freeway rights-of-way (ROW), along a commuter's IAC.
  - This is also supported by the finding of a strong positive association between the use of an NMT mode to access rapid transit with route directness, along a commuter's IAC.
- Small, personal service retail opportunities should be provided.
  - This is supported by the finding of a strong positive relationship between walking/bicycling and the presence of small retail/mixed uses along a commuter's IAC.
## 4.4 Do the New Measures Really Matter Toward Statistical Analyses of Consumer Behavior? Comparing the IAC with Zonal D-Variables

The final test of whether these new methods to measure the urban environment are useful in statistical analyses of consumer behavior is to compare model performance results between models with the new individual access corridor (IAC) measures against similar models with the more standard, zonal aggregation measures. While most of this dissertation refers to the new measures as representing the urban environment component framework of *land use activity, transport access*, and *traveler perceptions*, it makes sense in this instance to refer back to their origins as *refinements* of the D-Variables. For example, *Average Parcel Size* serves as a proxy for the intensity of development, or *Density*, as well as the new UE component, *traveler perceptions*. Further, the *Straight-Line-to-Network-Distance* (SL2ND) *Ratio* serves as a proxy for the currently recognized D-Variable dimension of (functional) *Design*, as well as a proxy for the UE component of *transport access*. Thus, for this analysis the distinction between the old and the standard measures is based mostly on their spatial unit of analysis (IAC vs. Zonal).

### 4.4.1 Standard D-Variables Used for Comparison with IAC Measures

In Ewing & Cervero's 2010 meta-analysis (the latest, most comprehensive guide of D-Variable-related findings), walk trips are found to be most strongly associated with *intersection density* (a measure of the functional aspect of *Design*) and land use activity (*Diversity*), jobs-housing balance, and distance to stores.<sup>60</sup> Based on these findings, the following is a list of the standard zonal D-Variables used for comparison with the new IAC measures developed in this dissertation:

- **Design:** A measure of intersection density is used, specifically the number of four-legged intersections within 1/2 mile of a BART station. This measure was tested against the new IAC measure, *Straight-Line-to Network-Distance Ratio*, identified in the new UE component framework as representing *transport access*, but can also trace its origins the D-Variable dimension of *Design*.
- **Density:** Although Ewing & Cervero (2010) found density to have a small influence on lowering VMT, once other factors of the built environment are controlled, it is worthwhile to include a measure representing the intensity of development (the *Density* D-Variable dimension) for comparison with the new IAC measure, *Average Parcel Size*, which serves as a proxy for the intensity of development, or *Density*, as well as the new UE component, *traveller perceptions*. The standard zonal measure for *density* is the combined number of people and jobs within a 1/2-mile radius of a station on a per-acre basis, *Population and Jobs per Acre*.

<sup>&</sup>lt;sup>60</sup> They also find walking to be most strongly related to measures of land use diversity, intersection density, and the number of destinations within walking distance, and bus and train use equally related to proximity to transit and street network design variables, with land use diversity a secondary factor.

- *Diversity:* Finally, this research produced and tested two indices of land use mixture or entropy, based on both the IAC and zonal spatial units of analysis. They are as follows:
  - A zonal Jobs-to-Housing/Mixed-Use Entropy index (*ZonJHEntropy*); and
  - An IAC Jobs-to-Housing/Mixed-Use Entropy Index.<sup>61</sup>

Model tests suggested that the standard zonal entropy index performs slightly better, from a model performance perspective, than the IAC entropy index, and thus the standard, zonal entropy index is used in this comparison.

#### Standard Zonal Diversity Index

The standard zonal entropy measure used for comparison is based on the same formula presented in Chapter 2, used for calculating a jobs-to-housing, mixed-use entropy index for the area within a  $\frac{1}{2}$  mile (straight-line distance) from this sample of BART stations. It is as follows:

Jobs-Housing/Mixed-Use Entropy Index =  $\{-\Sigma k [ (p_i) (ln p_i)]\}/(ln k)$  where:

 $p_i$  = proportion of total land-use activities in category i within a half mile (straight-line distance) of the station;

i categories are households (# of Single Family Units; and # of Multifamily Units), employment (retail and non-retail jobs);

and k = 4 (number of land-use categories).

<sup>&</sup>lt;sup>61</sup> IAC Jobs-to-Housing Entropy Index: This dissertation tested several approaches toward creating an IAC-based land use entropy/diversity measure. The final IAC land use entropy index tested is essentially a jobs-to-housing entropy score based on each individual respondent's access corridor (IAC) residential and employment land use proportion calculations, and is as follows:

<sup>=1- {(|</sup>Prop. Res- Prop. Emp|)/(Prop. Res + Prop. Emp)}

where:

Prop. Res = proportion of land area in residential land use category within a 200 foot buffer of each individual access corridor;

Prop. Emp = proportion of land area in employment land use category within a 200 foot buffer of each individual access corridor.

## 4.4.2 Model Specifications

The various model specifications, as shown in Table 4-12 are specified as follows:

## Model 1

This is the final model presented in Table 4-4, and contains the following new IAC-based measures for comparison:

- Land use activity: The new IAC land use measures representing distinct, parcel-level land use categories (representing the *Diversity* D-Variable dimension).
- **Transport access:** Straight-Line-to Network-Distance Ratio (representing the *Design* D-Variable dimension).
- **Traveler perceptions:** *Average Parcel Size,* which is used in this model comparison also as a proxy for the intensity of development, or *Density* D-Variable dimension.

## Model 2

In Model 2 the new IAC land use measures representing parcel-level identified land use categories are replaced by a more standard, zone-based jobs-to-housing measure of land use mixture, *ZonJHEntropy*, representing a proxy for the *Diversity* D-Variable dimension.

## Model 3

Model 3 makes the following changes to Model 2:

- Average Parcel Size (an IAC proxy for *traveller perceptions* and the intensity of development, or the *Density* D-Variable dimension), is replaced with a more standard zonal measure for *Density Population and Jobs per Acre*.
- The individual Straight-Line-to-Network-Distance (SL2ND) Ratio, a proxy for the *Design* D-Variable dimension, is replaced with a variable for the number of four-legged Intersections within ½ mile of the station.

The representation of the variables of the three models is presented in Table 4-12.

UE & PAT Components	Final Model Variables	Model 1* New IAC Measures	Model 2** Standard Zonal: <i>Diversity</i>	Model 3*** Standard Zonal: Density, Diversity, & Design
Transport Access	1= Station Parking Fills for AM Commute	х	х	x
	1 = Parking Fees at Station	х	х	Х
	# of Bike Parking Spaces	Х	Х	Х
	# of Parking Spaces at Station and ½ Mile around Station	х	x	x
	Est. Travel Time of Bus Trip (minutes)	x	x	x
	Network Distance (miles)	Х	Х	Х
Transport Access (Design)	Straight-Line-to-Network- Distance ratio (0-1, closer to 1 being more direct)	x	x	# of 4-Legged Intersections within ½-mile Zone of Station
Perception (Density)	Average Parcel Size (sq. ft)	х	x	Population & Employment/Acre
Activity (Diversity)	Retail/Wholesale	Х	DIVERSITY ZonJHentropy (½-mile Zone)	DIVERSITY ZonJHentropy (1⁄2-mile Zone)
	1= Res/Mixed Use/Small Retail	х		
	Prop. Ed/Religious/Communty Instit.	х		
	Proportion Employment Centers	х		
Activity/ Perception	Proportion Parking Lot	Х		
	Proportion ROW	х		
	Proportion Urban Park	Х		
Access to	1= High Income (Over 75K)	Х	Х	Х
	1= Low Income (less than 25K)	х	x	х
Opportunity/	1 = Male	Х	Х	Х
Personal	Number of people in HouseHold	х	х	x
(PATs)	1 = "Car Available for Trip Today"	х	x	x
	1= Black or NonWhite Hispanic	х	х	x
Measures of	Number of Observations	5694	5694	5694
Model	Number of Parameters	75	51	51
Performanco	Final Log-Likelihood	-3326.315	-3396.227	-3470.490
renormance	Adjusted rho-square	0.558	0.552	0.542

Table 4-12: IAC vs. Zonal Measures: Comparison of Access Mode Choice Models

\* Model 1: New measures model (same as the final model presented in section 4.2) \*\* Model 2: Standard, zonal measures for *Diversity* (ZonJHEntropy within ½ mile of station), replaces the new IAC land

use activity measures. \*\*\* Model 3: New IAC measures are all replaced with standard, zonal measures for *Diversity* (ZonJHEntropy within ½ mile of Destination), Density (Pop + Emp. Per Acre), and Design (# of 4-Legged Intersections within 1/2 mile of Station.

#### 4.4.3 Model Comparisons

#### Adjusted Rho-Square Comparisons

As opposed to using a likelihood ratio test (LRT) for comparing nested models (where one model is an iteration of another model), the correct procedure for comparing non-nested models, where different set of variables replace each other, is to compare the model's *adjusted* rho-squares. Adjusted rho-square (sometimes referred to as Rho Bar Square) is a modification of rho-square that adjusts for the number of terms in a model. In other words, the adjusted rho-square imposes a penalty for adding more explanatory terms (variables and parameters). Essentially, this is a standardized goodness-of-fit measure which, unlike rho-square, the *adjusted* rho-square increases only if the new variable, or set of variables, improves the models performance. This is important to the analysis in this section, as comparing Model 1 with Models 2 and 3, the variables decrease from 21 to 15, and the parameters decrease from 75 to 51.

### Comparing Model 1 (IAC, Land Use Activity) and Model 2 (Zonal, Land Use Diversity)

The different measures of land use activity are compared through examining the adjusted rho-squares of Model 1 and Model 2. Model 1 has the new IAC, parcel-level land use measures; Model 2 has standard zonal entropy measures of land use (*ZonJHEntropy*).

Comparing the adjusted rho-squares of the model results presented in Table 4-2, Model 1 (which includes the new IAC-based land use activity measures) and Model 2 (with a standard zonal, *Diversity* D-Variable measure) shows that Model 1 (0.558 *adjusted* rho-square) performs (fits the data) better than Model 2 (0.552 *adjusted* rhosquare). This finding shows that the new IAC land use measures show promise in becoming respectable refinements of the zonal measures of land use *Diversity* currently used in practice, because from a statistical modeling standpoint, they perform better.

In terms of the caliber of information these different land use activity measures can provide – in sum, comparing their validity and usefulness — the new IAC, parcelbased land use measures are able to provide richer, nuanced information about what particular land use activities may be associated with rapid transit access travel behavior. This would be true even if either of the standard zonal entropy measure of land use diversity (*ZonJHEntropy*) performed comparably (or even better) from a model performance standpoint.

This model comparison demonstrates the promise these new measures of the urban environment developed in this dissertation for opening the door to new, innovative ways to further our understanding of the relationship between specific land use *activities* and environmentally beneficial travel behavior.

### Comparing Model 2 and Model 3

Comparisons between Model 2 (0.552 adjusted rho-square) and Model 3 (0.542 adjusted rho-square), suggest that from a model standpoint, the new IAC *Average Parcel Size* (APS) measure, combined with the individual *Straight-Line-to-Network-Distance* (SL2ND) ratios, perform on the whole better than:

- A standard D-Variable measure of population and jobs per acre (within a <sup>1</sup>/<sub>2</sub> mile of station); combined with
- A standard D-Variable measure of *Design* (route-directness), the number of four-legged intersections (within a <sup>1</sup>/<sub>2</sub> mile of station).

In sum, these results support the conclusion that these new individual access corridor (IAC) measures present promise for use in future statistical models designed to further our understanding of the urban environment's influence on consumer behavior, beyond the standard zonal measures currently used in practice.

## 4.5 Summary and Conclusions

In this chapter, the new individual access corridor (IAC) measures are pragmatically applied to predictive models of transit access mode choice. They reveal useful insights on the urban environment's association with environmentally beneficial travel behavior. The analysis in this chapter achieves two things:

1. It provides a "proof of concept" that the individual access corridor (IAC) analysis supports *reliable* and *valid* model inputs toward furthering our understanding of the urban environment's influence on consumer behavior;

2. It provides useful, nuanced insight into the influence of a new set of urban environmental components (*land use activity* and *transport access & perceptions*)<sup>62</sup> on rapid transit access travel behavior, especially "green" NMT modes (walking and bicycling) and their attendant environmental benefits. By extension, it presents a guide toward design and policies supporting multiple sustainability achievements for the health, wealth, and equity of our communities.

In terms of the first achievement, these measures are found to be *reliable* and *valid* for the following reasons:

- The IAC methods and final collection of new measures are *reliable*, as they:
  - Can be both measured objectively and gathered in a resource permissive, uniform fashion, as presented in Chapter 3.
  - Provide consistently similar results through repeated, comparable experiments, as presented in Chapter 4.
  - Perform better, from a model performance perspective, than models with standard zonal D-Variable calculations, bearing witness to the promise these measures have toward furthering our understanding of the urban environment's influence on consumer behavior.
- Furthermore, using the new IAC methods are found to be *valid* for the following reasons:
  - Chapter 3 presents a thorough discussion of the empirical research, literature, and urban theory identifying and articulating the specific aspects of the urban environment each measure represents. This justifies the use of the final array of measures to be used as inputs into the predictive models of consumer behavior, as presented in this chapter.
  - These new measures of the urban environment yield interpretable and sensible results in predictive models of consumer behavior, as presented in this dissertation. And while the findings presented herein are consistent with most previous studies of the urban environment's influence on travel behavior, they provide a richer understanding of the association of *land use activity, transport access,* and *traveller perceptions* to support more environmentally beneficial travel behavior.

<sup>&</sup>lt;sup>62</sup> As "refinements" of the D-Variable framework.

In terms of the second achievement, the analysis presented in this chapter provides useful insight into the influence of three key urban environmental components (*land use activity, transport access and traveler perceptions*) on rapid transit access mode choice. Knowing what policies and design practices are associated with the probability commuters will access rapid transit stations (and the system itself) by walking or bicycling, for example, gives valuable guidance to practitioners on what planning and design decisions may yield a greater array of sustainability benefits, from lowering auto use, GHG emissions, congestion, to simultaneously improving air quality, street livability, the building of social capital, and individual opportunities for physical activity, and so on.

## PART III BRIDGE TO THE FUTURE

## **Chapter 5: Synthesis of Research Findings**

Two goals were defined at the beginning of this research. The first goal was to develop and refine new methods to measure the urban environment that could provide simultaneously *reliable* and *valid* information for studies of consumer behavior. The second goal was to apply these new measures to test their relationship to rapid transit access mode choice, serving both as a "proof of concept" and as an insightful analysis of policy and design practices that support environmentally beneficial travel behavior. Meeting this goal, by extension, furthers our quest towards achieving a broad array of sustainability benefits for the health, wealth, and equity of our communities.

# **5.1 Goal 1: Develop and Refine New Methods to Measure the Urban Environment**

In terms of the first goal, this research shows that capturing high-*resolution* information on the urban environment for each individual survey *respondent* can be done in a *replicable* manner for informative analyses of the relationship between the urban environment and travel behavior. Meeting this goal was facilitated via the application of a new spatial unit of analysis, the *individual access corridor* (IAC). This new spatial unit enables the collection of finer *resolution* data that is now becoming more commonly available for GIS analysis (e.g., parcel-level information on land-use and geometries, network distances, online transit schedules, etc.). These technological advances enable *refinements* in the ways we measure and understand the urban environment.

#### 5.1.1 Implications for Academic Researchers and Practitioners

The new methods to measure the urban environment show tremendous promise for both research and practice. They can improve both conventional and new activitybased travel demand models by providing reliable and valid measures *captured at the scale of the individual*. These new methods also capture subtle characteristics of the specific urban environmental context along an individual's route, the IAC. For example discretely identified parcel-level land use classes that can be attributed to individual trips provide more nuanced information than the standard, zonal entropy measures of land use mixture. This research also bridges important methodological gaps in the urban design and travel behavior literature, improving our understanding of how built environment factors influence bicycling and walking, as well as providing useful insights about the "perceptual qualities of the urban environment."

Furthermore, the methods developed in this dissertation enable us to incorporate the qualitative findings of urban design research into travel behavior research, and by extension, move towards better policy and design guidance of our transport and land use systems. By providing new ways to combine the findings and methods of urban design and travel behavior research, this dissertation shows how to capitalize on both the richness of urban design approaches and the cost-effective benefits of using objective, readily available data. Furthermore, the methods and measurements explored and developed in this dissertation prove to be meaningful, qualitative indicators of the factors that influence mode choice. Finally, they can be applied toward a wide range of urban settings and toward a better understanding of the influence of urban environmental characteristics on consumer behavior in general.

Further achievements of this research related to Goal 1 include the following:

- This research finds the individual access corridor (IAC) to be a useful spatial unit of analysis for consumer/travel behavior research, providing both a *reliable* and *valid* framework to uniquely examine the intermediate section of a trip between its origin and destination.
- Through numerous iterative tests, this research presents unique and useful strategies for dealing with specific, parcel-level land use classes, and parcel geometries that can then be uniquely attributed to individual respondents in predictive models of consumer behavior.
- The findings of this dissertation show that these new measures work better than currently used zonal aggregations, from a model performance standpoint, and thus support the conclusion that they are *reliable* for use in statistical analyses.
- This research shows that measuring parcel-level land use data over an access corridor buffer (the IAC) produces far richer results than the commonly used zonal entropy measures of land use mixture currently being used as a proxy for land use activity, and thus supports the conclusion that they are *valid* for use in statistical analyses.

# **5.2 Goal 2: Testing the Relationship of These New Measures toward Analyses of Rapid Transit Access Travel Behavior**

In terms of the second goal, these new methods to measure the urban environment provide a richer understanding of how urban environmental characteristics along an individual's access corridor to a rapid transit station influence travel behavior. Controlling for important individual socioeconomic attributes, the new measures used in the final models were proven to provide both statistically *reliable* and meaningful (*valid*) results, providing entirely new, richer insights into what urban environmental factors (*land use activity* and *transport access & traveler perceptions*) may influence travel choices. These travel choices, in turn, affect our progress toward reaching a broad array of sustainability objectives, including freeing up parking spaces,<sup>63</sup> lowering GHG emissions, and improving opportunities for physical activity.

<sup>&</sup>lt;sup>63</sup> To entice people to ride rapid transit who are truly too far to walk or bicycle.

<sup>&</sup>lt;sup>64</sup> The 1996 Surgeon General's Report on Physical Activity and Health documents the benefits of achieving moderate regular activity 30 minutes per day most days of the week, even through relatively brief physical activity (e.g., a 10-minute walk to and from transit). Walking is the most readily available physical activity to nearly everyone, offering transportation and environmental benefits at the same time enhancing health.

### Promoting Environmentally Sustainable Travel to Rapid Transit

In terms of environmentally sustainable travel to rapid transit, clearly walking and bicycling are and should be encouraged. People who currently drive to rapid transit, but can walk or bicycle, should be encouraged through pricing and education programs to leave their cars at home. Better managing the supply of station parking through appropriate pricing can support the achievement of this goal. And this can yield additional secondary benefits for the environment by freeing up parking spaces for those who are too far away to walk or bicycle, and would otherwise bypass the system altogether due to the difficulty in finding a place to park.

### 5.2.1 Policy and Design Guidance for Transit Access Corridors

A major objective underlying the work in this dissertation has been to help identify realistic and actionable policies and practices to effectively accommodate NMT access to rapid transit. Specifically, this work keeps an eye on guiding strategies to effectively retrofitting existing transit stations and their surrounding communities, as well<sup>65</sup> as how best to build new transit stations to work in concert with new and established communities. This dissertation also provides insight into best practices for transit operators to manage and design both their systems as well as their stations.

Based on a comprehensive consolidation of the major findings emerging from the models and other analyses undertaken during the course of this research, the following is a listing of specific planning policy and design strategies that should be considered along community *access corridors* leading to rapid transit stations:

### **Encourage Smaller Parcel Sizes**

In addition to the MNL model findings discussed at the end of Chapter 4, parcel size should be appreciated not just as a meaningful variable for research, but as a useful measure that can be applied directly in practice through ordinances. Regulating parcel size is one of the few tools local governments have in shaping the fabric of development, in contrast to measures of "density" which are a bit harder to directly articulate in ordinances. This more direct connection between the specification of parcel geometries in zoning ordinances and the resulting intensity of development further *validates* the use of parcel sizes as measure of the urban environment for consumer behavior research.

The findings from this research suggest that allowing for smaller parcel sizes can be especially useful in guiding developing areas around new rapid transit stations to support walking and bicycling, and thereby helping encouraging sustainable travel behavior in new station areas through subdivision ordinances. In existing station areas, zoning should allow for the sub-dividing of parcels into smaller sizes. In light of the billions of dollars now being considered for building high-speed rail lines in rural areas, these findings on the importance of smaller parcel sizes toward increasing more sustainable transit access travel behavior are particularly salient.

<sup>&</sup>lt;sup>65</sup> As through the articulation of such things as parcel sizes and building setback/built-to lines.

## Encourage Reasonably Higher Standards for Urban Design

As illustrated in Figure 5-1, policies should be developed that support zoning and design guidelines that encourage buildings:

- To be at a *human scale* (at least at the street wall).<sup>66</sup>
- To be located closer to the street (emanating senses of *intimacy* and *enclosure*).
- To have distinct characteristics such as front porches (making them imageable), and have a "visual richness" (giving them a sense of *complexity*).

This is supported by the finding of a strong negative relationship between the use of an NMT mode to access rapid transit, and the presence of larger ("big box") parcels, and auto-supporting land uses, such as parking lots, and road & freeway rights-of-way (ROW) along a commuter's IAC.



Illustration by Bruce Appleyard

Figure 5-1: In addition to illustrating desirable building form features, based on the findings of this research such as *human scale, enclosure* and *complexity,* the following are additional elements to create safe, inviting, and livable street environments. Doing so coax people out of their cars to walk or bicycle (Appleyard, 1981; Dumbaugh 2005; Ewing & Dumbaugh (2009); Jacobsen, 2003), and can help people overcome negative perceptions of distance (Isaacs, 2001):

- Width: paths should be at least five to six feet wide to provide enough room for two people to walk side by side and a third person to pass comfortably. Sidewalks along commercial streets should wider (12'-15') to accommodate the interaction between a building's activity and street life by allowing space for seating, displays, etc.
- A cyclist in motion requires about a five-foot-wide space to ride comfortably.

For more information see Appleyard, B. (2009).

<sup>&</sup>lt;sup>66</sup> After 3-4 stories, buildings can step up to a much greater height. Good examples of this practice can be found in Vancouver, British Columbia.

## Design Communities with Narrower, Well-Connected Streets and/or More Direct Walking and Bicycling Paths

This recommendation is supported by the finding of a strong, negative relationship between walking rates and the proportion of *ROW* and Parking Lots along transit access corridors, coupled with the strong, positive association with Route Directness. Best practices for route connectivity suggest pedestrians and bicycle paths should be every 300 to 500 feet. For motor vehicles, 500 to 1000 feet is recommended (Handy, Paterson, & Butler, 2003). Such connectivity can be implemented through subdivision ordinances, and stewardship of existing ROW. In other words, do not allow for the closing of alleys and streets. Finally, communities can consider creating better facilities for bicyclists, such as bicycle boulevards, as shown in Figure 5-2.

## Use Zoning Ordinances to Encourage Small, Personal Service Retail Opportunities along Likely Routes to Rapid Transit Stations

This recommendation is supported by the finding of a strong, positive relationship between walking/bicycling and the presence of *small retail/mixed uses*. These results are consistent with findings from other studies suggesting zoning should encourage more small to modest-size neighborhood stores and restaurants.

# **5.2.2** Policy and Design Guidance for Transit Stations

The findings in this research provide insight into several strategies rapid transit providers can employ in terms of the operation and design of their systems and stations to encourage



Figure 5-2: Prototypical bicycle boulevards function as through streets for bicycles while maintaining local access for automobiles through the use of traffic calming devices to reduce car speeds and through traffic. Traffic controls should be designed to limit conflicts between motorists and bicyclists and give priority to all bicycle movements.

For more information see Appleyard, B. (2009).

existing and potential riders to access rapid transit via "green modes" such as walking, bicycling and bus transit:

- They should appropriately price and better manage the supply and convenience of station area parking in order to coax people from driving short distances. This recommendation is supported by the finding of a strong, positive association with the likelihood of walking and bicycling to BART stations that have automobile parking fees.
- They should look towards *education* and *encouragement* programs that "nudge" current park-and-riders who access the system via short drives to walk or bicycle

in order to help free up a station's parking supply—that can then entice drivers who might otherwise bypass the system to become rapid transit riders.

• And finally, they should support bicycling access to transit stations by providing adequate parking facilities and accommodating bicycles on the trains.

### Meeting the Needs of Bicyclists Traveling to and at the Station

While bicyclists and pedestrians have many similar needs, the greater levels of speed, momentum, and inertia characteristic of bicycle travel make it more critical for planners to recognize that they respond to urban environmental characteristics differently, as is supported by the findings of this research.<sup>67</sup>

As bicycle facilities become more widely available at rapid transit stations, more people will likely be motivated switch from driving to bicycling. Here are some specific things transit operators can do in and around their stations to encourage bicycle access.

- In the case of some stations, bicyclists were observed to travel longer distances than many of the drivers accessing a particular rapid transit station<sup>68</sup>. These findings suggest that all rapid transit operators need to do as much as they can to accommodate bicyclists, in part to coax drivers out of their cars. Furthermore, while more confirmatory analysis is needed, the Fruitvale BART Station case study suggests that better "end-of-trip facilities" such as the presence of a bike station, secure bicycle-locking facilities, etc.<sup>69</sup> likely encourages bicycling to the stations.<sup>70</sup>
- As space constraints for bicycles on BART trains is evidenced in the figure to the right, a longterm suggestion for BART and other rapid transit operators to consider with regard to serving bicyclists is to rotate the seats 90 degrees so they all face inward. This will increase both the overall, and the bicycle carrying capacity, enabling the system to allow bikes on trains more often and on all train cars.



<sup>&</sup>lt;sup>67</sup> Bicyclists demonstrated a slightly weaker positive association with route directness, and the proportional presence of public rights-of-way than people walking.

<sup>&</sup>lt;sup>68</sup> In the case of the Fruitvale BART station, in 2008 a handful of bicyclists traveled farther distances than 95% of the drivers accessing the station.

<sup>&</sup>lt;sup>69</sup> Awarding zoning bonuses to developers who install such amenities in their buildings is one way to encourage bicycle use.

<sup>&</sup>lt;sup>70</sup> Way-finding signage, especially in suburban station areas, can be used to encourage the use of bicycle lanes, bike paths and boulevards to access and exit the station area.

## **5.3 Further Research**

Two complementary but distinct lines of research could immediately build on the work presented in this dissertation:

- Refining information gathered about individual *respondents* by:
  - Modifying the set of intercept survey questions; and
  - Conducting follow-up interviews with survey respondents (via email, phone, mail, etc.).
- Refining the use, capture, and *resolution* of information gathered about the urban environment

# **5.3.1 Refining the Information Gathered about Individual** *Respondents* through the Travel Surveys

## Conducting Follow-Up Interviews with Survey Respondents

Conducting follow-up interviews with survey respondents could provide invaluable refinements to the methods presented in this research:

- Respondents can confirm the routes they take to get to their destinations
- Interviewers can uncover important factors that reveal what truly influences a person's choices of mode, station, etc., including questions regarding the following:
  - Influence of the presence of specific businesses, institutions (schools) along a person's individual access corridor.
  - Influence of issues of personal security, which can be compared to specific geo-locations along the individual's *access corridor*.
  - Perceptual sense of the urban environment (enclosure, complexity, etc.), which can be used to examine the possible connection to the parcel size along the individual's access corridor.

## **Recommendations for Future Station Profile Surveys**

- As identified in the analysis of model results in Chapter 4, future station profile surveys could contain additional questions related to the following:
  - Did a driver to the station drop a passenger off at their place of work along their own IAC, thereby becoming a solo-driver when they arrived at the station?
  - Did a driver with passengers use the freeway HOV lanes to access the station?
- For electronic schedule estimates of bus travel time, future researchers will want to make sure the time captured in each survey matched the actual time the respondent arrived at the transit station. Further questions could be asked about how they actually arrived at the bus stop. Were they driven? Ride a bicycle, etc.
- In order to more accurately estimate the likely path a respondent takes to access the station, future surveys could include question to capture all the geo-coded locations of any linked trips along their way to the transit station.

# 5.3.2 Refining the use, gathering and *resolution* of information about the urban environment.

The research discussed in this dissertation opens the door for greater research possibilities. In particular, the high *resolution* information (parcel-level land use classifications, network paths, parcel geometries, etc.) explored in this dissertation hold great promise for future research efforts. Specifically, using specific, parcel-level land use information enables us to refine our understanding of the influence of individual land use activities on transit access behavior, as well as the synergistic relationships between various activities.<sup>71</sup>

Furthermore, while more confirmatory analysis is needed, now that parcel geometry can be measured at respectably high 3R methodological levels, it holds promise as a proxy for helping researchers better understand the influence of "perceptions of the urban environment" on travel behavior. Future research can build on these methods through refined processes and new data, as it becomes increasingly available for practical use. The following is an itemized discussion of what refinements could be made in the future.

### Land Use Activity: Detailed, Point-Level or Parcel-Level Land Use Information

Until now data, technology, and methods have limited the measurement of land use activity in the built environment and in travel behavior models to indices of mixed use or entropy. New capabilities explored in this research—specifically, the ability to capture and examine parcel-level land uses and then apply them uniquely to the estimated routes for thousands of survey respondents—opens the door for the re-examination of the fundamental approach to how land use activity should be incorporated into various analyses of consumer behavior. In the future, point source information, such as is provided by ESRI's Business Analyst software, should be used to further understand the specific businesses and institutions in a rapid transit access corridor and their synergies.<sup>72</sup>

### Transport Access: Straight-Line-to-Network-Distance Ratio

This research is one few studies to use the *straight-line-to-network-distance ratio*<sup>73</sup> at such a large sample size as a measure of route directness.<sup>74</sup> In the future it would be helpful to have more specific information on the following:

• For electronic schedule estimates of bus travel time, it is important to make sure that the times captured in surveys matched actual time the survey respondent

<sup>&</sup>lt;sup>71</sup> Much time and effort was spent working through the problem of land use information overload, creating a framework to make this information more *manageable* and *meaningful*.

<sup>&</sup>lt;sup>72</sup> This research tested many new methods in the realm of capturing highly detailed, parcel-level measures of land use activities. Specifically probing the question of whether it is better to use the actual distances of discretely identified land use classes along a route, or the proportions. This may be especially important when comparing across travel modes with differing sensitivities to distance.

<sup>&</sup>lt;sup>73</sup> 0-1 scale measuring straight-line distance /shortest street network distance.

<sup>&</sup>lt;sup>74</sup> Another major study using a similar route directness measure, but using a 0-1 scale measuring shortest street distance/straight-line distance, is Cervero et al. (2009a).

arrived at the transit station. Therefore, survey protocols should be designed accordingly to capture this information.

- Additional measures may need to be included for both the amount of time one may have to wait at the bus stop, as well as the true time it takes for one to get to the bus stop (whether by walking, being driven and dropped off, or bicycling).<sup>75</sup>
- Future studies should consider the quality of the street and transport environment, specifically street widths, traffic speeds and volumes, and how much time it actually takes a park-and-rider to find a space, pay for it, and walk to the platform. With that information we could more accurately model the actual auto travel time for a park-and rider-and a person being dropped off at the station. Lacking accurate information on this hampers current modelling efforts. Not only could this data provide more information on auto travel time, it could tell us more about the influence of street livability travel choices.<sup>76</sup> Another important dataset to include in the analysis would be point collision information, particularly as it relates to bicycle and pedestrian casualties.<sup>77</sup>

### Traveler Perceptions: Average Parcel Size

Absent having GIS-based building footprint and envelope data, the average parcel size (APS) promises to serve as a decent proxy for the "perceptual qualities of the urban environment." Nevertheless, as is the case with most of these new methods, future research will want to keep a watchful eye on the intent of what is meant to be measured. For example, in trying to capture such perceptual qualities as "human scale" and "enclosure," one would need to select the parcels with land uses that would reflect, as much as possible, the actual building footprint and massing envelope. A better alternative, had it been available, would have been to use digital building footprint information. This researcher made inquiries to several sources about this alternative, but the data were not yet available. In the future, these data may be more readily accessible.

Finally, to further understand the connection between parcel size and traveler perceptions, future research should look at the relationship between average parcel size and a sample of specific urban form characteristics, such as:

- Building setbacks and heights-associated with human scale, sense of enclosure
- Age of buildings, presence of streets trees, furniture, etc.— associated with *complexity* and *imageability*

Many of these elements could be verified through satellite imagery and Google's *Street View* technology.

<sup>&</sup>lt;sup>75</sup> Future station access surveys (whether for BART, or other operators) should consider asking questions regarding how people arrived at the bus-stop itself.

<sup>&</sup>lt;sup>76</sup> One tool we could use is the new CompleteStreets LOS software, based on the Multi-Modal Level of Service (MMLOS) work conducted under the National Cooperative Highway Research Program's Project, NCHRP 3-70.

<sup>&</sup>lt;sup>77</sup> The University of California's SafeTREC is developing an on-line GIS-based analysis tool to dynamically look up Statewide Integrated Traffic Records System (SWITRS) data.

## **5.4 Summary and Conclusions**

This research presents new methods to measure the urban environment that provide statistically reliable and meaningful insights into the influence of components that help inform our understanding of how to support and encourage more environmentally beneficial travel behavior. The new measures developed in this research, guided by the 3R principles of methodological development and utilizing the new individual access corridor (IAC) spatial unit of analysis, enable us to *replicably* capture high *resolution* information (parcel-level land use activities, transport route directness, parcel geometries) for each individual survey *respondent*. In sum, the capabilities presented in this research to use ever increasingly available data for geo-spatial analysis of the relationship between the urban environment and travel behavior opens the door to refining current approaches. For example, the ability to capture land use activities identified at the parcel-level, and then apply them uniquely to the estimated routes for thousands of survey respondents via the IAC spatial unit of analysis opens the door for greater *refinement* of our application of urban environmental measures to consumer behavior research.

Furthermore, the new IAC measures used in the final models were proven to provide statistically reliable, valid and nuanced insight into the influence of *land use activity, transport access* and *traveler perceptions* on choosing "green" NMT modes. By extension, gaining a better understanding of the various factors that influence rapid transit access can help us identify realistic and actionable policies and design practices that can help effectively move us toward achieving a greater array of sustainability benefits, such as lowering auto use, GHG emissions, and congestion, while simultaneously improving air quality, street livability, the building of social capital, and individual access to opportunities for their enduring health and prosperity.

## **Chapter 6: Review, Closing Remarks, and Reflections**

## 6.1 Review

This dissertation has three main parts, as follows:

### **PART I: FOUNDATIONS**

**Chapter 1** introduces the problem that this dissertation will address: the need for better measurements of the role urban environment in travel behavior. **Chapter 2** reviews how researchers have been measuring the urban environment including a) the relationship of the "perceptual qualities of the urban environment" (Ewing et al., 2006; Ewing & Handy, 2009) with travel behavior, and b) how urban environment factors influence bicycling, as well as walking. This chapter also situates this dissertation in the field, as well as its place along a methodological progression of urban environment measures from aggregate (zonal) to disaggregated individual access corridor (IAC). Overall this work builds on the vast and rigorous literature on travel behavior and the built environment conducted ever since Cervero and Kockelmann (1997) pioneered the D-Variable framework in the mid-1990s, and refined through the seminal syntheses of the travel behavior and built environment literature conducted by Ewing & Cervero in 2001, and in 2010.

Part I also introduces and illustrates the central evaluative framework guiding the exploration and development of these new methods: the 3R principles of methodological development, *resolution, respondents,* and *replicability*. Finally, the new spatial unit of analysis, the individual access corridor (IAC), is more formally discussed for its benefits towards broadening our currently used zonal D-Variable measures by enabling a much higher resolution of data gathering that can then be attributed to each individual survey respondent.

### **PART II: KEYSTONE**

Throughout Part II, both the 3R principles and the real-world issue framework of rapid transit station access are applied toward the evaluation of both current methods to measure the urban environment and the new methods explored in this dissertation. **Chapter 3** covers the vast body of previous research and the method development presented in this dissertation, establishing the reliability of these measurements as well as their validity in meaning. **Chapter 4** tests the relationship of these new methods to measure the urban environment with environmentally beneficial rapid transit access travel behavior, as well directly testing for model performance the final set of new IAC D-Variable measures of the urban environment against a standard set of zonal D-Variable measures.

### PART III: BRIDGE TO THE FUTURE

**Chapters 5 and 6** contain conclusions regarding the new methods to measure the urban environment presented in this dissertation, as well as how these findings can help guide planning and design practices to make rapid transit station access more environmentally sustainable. An overarching goal of Part III is to help guide both future travel behavior research/modeling efforts and the evaluation of current and future designs and plans for their ability to lower auto use and GHG emissions and provide a host of additional benefits for the health, wealth, and equity of our communities.

## 6.2 Closing Remarks

While some will argue about the magnitude to which the urban environment influences travel behavior, there are at least two compelling examples presented herein as to 1) why practitioners and researchers should care about transforming the urban environment to influence travel behavior and 2) why they should not only endeavor to transform the urban environment (its physical as well as operational components), but also offer programs to increase its ability to influence behavior. First, the example of General Motors' continuing policy of free gas for white-collar employees not only clearly illustrates how changing the cost of transport is quicker and easier than transforming the urban environment, but also shows the extent to which this change can be "tremendously disruptive" (in this case to the lives of wealthy executives). Considering that the majority of poor people in the U.S. now live in suburban environments<sup>78</sup> the social equity implications alone warrant greater attention from both practitioners and researchers.<sup>79</sup> Second, McFadden's<sup>80</sup> articulation of "consumer agoraphobia" (how people's behavior in the marketplace can be deeply entrenched and habituated) gives practitioners justification for providing additional programs to encourage, or "nudge," people towards socially optimal behavior through the redesign of both the physical and operational components of the urban environment (Thaler, 2008).

During the closing remarks of the May 2008 Volvo Foundation's international academic research conference in Berkeley, CA, it was concluded that the looming global climate crisis cannot be solved solely by improved infrastructure or technology. To sufficiently reverse transport's generation of heat-trapping gases, the key missing piece is lowering demand for GHG-producing vehicle trips. According to (Ewing & Nelson, 2008), a dramatic shift in the old paradigm is needed immediately; rather than lowering congestion, planners and engineers need to effectively lower ALL types of GHG-producing trips, at all times. Thus far, California's Air Resources Board (as shown in their 2008 Scoping Plan) has not recognized the enormous role that land use planning and urban design needs to play in coordination with transportation planning (Ewing & Nelson, 2008).

Furthermore, a common strategy considered in California—as well as in many of the visioning processes in the past two decades (in Portland, OR; Salt Lake City, UT; the Los Angeles Metropolitan Area; etc.)—is a "blueprint visioning" plan which often focuses on intensifying development around transit stations. In all of these cases, regional agencies try to work to balance the needs of numerous local governments. However, as Deakin (2008) points out, these blueprint plans "are not yet backed by an implementation strategy." Furthermore, while these "blueprint visioning" processes are underway across California, "The problem, of course is that the state has not yet developed a coherent

<sup>&</sup>lt;sup>78</sup> United States Census of Population and Housing. (2000).

<sup>&</sup>lt;sup>79</sup> Furthermore, Handy (2006a) says "there seems to be little evidence that building walkable communities will do anyone any harm.

<sup>&</sup>lt;sup>80</sup> Daniel McFadden is the 2000 Nobel Prize winning economist for his pioneering work developing logit models for mode choice analyses, exposing how people weigh such attributes such as speed, comfort, cost and time.

vision for growth nor planned for the infrastructure that it would require" (Deakin, 2008). Additionally, across the country many regions are considering retrofitting existing parkand-ride rapid transit stations, as well as building new stations. Furthermore, billions of dollars are now being considered for high-speed rail (HSR) projects meant to serve, in part, auto-dependent rural/suburban areas – mirroring many of the stations in this study and presenting a challenge to optimize the achievement of sustainability benefits.<sup>81</sup>

While it is often a matter of debate, few would disagree that rapid transit projects, like most highway projects, have often fallen short of realizing their full potential.<sup>82</sup> In many U.S. cities, rail transit can lower automobile dependence, GHG emissions and our reliance on foreign oil. To do so, we must improve connections between riders and rapid transit stations. One way to improve these connections is to fully understand how various factors—especially the built environment of the surrounding community, station design, internal and external operations of the transport systems, and the personal attributes of the riders—influence rapid transit access travel behavior. Another factor considered in this research is the cost and accessibility of station area parking. The findings of this research affirms the argument of Cervero that subsidized (free) and oversupplied parking discourages sustainable development and sustainable consumer behavior (Cervero et al., 2009b). This dissertation finds that better management of parking (e.g., of the price, convenience, and supply) may encourage more people to walk or bicycle to access rapid transit stations. Furthermore, coax current drivers out of their cars, freeing up spaces for those who must drive, attracting new users to the rapid transit system.

While this dissertation pursues better ways to measure and analyze the influence of the urban environment, it also presses on the question of how to take better advantage of high-capacity transit systems. The San Francisco Bay Area Rapid Transit (BART) system, like many similar rapid transit systems<sup>83</sup> across the country, designed many of its non-CBD transit stations to optimize automobile access and circulation, with local bus, pedestrian, and bicycle access left as an afterthought. Local buses, pedestrians, and bicyclists often experience difficulties operating in the same space as automobiles. This intermodal conflict discourages non-auto access to stations. If these conflicts are not resolved, many commuters will continue driving to transit stations, even for short trips. Transit access behavior needs to change in order to improve air quality, lower greenhouse gas emissions, and increase opportunities for physical activity. Together these changes will not only contribute to sustainability, but also to community vitality in terms of economic growth, public health, and social equity.

<sup>&</sup>lt;sup>81</sup> There are many high speed rail (HSR) systems proposed for California, Florida, Texas, and Pennsylvania among others speak to the growing interest in HSR across the U.S. However, the provision of convenient access to HSR stations will undoubtedly require the careful planning and design of station area land uses.

<sup>&</sup>lt;sup>82</sup> O'Toole, Randal (2008, April 14). Does Rail Transit Save Energy or Reduce Greenhouse Gas Emissions? Retrieved 2/9/09, from the Cato Institute Web site: <u>http://www.cato.org</u>

<sup>&</sup>lt;sup>83</sup> DC's WAMATA, Atlanta's MARTA, LA's Metro, and the numerous commuter rail systems around the country and the world.

## 6.3 Reflections

On the face of it, this may appear to be a myopically technical dissertation. But underlying the innovation herein is a tale of social networking and knowledge transfer, with long hours spent in conversation, face to face, on the phone, or via emails, discussing new ways to measure the urban environment for meaningfully applications in a broad range of research and analysis. Google, ESRI, MTC, and BART all donated valuable data. But perhaps more importantly, they graciously shared with me their knowledge of how to do things. This technological transfer was indispensable to achieving the objectives laid out in this work.

Surely they benefitted from my coming up with the questions emerging from the issues I was wrestling with; and I equally benefitted from their sharing with me the knowledge and skills to perform the tasks that led to the creation of these new methods to measure the urban environment. Such interplay is the foundation of meaningful innovation – between those who endeavor diligently at a computer or in a lab furthering our technical skills and tools and those who are in the trenches, clawing their way through the "wicked"<sup>84,85</sup> muck to find solutions to the issues before them. The healthy tension between these two task environments leads to relevant innovation and is, at least metaphorically, represented in this dissertation through the quest to ensure that the new methods to measure the urban environment balance both reliability and validity.

This dissertation shows that it is not only knowing how to do something that matters, but knowing what to do and how it is going to be practically applied. Innovation without this understanding risks becoming irrelevant.

Creating meaningful innovations to solve important problems does not easily occur when people work alone. And although this dissertation represents many hours working in solitude, I was constantly reaching out to others. Effective innovation occurs because dedicated people communicate and purposefully assist each other. At its core, the gracious sharing of knowledge is a tremendously admirable human quality. In the case of this dissertation, people did not do this for monetary gains, but for higher purposes – in large part to help another person who hopes his work can help make the world a better place.

Such applied, trans-disciplinary collaborations are essential if we are to achieve the critical sustainability objectives needed to secure a better future for the people of the world.

<sup>&</sup>lt;sup>84</sup> Rittel, H., Webber, M. (1972).

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