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Defining, Measuring, and Evaluating Path Walkability, and Testing Its Impacts on Transit Users’ Mode Choice and Walking Distance to the Station

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Spring 2008

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by

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Spring 2008

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ABSTRACT

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Sungjin Park

Doctor of Philosophy in City and Regional Planning

University of California, Berkeley

Professor Michael Southworth, Chair

The major purpose of this research is to test the effects of street-level urban design attributes on travel behavior. There are two goals: (1) operationalizing path walkability, which includes developing a walkability measurement instrument and quantifying path walkability, and (2) testing the effect of path walkability on transit users' access mode choice and walking distance to the station.

A case study was conducted in the station area of Mountain View, California. In 2005, three different surveys were done. A station user survey was conducted by distributing self-administered, mail-back questionnaires to the entering transit users at the gates of the station. The user survey collected access mode choices, trip origins, and socio-economic data from 249 transit users who provided their routes. A walker perception survey was conducted with 68 transit users who walked to the station. This on-board survey asked them to score their walking routes. Based on the routes identified by both surveys, this research selected 270 street segments. For each segment, 30 street

elements were measured by using a two-page survey instrument. The surveyed street data produced more than 40 path walkability indicators.

The first part of this dissertation conducted a factor analysis with the path walkability indicators derived from the 249 surveyed routes, and found four path walkability factors: “sidewalk amenities,” “traffic impacts,” “street scale and enclosure,” and “landscaping elements.” With the four factor scores as new variables, a pair of logit analyses was conducted. All four path walkability variables significantly influence transit users’ mode choice decision – good walkability increases the transit users’ chance of walking over driving to the station. The second part created a composite walkability index based on the walker perception survey result. The walkability index was also tested in mode choice models, which confirmed that good path walkability increases the chance of walking. The third part conducted a regression analysis of transit users’ walking distance, and found that a traveler’s walking distance increased by more than 300 feet for every 0.5 increase in the composite walkability score. This research also found a donut-shaped critical walking zone, where walkability mattered more.

Chair ____ Date_________________

DEDICATION

To Junhee, Gene, and My Parents

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Acknowledgements

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Mountain View station. Most of them were busy with their own dissertations and theses, but helped me when I had a hard time recruiting surveyors. It was a job no one else would do; they had to wake up at 3:30 AM for a one-hour trip to Mountain View to catch the first riders of the mornings. Special thanks also go to David Son, Lydia Kim, Eunjoo Im, and Devon Williamson, who helped with street measurements under the scorching California sun. My high school friend, Sungsoo Ryu, held a lantern and a clipboard on many nights while I measured luminosity in Mountain View. At that time, he was working for a Silicon Valley hi-tech company earning a six-figure income without a Ph.D., and never understood my obsession. I finally thank Yeontae Kim for providing me with graphic advice, and Changdeok Kang, who shared his knowledge of GIS and provided me Santa Clara County DEM data.

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Sungjin Park

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INTRODUCTION

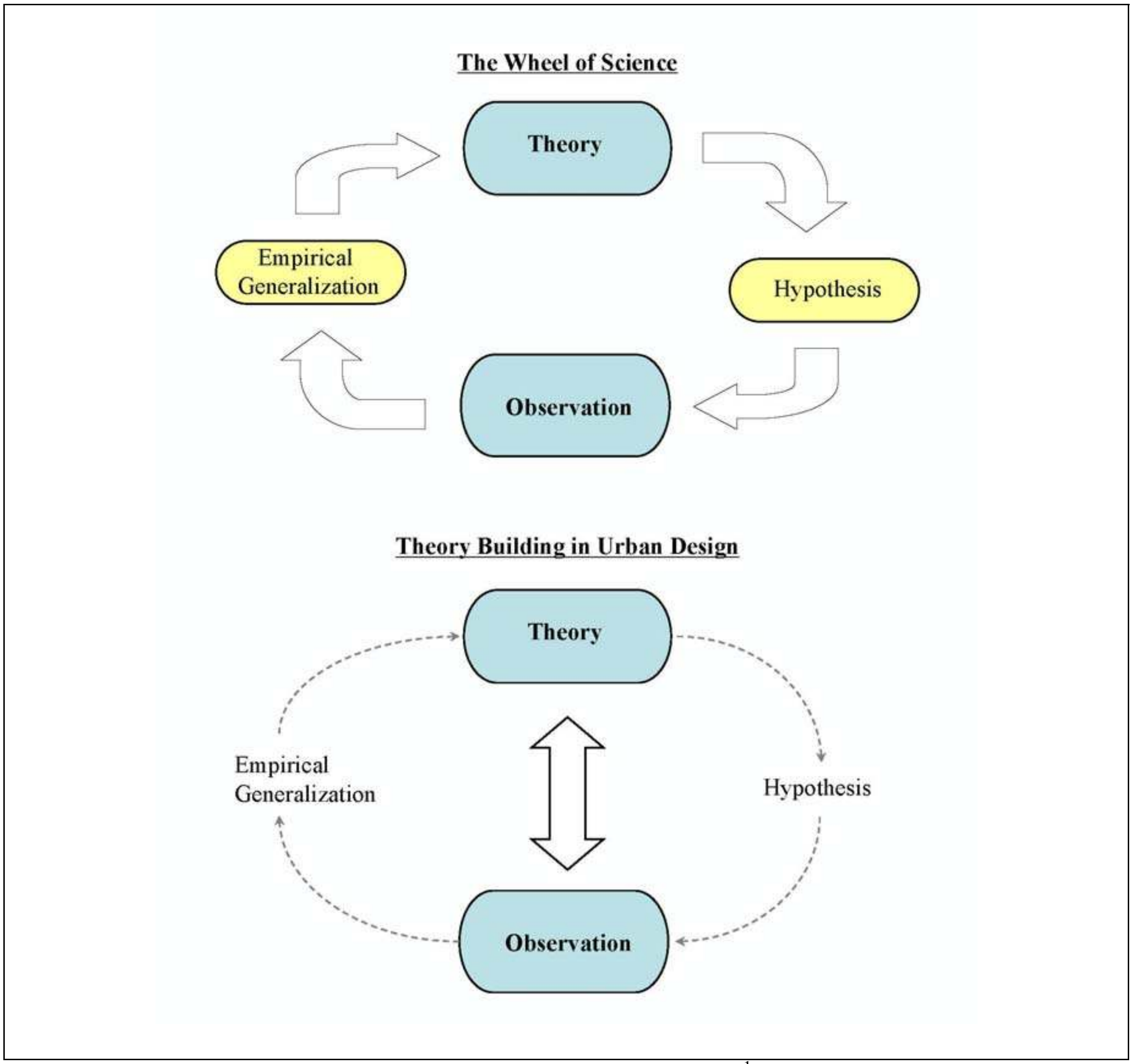
Dreaming of Neo Empiricism…

For a long time, urban design research has remained in the realm of subjectivity. The insights of the great early urban design theorists have not been fully tested during the last three decades. Urban design theory has often been built on intuition, observation, and experience, rather than on scientific research evidence (Figure 0.1). The lack of scientific evidence could lead to no interventions and no improvements, because there are no facts to convince policymakers. In the struggle for public money, those with the fact have more chance to get the funds.

Walkability research is no exception. Many design principles and codes for good walkability have been established, claimed, and practiced. Most of them seem “right” – intuitive, logical, and circumstantially supportable – but they are not backed by scientific research evidence. This might be one reason most of us do not live in walkable cities.

It is important to find scientific research evidence for behavioral benefits of good walkability. The purpose of this research is to help find the evidence that can be trusted, embraced, and utilized by those in other academic fields. The author hopes that this research will become part of new empirical foundation for future urban design theories.

Figure 0. 1: Scientific Theory Building Process



Sources: “the wheel of science” was adapted from Healey, 1999.[1]

[1] It was originally from Walter Wallace. 1971. The Logic of Science in Sociology. Chicago: Aldine-Atherton.

Lack of Scientific Research Evidence in Walkability Research

Walking is currently an intense topic of discussion in planning. People are starting to look at increasing walking as a means to solve many social ills, from global warming, air pollution, traffic congestion, and foreign oil dependency, to obesity and other health problems. While planners, policymakers, and researchers are all eagerly looking for ways to encourage people to walk, relatively little attention has been paid to the quality of the street-level walking environment, which this research calls "path walkability." Some policymakers have not viewed improving path walkability as a viable way to encourage people to walk, partly because the lack of proof that path walkability affects walking travel behavior.

The lack of research evidence is linked to the lack of objective ways to define and measure micro-level walkability. Travel behavior research has not been fully successful to embrace urban design attributes in defining and testing walkability, mainly because there has been little objective and systematic way to measure and quantify urban design attributes. Therefore, many studies overlooked street-level factors that urban designers believe to be important in walkability, such as street enclosure and façade permeability. Instead, many studies connecting the built environment and walking travel behavior evaluate the walking environment based on macro-level urban form and land use attributes, such housing density and street patterns at the census tract level. But, changing these neighborhood level attributes is often more difficult and costly than improving micro-level walkability. Improving micro-level walkability could be a useful planning tool, but only after the behavioral benefit of micro-level walkability is tested in a scientific way. The first step for the test is to develop objective ways to measure and evaluate micro-level walkability.

Hypotheses and Structure of the Dissertation

The primary goal of this dissertation is to test the effect of path walkability on travel behavior, assuming that actual benefit can best be measured by possible behavioral change. Two kinds of travel behavior will be tested: transit users' access mode choice, and walking distance to the station. This research tests the following two hypotheses:

Hypothesis 1: A higher level of path walkability will increase transit users' likelihood of choosing walking over driving to the transit station.

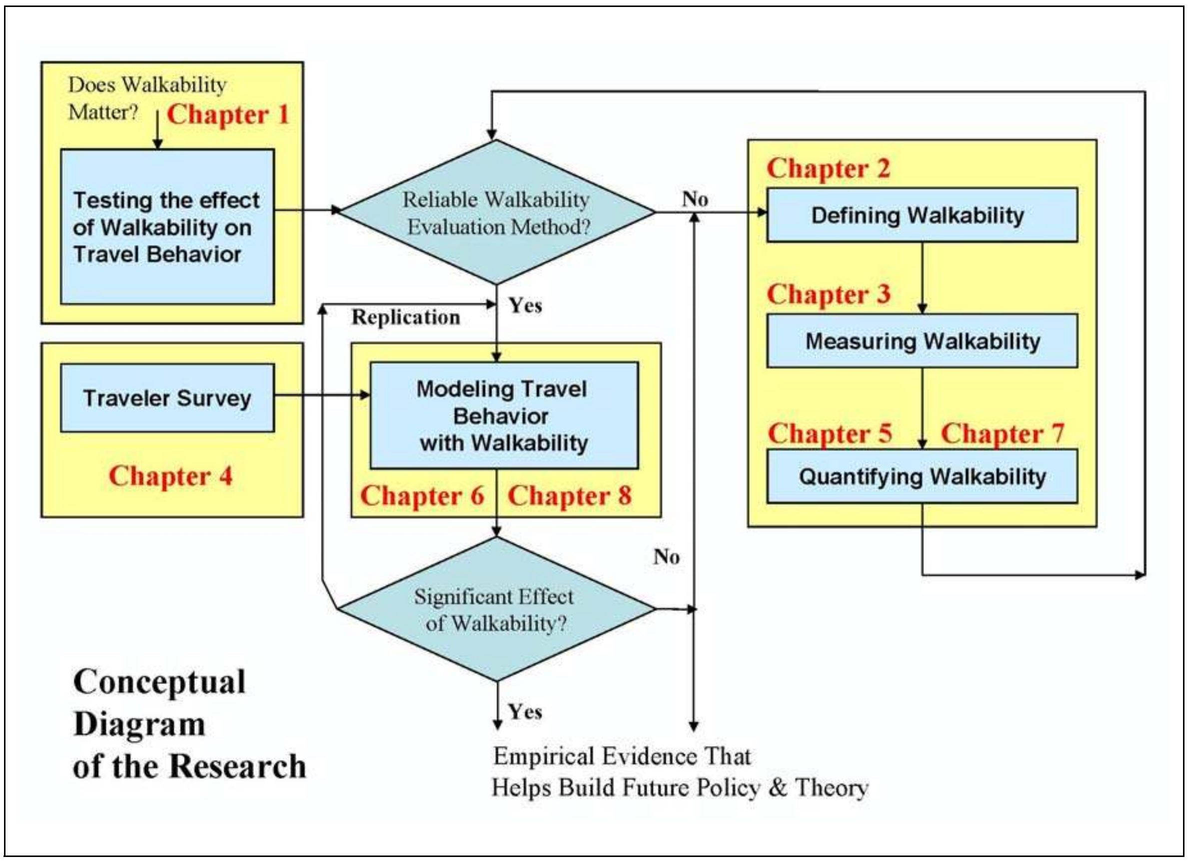
Hypothesis 2: A higher level of path walkability will increase the distance transit users will walk to the transit station.

Figure 0.2 shows the conceptual structure of this research and the goal for each chapter. Chapter 1 discusses existing walking and walkability-related literature. One problem of this research was that when the research began there were few comprehensive walkability evaluation methods available, which embrace micro-level design attributes.[2] Therefore the author began by defining micro-level walkability in Chapter 2, and new

[2] Boarnet el al. 2006 and Ewing et al. 2006 were published two years later.

methods to measure micro-level walkability were developed in Chapter 3. Meanwhile, in concert with devising the measuring methods, an appropriate site was selected in Chapter 4; this was a suburban transit station in Mountain View, California. Research design for testing the effects of walkability and survey method for collecting traveler information were also discussed in Chapter 4.

Figure 0. 2: Conceptual Diagram of the Research



Two different ways of quantifying micro-level walkability were explored; path walkability was quantified by an inductive method in Chapter 5 and by a deductive method in Chapter 7. With the new path walkability variables derived from Chapter 5 was tested using mode choice models in Chapter 6. The new path walkability variable, a composite walkability score from Chapter 7 was tested using mode choice models in Chapter 8. The effect of walkability on transit users' walking distances was also tested in Chapter 8.

1. LITERATURE REVIEW

1.1. Walking Matters, But Does the Walking Environment Matter?

Today, walking matters. With so many associated benefits ranging from reducing air pollution, traffic congestion, and foreign oil dependency to slowing down global warming, to solving obesity and other health problems, "walking" has become a critical research topic in America. There has been an increasing amount of walking-related research in planning, transportation, and public health. If walking can bring promising economic, environmental, and health benefits to our society, maybe one of the most critical questions for planners is how to encourage people to walk.

As policy makers eagerly look for ways to encourage people to walk, an increasing number of urban designers and transportation planners are interested in improving the walking environment as one incentive. Can an improved walking environment encourage people to walk? Will people choose to walk instead of drive if the sidewalks are lined with storefronts and have more landscaping? Or would they walk more and farther if their streets had more trees, lights, and benches? Many urban designers intuitively believe that walking is encouraged by improving the walking environment, but there has been surprisingly little scientific evidence so far to support this claim. The connection between the walking environment and actual walking is still missing.

One reason for the lack of research evidence could be linked to lack of cooperation between urban design and transportation researchers. Most walking behavior studies have been dominated by researchers with transportation backgrounds, and their studies have often overlooked micro-level walking environment and thus not fully tested its effect on walking travel behavior. Meanwhile, the urban design researchers haven't been fully successful either in developing objective methods to measure and evaluate micro-level walkability.

1.2. Walking-Related Studies in the Past.

The two planning groups most actively pursuing walking-related topics during the last half century have been transportation planners and urban designers, although their foci have been quite different. The former group is interested in analyzing the walking travel behavior, whereas the latter is more interested in the quality of walking environment (Southworth, 2005). One might think that those two groups could easily come together to test the effect of the walking environment on walking travel behavior. But so far it has not been easy for either group to leave its own territory. However, recently some travel behavior researchers have started paying more close attention to the effect of the micro-level walking environment on travel behavior, while some urban design researchers have started developing objective ways to measure and quantify the micro-level walking environment, which is a prerequisite for modeling walking behavior.

1.2.1. Transportation Literature

Traditionally, walking has been overlooked by the transportation research, which focused more on motorized travel. The walking environment has continued to be ignored even more, and until recently relatively little research has been done on walking behavior in the relation to the walking environment. The dominant documents shaping the walking environment in postwar American cities were engineering road design manuals. The primary purpose of the manuals was to create efficient traffic flow (Southworth and Ben-Joseph, 2003), and thus early road design manuals paid less attention to the walking environment (e.g. AASHTO, 1973; ITE, 1965).

In the early 1970s, researchers started paying more attention to the pedestrians and their walking behavior. But still some studies continued to apply traffic engineering concepts to walking. Their primary interests were walking speed, spacing between pedestrians, and flow of the pedestrian movement, which reflected the concepts used in a highway operation. Methods to estimate the demand (pedestrian volume) and supply (infrastructure, mainly sidewalk width) were developed (Fruin, 1971; Pushkarev and Zupan, 1975). The primary goal of their research was to maintain an optimum level-of-service, providing unobstructed pedestrian movement. Later their emphasis on optimum capacity influenced engineering road design manuals, which included design guidelines for pedestrian facilities (AASHTO, 1984; ITE, 1989). For these manuals, creating a good walking environment was to have a sidewalk wide enough to provide unobstructed movement for a given number of pedestrians.

Another functional value emphasized by the road design manuals has been traffic safety. This has always been a major concern for the drivers, and therefore the transportation engineers took it as a critical value in evaluating the walking environment, because their priority was also on the unobstructed flow of auto traffic without any conflicts with pedestrians (Southworth and Ben-Joseph, 2003). Undoubtedly pedestrian level-of-service and safety were very important issues for pedestrians, but road design manuals' emphasis on them sometimes led to ignoring other attributes. The functional view deeply influenced many walking advocates' pedestrian design guidelines (Harkey, 2004; Bicycle Federation of America 1998) and also research focusing on the walking environment. For example, there have been a series of transportation studies to measure and quantify the micro-level walking environment (Emery et al 2003; Gallin 2001; Landis et al 2001; Evans et al 1997). They indeed try to measure some micro-level data, but the selected variables are predominantly related to pedestrian level-of-service and traffic safety, such as the total number of traffic lanes, average width of sidewalk, and types of traffic control device.

Undoubtedly, this engineering tradition set in motion by Fruin and Pushkarev significantly shaped the way to define, measure, and evaluate the walking environment in transportation planning. Applying the value of efficiency to human behavior, however, their research overlooked the qualitative aspects of walking. Pedestrians interact with their surrounding environments more directly than drivers in fast-moving vehicles. But, transportation researchers rarely asked pedestrians directly about their perception of the walking environment, and sometimes paid too much attention to capacity building, which may be a necessary condition but not a sufficient one for a good walking environment. For example, the width of the sidewalk was promoted as the most important indicator to evaluate the quality of the walking environment, but crowded sidewalks are hardly a major problem in most American cities. By the same token, an accident-free street is most likely to be an auto-oriented street restricting all other uses than auto traffic, and this is hardly a good walking environment either. Safety is important, but in auto-oriented American cities, given the lesser emphasis on pedestrian activity, there is a possibility that separation for safety unequally worked against having a good walking environment and eventually reinforced auto-dependency.

It was not until recently that engineering manuals have acknowledged the importance of other qualitative walking values, such as comfort, sense of security, and visual attractiveness (AASHTO 2004). But still most pedestrian design guidelines emphasize the functional values over qualitative aspects.

1.2.2. Urban Design Literature

Since Jane Jocobs' seminal work in the early 1960s, many urban design theorists have made creative contributions to the theories of good walking environment (Jacobs 1961). They tried to answer the question: What makes for an enjoyable walking experience rather than simply what creates an efficient walking flow? Unlike researchers with transportation backgrounds, they looked at non-functional aspects of walking, such as sense of security and visual interest.

According to this body of literature, other pedestrians are no longer impediments to anyone's walking travel. They attract more pedestrians and street activities ("self-congestion" in Whyte, 1980) and increase the sense of security ("eyes upon the street" in J. Jacobs, 1961). The elements of a good pedestrian environment should be addressed at the street level ("path quality" in Lynch, 1974). Residential streets should serve not only auto drivers but all kinds of users sharing the space (Southworth and Ben-Joseph, 2003). Pedestrian access also needs to be improved by leveling walking routes and eliminating grade separation ("barrier free access" in Untermann, 1984). Automobiles are a threat to the pedestrians that need to be tamed ("traffic calming" in Buchanan, 1963 and in Appleyard, 1981) or have their negative environmental effects buffered ("green buffer zone" in A. Jacobs, 1990). Researchers have also looked at the space created by nearby buildings and their role as quasi-public space that increases street livability ("soft edges" in Gehl, 1987). Theorists are also interested in how pedestrians perceive their walking environment: the unfolding vistas experienced as one moves through the traditional townscape ("sequence of revelation" in Cullen, 1961), and the perception of space should be related to the time of movement ("simultaneous movement system" in Bacon, 1967).

Perhaps the most important work in this field is Jane Jacobs' 1961 book, *Life and Death of Great American Cities*. She paid attention to the values of the walking environment, which had been overlooked, such as a sense of security and pedestrian comfort. She insisted that a sense of security in a public space is critical and can only be maintained by the existence of other people – pedestrians, shop owners, and restaurant customers (J. Jacobs, 1961), and her observation still has a fresh meaning in improving the public space of today's American cities. Another important reference is Donald Appleyard's 1969 study, *Livable Streets*. His research team conducted a comparative case study in three street segments in San Francisco, which existed in the same neighborhood but with significantly different traffic volumes. His research found that fast-moving automobiles discourage social interaction and street activities, and therefore critically decrease neighborhood livability (Appleyard, 1981).

While the findings were very interesting, what made his research important lay not in the findings but in his effort for scientific research design. He set the tone for future environmental research with his unique research design: quasi-experimental, micro-level comparative case study with environmental factors as independent variables and human perception/ behavior as a dependent variable. His empirical approach also emphasized detailed data collecting. To objectively measure environmental factors, he conducted micro-level street survey, which measured all the dimensions of streets, including the width of rights-of-way and sidewalks, and also gauged traffic characteristics, including average daily traffic volumes, speed, and noise. To evaluate the effect on human behavior, his research team administered household interviews, to ask about residents' perceptions of social interaction, privacy, and territoriality. His seminal research design and methods were revisited by Bosselmann et al (Bosselmann et al. 1999), but have not been fully utilized by other urban design researches to test the possible benefit of the good walking environment.

Undoubtedly the intuitive observations of the urban design theorists have helped expand the meaning and role of the walking environment, but after their contributions, there has been little effort to prove their claims in a scientific way. Urban design researchers have not been interested in developing an objective way of measuring the walking environment and in testing the early theorists' intuitions based on the measurement. There have been few, if any, controlled comparative case studies or research based on user perception surveys. With little scientific evidence, the urban designers' theories have relatively little chance of being implemented. Their findings have been incorporated into design guidelines for the local governments, but often as an appendix to a city's general plan. The guidelines are often just suggestions that carry little legal force and are thus less influential than the engineers' road design manuals in shaping the walking environment of American cities.

Since the early 1990s, the New Urbanists entered the walkability discussion. While New Urbanist design projects garnered growing public support, they have not been fully successful in measuring and testing the micro-level walkability. Without viable tools to measure and test the micro-level walking environment, their interests gradually shifted to macro-level, walking-conducive "urban form," which already have well-established theoretical foundations through the years of research in non-design fields, especially transportation planning (see Section 1.4). The walking-conducive urban form was often represented by compactness, mixed-use, and a gridiron pattern. Although they are very promising attributes, it might be very difficult to achieve them, which designers traditionally have relatively little control in most existing urban areas, because changing them often require political solutions rather than design solutions.[3]

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[3] They could be achieved more easily in a master-planned new development

1.3. Recent Research on Walking and Walkability

1.3.1. Travel Behavior Research

Since the early 1990s, a group of transportation researchers took the lead in walking travel behavior research. Through comparative case studies, they have tried to test how environmental factors affect walking travel behavior (Cervero 2003; Greenwald and Boarnet 2001; Handy 1996). At the beginning, they were interested in the potential of micro-level design attributes (Cervero and Kockelman 1996; Handy 1992), but they soon found that those design variables are not compatible with traditional transportation research design. Facing difficulties in data collecting, they ended up excluding micro-level design variables in their research and focusing more on the effects of macro-level "urban form," or the "built environment." The "urban form" is often measured by three major variables: housing density, land use diversity, and neighborhood street patterns.[4]

These are important variables to test because they have a great potential to positively influence people's walking behavior and physical activity. The three variables are expected to foster more walking trips in the following ways: (1) Increased housing density near the transit station or bus stop reduces the trip distance to public transit; (2) Neighborhood land use diversity reduces the trip distance to shopping and other services; and (3) A close-knit grid street pattern increases "connectivity" and thus reduces trip distance. Thus the major benefit of the three "urban form" variables is basically to

[4] "Urban form" is different from urban designer's "city form."

improve neighborhood accessibility. Accessibility has been a central theme for today's travel behavior research, but accessibility alone cannot completely measure the walking environment, at least from the urban designer's point of view. Increasing efficiency by reducing walking distance does not necessarily lead to improving the quality of walking experience, which urban designers value most. Thus these three "urban form" variables do not fully represent the values of urban designers because their expected benefits are not always parallel to the values of urban design.

The "urban form" concept misses most pedestrian-level urban design attributes that capture the quality of streets, sidewalks, and nearby buildings. The literature often mentions the importance of "design" variables in measuring "urban form," but most of them look solely at the macro-level (neighborhood level) street patterns (e.g., the grid vs. cul-de-sac).[5] Under the "urban form" approach, the most commonly measured design attributes are intersection density (*number of three-way and four-way intersections per square mile*), dead-end density (*number of dead- ends per square mile*)*, and average block size*, which can be collected by using Geographic Information System (GIS) or other desktop applications even without a single field observation. These neighborhood-level data cannot capture any difference between streets, whose pedestrian-friendliness may vary even within a neighborhood.

There seem to be two reasons for the inability of the "urban form" to include micro-level urban design attributes. The first reason is the scale of measurement. Travel behavior researchers in transportation are often interested in the entire picture of travel

[5] For further discussion, see Rodriguez et al. 2006.

behavior, including other motorized travels, and thus their studies are designed to deal with quite large study areas and to rely on pre-existing regional travel data. Collecting detailed qualitative design data is almost impossible on a scale of their research designs (Southworth, 2005). Secondly, until recently little viable, available method has been developed to measure and quantify micro-level urban design attributes. However, developing such a method may not be either strength or interest of travel behavior researchers. It is the job of urban design researchers, whose interest lies more in the micro-level walking environment. But so far, walking-related studies in transportation and urban design have not been fully successful in developing a comprehensive definition of walkability that integrates the interests of both fields. A fair amount of credit, however, should be given to some travel behavior researchers, who have tried to embrace the “design” attributes even though the attributes are beyond their traditional research interests.

1.3.2. Research Measuring and Quantifying Walkability

One of the seminal attempts to measure and quantify walkability was a 1993 study, “Making the Land Use, Transportation, Air Quality Connection” (LUTRAQ), conducted in Portland Oregon (1000 Friends of Oregon, 1993). The research team developed the Pedestrian Environmental Factor (PEF) index with the following four indicators: (1) ease of street crossings, (2) sidewalk continuity, (3) local street characteristics (grid vs. cul-de-sac), and (4) topography. Each indicator was scored on a

3-point scale and the composite score, ranging from 4 to 12, was calculated for each of 400 transportation analysis zones (TAZ).

Since the mid-1990s, scholars have developed many indices to measure and quantify the walking environment, for example, the Pedestrian Level-of-Service (LOS) (Dixon, 1996; Landis et al., 2001; Gallin, 2001), the Transit Friendliness Factor (Evans, 1997), the Environmental Scale Evaluation (Saelens et al., 2003), and the Walking Suitability Assessment (Emery et al., 2003). One notable research effort was the “Safe Routes to School” study conducted by a UC Irvine research team led by Marlon Boarnet (Boarnet et al., 2003, 2005). The research monitored a walkability improvement project near local schools and surveyed parents’ mode choices and perceptions. They found that the improvement led to an increase in walking to the school. This research effort led to the development of the Irvine-Minnesota Inventory, a list of built environment features developed by Marlon Boarnet’s research team (Boarnet et al., 2006; Day et al., 2006). The purpose of the inventory is to provide a reliable measurement tool to test the correlation between the neighborhood built environment and physical activity, which includes walking. Their research yielded an extensive list of built environment attributes –162 items in four different categories: accessibility, pleasurability, perceived safety from traffic, and perceived safety from crime. One of the most important issues in environmental measurement is inter-rater reliability: the authors tested how accurately and consistently each item could be measured by surveyors.

With a growing interest in the possible correlation between the built environment and physical activity, there has been a series of recent efforts to develop environmental audit methods (Moudon et al., 2006; Moudon and Lee, 2003) and GIS-based environmental audits (Schlossberg and Brown, 2004). The major goal of the research was to yield an operational definition that provides an objective way of both measuring walkability and a systematic way of quantitatively evaluating it.

Ewing and Handy's 2006 research is the most significant published effort so far to embrace qualitative urban design concepts in defining walkability and to quantify the attributes (Ewing et al, 2006). They used expert panel studies, inviting urban design and planning experts to evaluate the walkability of streets, which were filmed by the research team. They analyzed measured walkability and expert ratings to find the statistical relationship between them. Based on the results of multinomial models, they developed an "operational definition" and "measurement protocols" for urban design attributes determining walkability. A similar method is used to operationalize path walkability in Chapter 7 of this dissertation.

1.3.3 Research on Transit Users' Walking Distance

There has been relatively little research done on how far transit users will walk to the station, and whether walkability influences their walking distance. There have been two notable studies conducted in North America. A Canadian study done in Calgary showed that 75 percent of his sample walked 2,756 feet (840 meter) or less to a suburban LRT station, and the distance was shorter in the CBD, at 1,375 feet (419 meter) (O'Sullivan and Morrall, 1996). Weinstein et al. conducted surveyed transit users at five transit stations in the Bay Area and in Portland, Oregon. Although it varied by station, they found that 75 percent of travelers walked maximum (network) distances between 3,643 feet (0.69 mile) and 5280 feet (1 mile). A majority of the survey respondents chose the shortest route (64%), which was their first priority, and safety was their second priority (28%) (Weinstein et al., 2007). The transit users' walking distance to the downtown Mountain View station is analyzed in Section 8.2 and 8.3.

The literature review on transit access mode choice modeling is included separately in Section 4.2.

2. DEFINING WALKABILITY

2.1. Boundary and Scale of Defining and Measuring Walkability

The term "walkability" is growing in popularity, but there still is a great deal of confusion in defining it (Southworth, 2005). Like other terms in urban design, such as "livability" or "sustainability," the meaning of "walkability" is evolving and seemingly expanding with each new suggestion. This snowballing makes it harder to define what walkability is in a concrete way. Today many non-design determinants, such as housing density and land use, have been added and seem to play an even greater role than design factors in defining walkability. As a result, many design practitioners and walking advocates think of walkability as the neighborhood "urban form" with some added micro-level design characteristics. This urban form-based walkability, defined and measured at the neighborhood level, could limit both urban design research and practice in the following ways:

First, in urban design research, using this broad definition of walkability will reduce the future likelihood of proving the possible effects of the urban design attributes on walking travel behavior. The three major urban form variables – neighborhood housing density, land use diversity, and street patterns – require a (geographically) larger scale research than street-level urban design attributes. Previous travel behavior research shows that researchers sometimes had difficulties in measuring density and land use variables at the street-level, or could not afford to collect all the micro-level urban design data at the macro-level. Such macro-level travel behavior studies have not been able to test what urban designers traditionally believe to be critical for walking. Second, in urban design practice, modifying urban form is often beyond the urban designers' realm in practice, because in many existing urban areas, they relatively have little control over land use, density, and even street patterns unless they are designing for a master planned new town. Changing the street patterns or zoning codes in an existing urban setting is difficult and frequently beyond the urban designers' scope (Handy, 2006).

Thus it may be more beneficial to narrowly define walkability, focusing on micro-level design attributes, and to measure walkability on a smaller scale. First, measuring walkability at the street level rather than at the neighborhood level will allow researchers to conduct disaggregated travel behavior analyses, taking advantage of delicate individual variations in walking environment. In other words, walkability of a traveler's route can be analyzed for a specific trip rather than using the walkability of the traveler's entire neighborhood. Second, in defining walkability, it may also be beneficial to focus on the micro-level attributes, which can be easily improved than a neighborhood urban form. For example, improving street designs can be done at a relatively low cost and with less public opposition than changing zoning ordinances or street patterns.

In terms of definition boundary and measurement scale, this research defines walkability as the quality of walking environment perceived by the walkers as measured by micro-level urban design attributes. A more complete definition of walkability will be proposed in the later subchapters (6.5. and 7.9).

2.2. Operationalizing a Construct

Walkability is a "construct." Aneshensel defined a construct as "mental images or representations of intangible things that are thought to exist but not in a material or physical form," and stated, "a construct cannot be observed directly precisely because it is intangible" (Aneshensel, 2001). For example, a tire or a pencil is not a construct because one can directly observe it and know what it is. However, most academic concepts are constructs – "anxiety" in psychology, "capitalism" in social science, "state" in political science, "utility" in economics, "intelligence" in education, and "biodiversity" in ecology (Ewing, Pendall, and Chen, 2002). By the same token, many terms in the fields of planning and landscape architecture are also constructs, such as sprawl, smart growth, sustainability, and livability. Because of the intangible and fuzzy nature of a construct, empirical research in social science has to define the construct both in an operational and a conceptual way. A conceptual definition tells what the construct is, but does not explain what to observe and how to accurately and concretely measure it. There are various walking definitions from walking advocates' pamphlets and academic articles, but most of their definitions are conceptual rather than operational.

Generally, an operational definition is referred by a number of smaller and tangible components that represent parts of the construct; inclusion and exclusion of the marginal components eventually determine the boundary of the construct (Gerring, 2001).

Operationalization also requires measuring these components[6] in an objective way, and ideally quantifying them. For example, the Merriam-Webster dictionary defines "anxiety" as "painful or apprehensive uneasiness of mind usually over an impending or anticipated ill."[7] This conceptual definition tells roughly what "anxiety" is, but it is not sufficient to decide whether a person has anxiety, or person A is in a higher anxiety level than person B. Anxiety itself is not directly observable. Behavioral indicators, such as nervous tics or a painful facial expression, can be observed, and physical indicators such as blood pressure or pulse can be measured. But these could also indicate some other types of mental or physical condition. The only way to find out is asking the person if he or she feels anxious, but researchers do not ask directly "are you anxious?" because anxiety is a complicated concept that subjects can interpret differently. Identifying or measuring anxiety is even more difficult if the researcher is investing a special kind of anxiety. The best way of dealing this complexity is to indirectly ask about a smaller component, which is more tangible, and thus easier to measure. "Uncertainty" might be one component, through which the researcher might indirectly ask the subject about the construct. For example, the researcher could ask, "are you currently waiting for some pending decision that is very important to your future?"[8] For statistical purposes, these questions are usually designed to have scaled answers using the Lickert scale (e.g. see Figure 2.1).

[6] In social science, components are generally called "variables," but this research calls them components to avoid possible confusion with the travel and socio-economic variables used for the mode choice models in the later chapters

[7] The author used the first definition of "anxiety" from www.w-m.com

[8] This question was created as a plausible example to explain the relationship between a construct and a component, with no theory-based knowledge in the subject

Figure 2. 1: Example of the Lickert Scale

3. based on the images you have seen, how desirable is the neighborhood in terms of: a. stores and services -3……….-2……….-1……….0….…….1….……2………..3 undesirable neutral very desirable

Sources: (from Cervero and Bosselmann,1998, p80)

The final result will be more useful, if the score for each component can be associated with measurable behavioral or physical indicators. If the researcher can survey a significant number of subjects using a standardized questionnaire, and also measure their behavioral/physical indicators with objective measurement instruments, the surveyor may correlate a certain combination of behavioral/physical indicators with the level of uncertainty. Thereafter the behavioral/physical indicators can be used as a proxy for the uncertainty component of anxiety. If the researcher can also find observable and measurable proxies for the other components of anxiety, he or she may be able to create an anxiety index. The index can then be tested as an experimental variable in statistical modeling, which eventually maximizes the benefit of operationalization.

Walkability is also a construct, which is still exploratory at best, because there has been very little attempt to operationalize it. Walkability may be more complicated to operationalize than anxiety, because environmental and human factors must be considered simultaneously. One would like to define walkability using physical indicators, but equally important are individual perceptions and behaviors: whether people want to walk and/or actually do walk. Ordinary people might define walkability more narrowly than urban design experts, focusing purely on their own needs and interests when they evaluate walkability. Thus it is important to divide walkability into its smaller and more tangible components. In order to complete the operationalization, this research investigates the associations between physical/environmental indicators and real users' perception about the environment, and also statistically determines the physical proxies for the qualities that matter the most to the potential walkers. Undoubtedly this is the greatest challenge for this research.

2.3. Inductive Operationalization and Deductive Operationalization

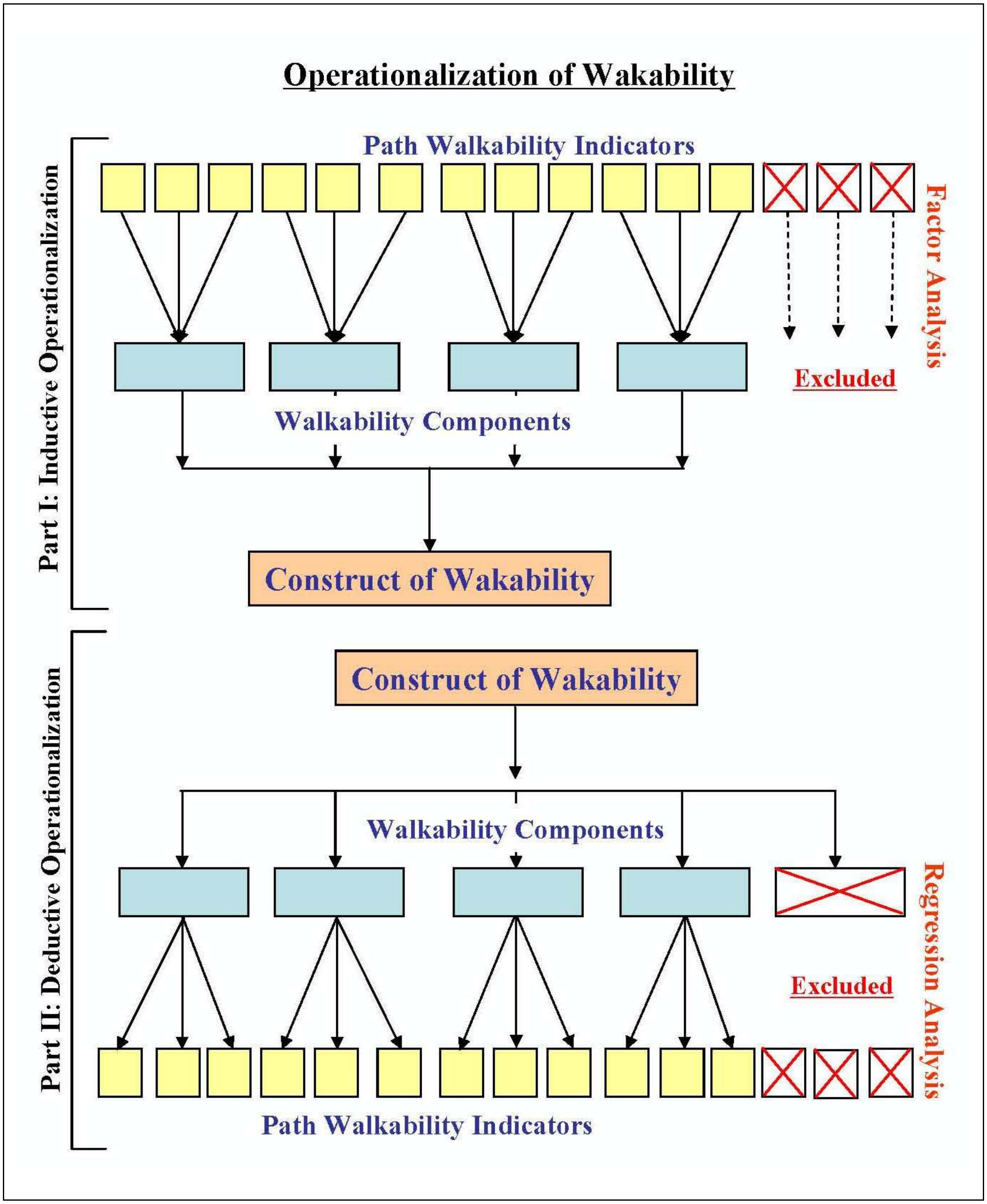
There appear to be two different ways to operationalize walkability especially in determining walkability components and associating them with walkability indicators. The first method is inductive operationalization. Here a researcher ignores any findings or claims from the previous research and creates new components (or often called reference variables[9]) directly from his/her environmental measurements. A statistical tool called "factor analysis" can be used for this purpose. Cervero and Kockelman used this method to extract three reference variables, which are now famously referred as the 3D (density, diversity, and design), to define the construct of the "built environment." These three new variables were extracted directly from their environmental measurements, which minimizes human bias, including both researchers' presumptions

[9] The author used "components" rather than "variable" to differentiate them from travel and socio-economic variables used for the mode choice models in the later chapters

and subjective human perceptions of their environment. This method is useful for exploratory research when the goal is to define a construct or to redefine a construct by discovering new sets of reference components. The inductive method suits this dissertation research, which attempts to redefine walkability differently from previous approaches.

The second method is deductive operationalization, where a researcher decides the reference components for his/her construct, usually based on the existing theory. Having the right set of reference components is very important to define the boundary of a construct; including or excluding a certain reference component at the initial stage is entirely up to the researcher. Ewing et al. used this method to define walkability (Ewing et al, 2006). They determined reference variables based on the existing urban design claims and theories, and tested their associations with "walkability" scores provided by a "design expert" group. This method is used more widely than the inductive method for two reasons: first, using the inductive method is somewhat risky because there is a high chance that it may not derive meaningful reference components from the factor analysis; second, unlike the case-specific factor scores (to be used as the proxies of reference components), the regression formula from a deductive operationalization can be easily applied to other cases. However, deductive operationalization can introduce human bias, both from researchers and evaluators, and thus could be less objective.

Figure 2. 2: Inductive Operationalization vs. Deductive Operationalization

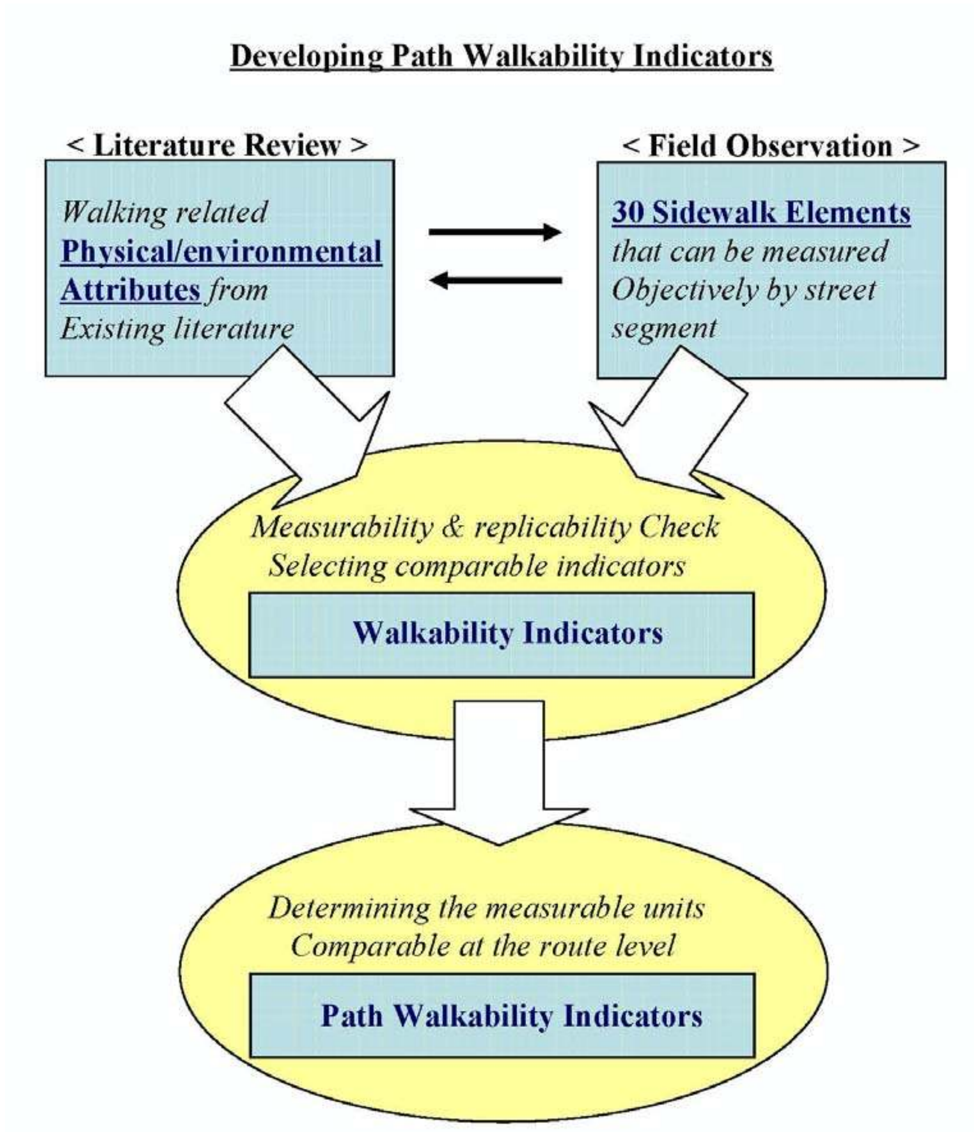


The ideal research method would be to use inductive operationalization first and then use that result for deductive operationalization, that is, to use the reference components extracted from the factor analysis for deductive operationalization. However, even used separately, these two methods can be complementary: if the researchers can prove that when they put the two constructs (one from inductive operationalization and the other from deductive operationalization) into behavioral models as an experimental variable, the two constructs lead to the same result, then this result will give added credence to the deductive method.

Both inductive and deductive operationalizations were used to define walkability in this dissertation. Chapter 5 defines walkability through inductive operationalization, starting with empirical environmental measurements, and extracted walkability components from the walkability indicators. Chapter 7 develops walkability components from the previous research and derives a composite walkability index through a deductive operationalization. This research began with an inductive operationalization of walkability because it is more objective. The walkability derived through the inductive method was tested using a mode choice model. In Chapter 7, deductive operationalization was applied to the same data base to create a composite walkability index, and the index was tested using the same model. The hope is that the two methods will yield the same result, giving credence to the composite walkability index derived from the deductive operationalization. Walkability will be fully operationalized (defined) throughout the next five chapters, and it is simply referred to as "the quality of the micro-level walking environment."

2.4. Walkability Attributes from Existing Literature

Figure 2. 3: Developing Path Walkability Indicators



To operationalize walkability, the first step is to decide what physical attributes to examine and measure (Figure 2.3). This research reviewed previous walking-related studies, focusing on what physical/environmental attributes are mentioned as potential indicators influencing pedestrian perceptions and behavior, instead of on how the existing literature defined walkability. There are many physical/environmental attributes that have been explored and given importance by previous research. Although many of them are logical and intuitive, most of them have never been tested by scientific methods. This research reviewed various existing literature and determined the attributes that could be measured and eventually converted into walkability indicators.

The final set of walkability indicators was established and the street survey was started in early 2005, which means that some relevant studies published after 2005 could not be included.

2.4.1. Attributes Related to Curb-to-Curb Roadways

Many studies have pointed out that various attributes related to curb-to-curb roadways might influence pedestrians. The general idea is that a wider street draws fast-moving traffic, which decreases the sense of safety, and thus a narrower street is more pedestrian-friendly (Southworth and Ben-Joseph, 2003, p8). Southworth and Ben-Joseph suggested 24 feet as the ideal curb-to-curb width. Using the same logic, some studies focused on the traffic zone, counting only the roadway space for moving traffic and excluding the width of street parking and bike lanes. Some researchers counted the number of traffic lanes instead of the width of traffic zone. Lamont and Boarnet used the number of through-traffic lanes excluding turning lanes in their studies (Lamont, 2001, p293; Boarnet, 2003, p11). Emery's Walking Suitability Assessment Form used three categories: less than three lanes, three to four lanes, and more than four lanes (Emery, 2003). Some researchers insisted that a smaller number of traffic lanes is also beneficial for pedestrians because it reduces street crossing distance (Harkey and Zegeer, 2004, p63). Various researchers have also pointed out the contribution of traffic calming elements to pedestrian safety, because they also reduce traffic speed (Boarnet, 2003; Ewing, 2005).

2.4.2. Attributes Related to Pedestrian Crossings

What makes pedestrian crossing safer and easier? Many studies have answered this question by suggesting the crossing design attributes, such as the types of crosswalk markings, quality of illumination/signage, raised pedestrian crossings, existence of median/refuge islands, and curb extensions (Bicycle Federation of America, 1998, p37, p44, p48, p53). Crossing distance, pedestrian crossing signals, traffic volume, and traffic speed have also been addressed (1000 Friends of Oregon, p5, p11). Other researchers have pointed out that special pavement for crossings and one-way traffic may also contribute to safer and easier pedestrian crossing (Harkey and Zegeer, p54; Lamont, 2001, p293). Some studies have also claimed that mid-block crossings are critical for pedestrians (Bicycle Federation of America, 1998, p53).

2.4.3. Attributes Related to Buffer Zone

There are many studies claiming that a buffer zone between the walking zone and the traffic zone is important because it protects pedestrians from the negative impact of fast-moving traffic (Jacobs, 1993, p293; Boarnet, 2003, p11, vii; Jacobs and Macdonald, p108; Guttenplan, 2001, p151; Landis et al, 2001, p85-86). The buffer zone is defined as the space between the edge of the sidewalk and the edge of the thorough-traffic lane, including the following three major street elements: landscape strips, parking lanes, and bike lanes.

Lamont measured the "tree/shrub planting strip" and also noted whether the street had "parallel, diagonal, or perpendicular on-street parking (Lamont, 2001, p295). The benefit of on-street parking was pointed out by Lynch and Hack: "Curb parking can be ameliorated by occasional projections of the planting strip, to break the line of cars and to provide a safe launching pad for crossing the street" (Lynch and Hack, 1984, p265). Some literature also promoted "angled on-street parking" (Calthorpe and Poticha, 1993). There was no research insisting that bike lanes help pedestrians, but it would add three to four additional feet into a buffer zone, and possibly decrease traffic speed.

2.4.4. Attributes Related to Sidewalks

The importance of the characteristics of the sidewalk is mentioned by almost all walking-related studies. The existence and width of the sidewalk has been the focal point of many (Bicycle Federation of America, 1998, p24; Emery, 2003, Appendix; Boarnet, 2003, p11; Knaap, p24). One notable concept is having a "clear passage," excluding sidewalk space that accommodates street appurtenances, such as parking meters, planters, mail boxes, light poles, benches, transit shelters, fire hydrants, and utility poles (Bicycle Federation of America, 1998, p28).

The minimum width of the clear passage is another popular concept, which originated from pedestrian level-of-service studies. Three feet of clear passage is frequently mentioned (ITE, Design and Safety of Pedestrian Facilities; Bicycle Federation of America, 1998, p29). The underlying logic is that two adult pedestrians walking opposite directions need three feet of width to pass without conflict. However, no researchers have tested whether less than three feet of clear passage significantly affects pedestrian perceptions or behavior. Another issue is the sidewalk length. Some researchers claim that lengthy sidewalk segments (or blocks) at the neighborhood level are associated with lower levels of street connectivity and thus work against pedestrians (1000 Friends of Oregon, 1993, p5; Boarnet, 2003, p11). But at the route level, longer blocks or segments might work for pedestrians because they may reduce conflict points with traffic and delay time spent on crossing streets.

Driveway curb-cuts is also mentioned as an important attribute of sidewalks, because they reduce sidewalk continuity (Bicycle Federation of America, 1998, p38; Boarnet, 2003, vii), although some research haven't found any correlation between driveway curb-cuts and the perceived safety of pedestrians (Landis et al., p87). This is one of those street elements that is difficult to measure: How does one differentiate a curb-cut into a single family lot from a curb-cut into a Macdonalds parking lot?

Sidewalk steepness might also be an important walking-related attribute. Some studies suggest a 10% grade as a maximum acceptable steepness (Lynch and Hack, Site Planning, p218; Bicycle Federation of America, p30). Although a slope gives more views sometimes, it seems intuitive that a steep sidewalk is not good for pedestrians (Jacobs, 1993, p305), but there has been little effort to test steepness and pedestrian behavior. There has been relatively little research interest in types of pavement, though in his Walking Suitability Form, Emery gave higher scores to sand/dirt/gravel/woodchip than asphalt/concrete/brick pavements (Emery, 2003).

2.4.5. Attributes Related to Sidewalk Facilities

The importance of street trees was mentioned in numerous studies. Jacobs et al. pointed out two benefits of street trees: shading from sunlight, and physical and psychological buffer from fast-moving traffic (Jacobs et al. 2002). Some scholars also claimed that trees effectively reduce wind velocities (Lynch and Hack, p55). Ewing's visual preference survey found that "trees along the street" was one of the top five determinants influencing bus users' route choice to bus stops (Ewing, 2000, p24). Many researchers mentioned street furniture (Ewing, 2000; Boarnet, p11), but there has been relatively little discussion about what kinds of street furniture matter and how they influence pedestrians. Some studies also mentioned street lighting, especially pedestrian-level lighting (BFA, p21; Harkey and Zegeer, p57), reflecting an intuitive belief that well-lit streets are important for pedestrians' sense of security.

2.4.6. Attributes Related to Street Scale and Enclosure

Urban design experts have pointed out that there may be an "intimate human scale," which is determined by street width (building-to-building distance) (Jacobs, 1993, p278). This theoretical human scale is based on whether a pedestrian on one side of the sidewalk can recognize the facial expression of pedestrian on the other side. Building height has also been proposed as an important factor in street scale. Jacobs cited Blumenfeld's study claiming that three-story (or 30-foot) buildings, (along with a-36 foot building width and a 72-foot street width) is the maximum dimension for human scale. To evaluate building scale, Knaap et al. suggested measuring both "average height of buildings" and "average width of buildings" (Knaap et al., p24). Jacobs also suggested that the ratio between building height and street width is important. He claimed that the best ratio is 1:3.3, such as a 20-foot building height coupled with a 66-foot building-to-building distance, while 1:2 (or less) gives a strong sense of enclosure, and 1: 5 (or more) shows a weak sense of enclosure (Jacobs, 1993, p280). He also mentioned "the spacing of buildings along a street"; he believed that "tighter spacing" creates "street definition." Knaap et al. suggested measuring the percentage of block face without building façades to measure "street enclosure" (Knaap et al., p24). Lamont called the same concept "streetwall quality" (Lamont, 2001).

2.4.7. Attributes Related to Nearby Buildings and Properties

Building setbacks have often been mentioned (Knaap p24, Lamont, 2001), but there has been no findings as to whether a building setback is good or bad for pedestrians. Façade transparency has been mentioned by many researchers (Jacobs, 1999, p285; Lamont, 2001; Boarnet, 2003, p11). The general concept is that more façade with transparent glass, especially on the first floor, is good while a blank wall is bad for pedestrians (Urban Design Guidelines, City of Tampa Bay). It has also been suggested that it is better for pedestrians when an entrance to a building faces the street rather than parking lots (Calthorpe and Poticha, 1993; Knaap et al.). Fencing has also been suggested as an attribute influencing pedestrians (Lamont, 2001). Mixed land use was also considered a good attribute for pedestrians (Lamont, 2001; Calthorpe and Poticha, 1993), while vacant lots and unoccupied buildings are bad (Boarnet, 2003, p11). Commercial uses are generally considered good for pedestrians, but without explanation as to what kind of commercial use.

There is no shortage of literature dealing with physical attributes that might influence pedestrian perceptions and behavior. The attributes mentioned above were included as candidates for walkability indicators of this research. Among those attributes, however, only those that can be measured in an objective way were eventually selected as walkability indicators. After the measurability test (Section 3.2.), this research excluded many possible attributes because they are difficult to objectively measure. There were two groups of excluded physical attributes:

(1) This research excluded abstract attributes with blurry boundaries that were hard to measure objectively: e.g. sidewalk maintenance, garden maintenance, building façade maintenance, existence of graffiti, street art, street vistas, architectural quality, and architectural diversity in style.

(2) This research excluded non-physical, time-sensitive indicators, such as the number of pedestrians, traffic speed/volume, or sidewalk shading.

With the list of the street attributes selected from the literature review, the next step was to decide the street elements that should be measured to capture those attributes.

3. MEASURING WALKABILITY

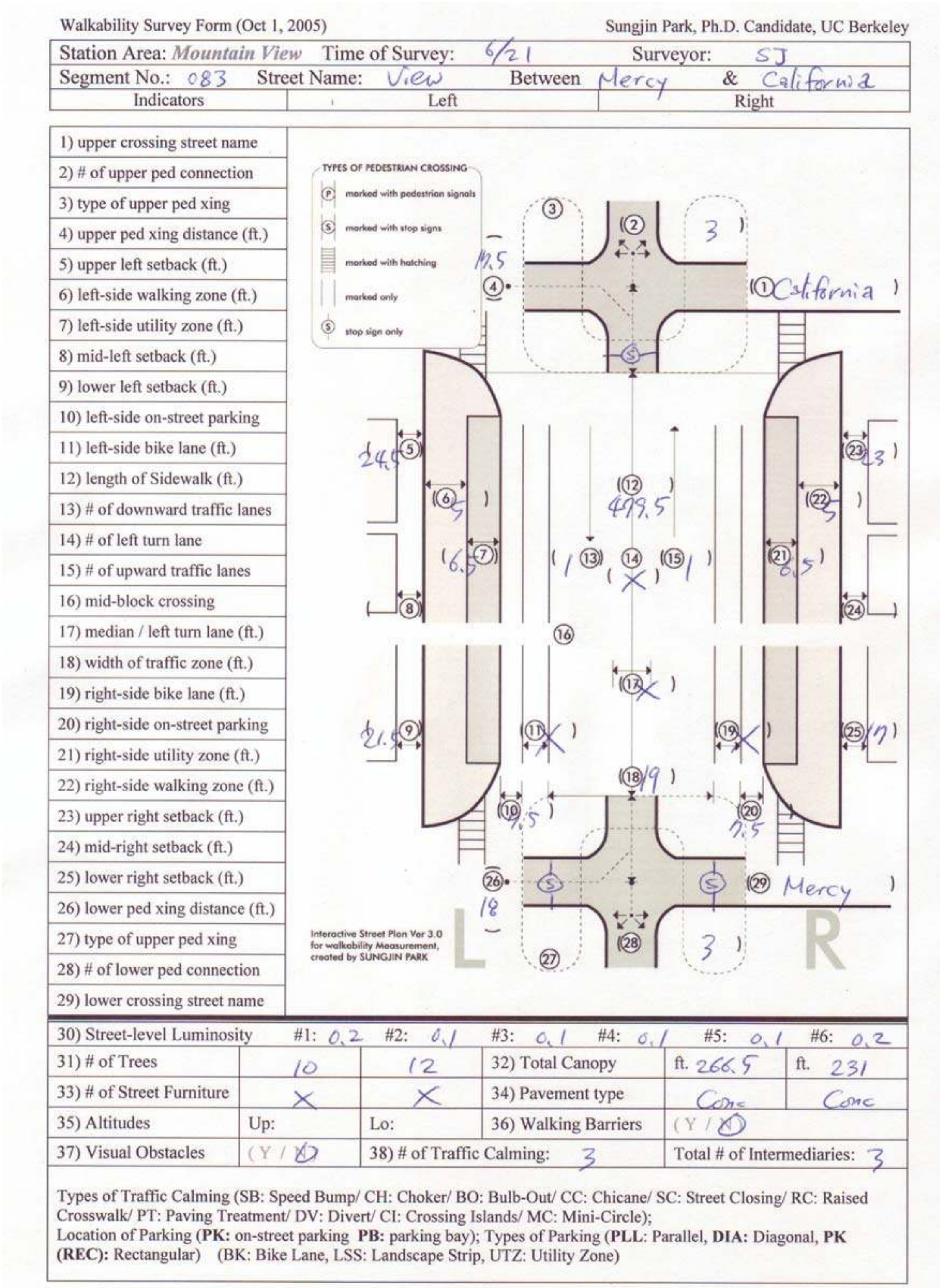
In selecting the candidates of possible walkability indicators, this research tried to be as inclusive and detailed as possible, but the main question was how many attributes and how much detail can be measured without losing objectivity. Although the literature on street attributes is rich, only a small portion of it provided concrete measurement methods. It was left to the author to evaluate the measurability of each attribute and then to develop walkability measurement instruments.

3.1. Developing the Walkability Measurement Instrument

Unlike most previous studies focusing on neighborhood walkability, this research focused on capturing micro-level walkability, most of which can only be measured on foot at the street level. In late 2004, the author went into the streets near the North Berkeley and Rockridge BART stations near the UC Berkeley campus with a wheel measurer and clipboard. The author experimented with measuring street elements for each candidate of walkability indicator, and included and excluded them based on their measurability.

One of the most difficult things in the street survey was to accurately record detailed spatial data. Recording all the details by street segment or even by building with only a list of street elements was overwhelming. It became clear that it would be much easier to record and read the survey data, if the survey form had interactive maps. The

Figure 3. 1: Walkability Measurement Instrument I



Walkability Survey Form (Oct 1, 2005) Sungjin Park, Ph.D. Candidate, UC Berkeley

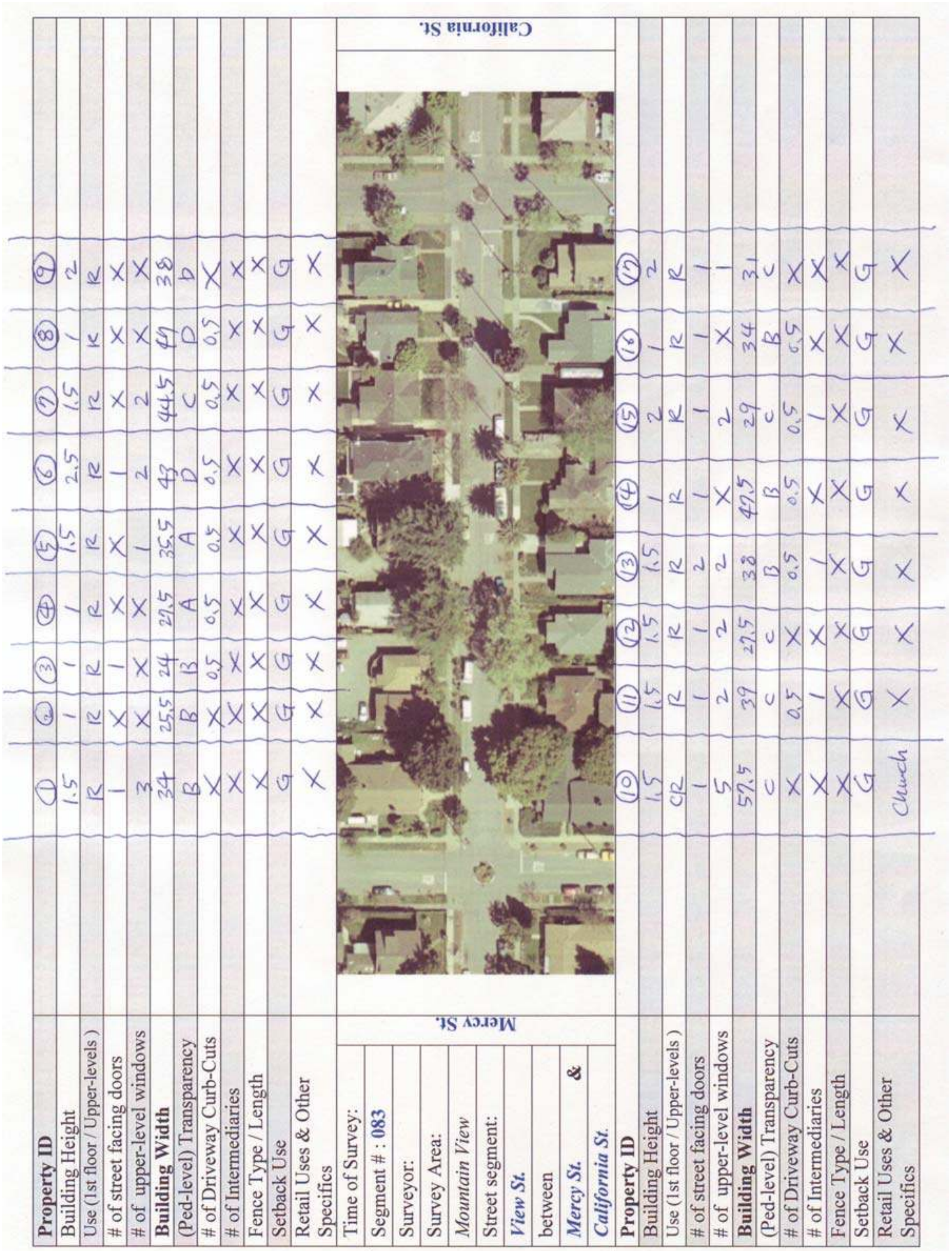
Station Area: Mountain View	Time of Survey: 6/21	Surveyor: SJ
Segment No.: 083	Street Name: View	Between Mercy & California

Indicators	Left	Right
1) upper crossing street name		
2) # of upper ped connection		
3) type of upper ped xing		
4) upper ped xing distance (ft.)		
5) upper left setback (ft.)		
6) left-side walking zone (ft.)		
7) left-side utility zone (ft.)		
8) mid-left setback (ft.)		
9) lower left setback (ft.)		
10) left-side on-street parking		
11) left-side bike lane (ft.)		
12) length of Sidewalk (ft.)		
13) # of downward traffic lanes		
14) # of left turn lane		
15) # of upward traffic lanes		
16) mid-block crossing		
17) median / left turn lane (ft.)		
18) width of traffic zone (ft.)		
19) right-side bike lane (ft.)		
20) right-side on-street parking		
21) right-side utility zone (ft.)		
22) right-side walking zone (ft.)		
23) upper right setback (ft.)		
24) mid-right setback (ft.)		
25) lower right setback (ft.)		
26) lower ped xing distance (ft.)		
27) type of upper ped xing		
28) # of lower ped connection		
29) lower crossing street name		

30) Street-level Luminosity	#1: 0.2	#2: 0.1	#3: 0.1	#4: 0.1	#5: 0.1 / #6: 0.2
31) # of Trees	10	12	32) Total Canopy	ft. 266.5	ft. 231
33) # of Street Furniture	X	X	34) Pavement type	Conc	Conc
35) Altitudes	Up:	Lo:	36) Walking Barriers	(Y / N)	
37) Visual Obstacles	(Y / N)	38) # of Traffic Calming: 3		Total # of Intermediaries: 3	

Types of Traffic Calming (SB: Speed Bump/ CH: Choker/ BO: Bulb-Out/ CC: Chicane/ SC: Street Closing/ RC: Raised Crosswalk/ PT: Paving Treatment/ DV: Divert/ CI: Crossing Islands/ MC: Mini-Circle);
Location of Parking (**PK:** on-street parking **PB:** parking bay); Types of Parking (**PLL**: Parallel, **DIA:** Diagonal, **PK (REC):** Rectangular) (BK: Bike Lane, LSS: Landscape Strip, UTZ: Utility Zone)

Figure 3. 2: Walkability Measurement Instrument II



author developed a two-page survey form that corresponded to an interactive street map: the first page had a simplified street drawing designed to capture the characteristics of both the sidewalks and curb-to-curb roadways (Figure 3.1), and the second page had an aerial photo to record the attributes of nearby buildings[10] and properties (Figure 3.2). Each street survey form required a different aerial photo, which took a lot of time, but in the end it saved time and increased accuracy and replicability. Since the basic unit of street measurement was a street segment, which is a street span between intersections, a separate survey form was required to measure each street segment.

3.2. Defining Street Elements

Through a series of pilot surveys, 30 street elements were finally selected based on their measurability and replicability (Table 3.1).

Figure 3. 3: Divisions of A Street

[10] The author refers to buildings on a segment facing the street as "nearby building."

Table 3. 1: 30 Street Elements

<u>Street Elements within Curb-to-curb Roadways</u>

- Existence and Type of Pedestrian Crossings
- Existence and Type of On-Street Parking
- Existence and Type of Bike Lanes
- Number of Traffic Lanes
- Width of Traffic Zones (ft.)
- Existence of Mid-Block Crossings
- Type and Number of Traffic Calming Devices
- Existence and Width of Medians (ft.)

<u>Street Elements within Sidewalks</u>

- Width of Walking Zones (ft.)
- Width of Utility Zones (ft.)
- Width of Landscaping Strips (ft.)
- Length of Sidewalks (ft.)
- Length of Segment (ft.)
- Luminosity (fc)
- Number of Street Trees
- Lengths of Tree Canopies
- Number of Street Furniture
- Type of Sidewalk Pavement
- Walking Barriers and Visual Obstacles
- Number of Driveway Curb-Cuts
- Number of Intermediaries

<u>Street Elements within Nearby Properties</u>

- Building Setbacks (ft.)
- Numbers of Buildings
- Heights of Buildings
- Primary First Floor Use of Buildings
- Number of Street-Facing Entrances
- Number of Upper-Floor Windows
- Widths of Buildings (ft.)
- Street-level Façade Transparency
- Types and Lengths of Fences

3.2.1. Street Elements within Curb-to-curb Roadways

- **Existence and Type of Pedestrian Crossings:** For both segment intersections on page 1 of the survey form, all the pedestrian crossing facilities were recorded on the interactive map using symbols (shown at the upper left corner of the map) to identify the following four types: (1) marked crosswalk with pedestrian signal light, (2) marked crosswalk with stop sign, (3) marked crosswalk with hatching, and (4) marked crosswalk only. Surveyors also recorded intersections with stop signs only and no marked crosswalk.

- **Existence and Type of On-Street Parking:** For both sides of the street, the surveyor recorded the type of on-street parking: (1) rectangular, (2) diagonal, (3) parallel, or (4) no parking. A surveyor measured the width of the parking spaces if they were marked with lines. A surveyor allotted 7.5 feet of width to parallel parking that did not have lines, which was common in the study site.

- **Existence and Type of Bike Lanes:** For both sides of the street, the surveyor recorded the width of bike lanes.

- **Number of Traffic Lanes:** The surveyor counted the through-traffic lanes on both sides and left-turn lanes

- **Width of Traffic Zones:** The surveyor measured the width of the moving traffic zone (excluding on-street parking, bike lanes, left-turn lanes and medians).

- **Existence of Mid-Block Crossings:** The surveyor recorded if there was a mid-block crossing.

- **Type and Number of Traffic Calming Devices:** The surveyor recorded the number and types of traffic-calming devices, including: (1) speed bumps, (2) chokers, (3) bulb-outs, (4) chicanes, (5) street closings (with bollards), (6) raised crosswalks, (7) textured paving treatments, (8) diverters, (9) crossing islands, and (10) mini-circles.

- **Existence and Width of Medians:** The surveyor measured the width of the median if there was one.

3.2.2. Street Elements within Sidewalks

- **Width of Walking Zones:** The surveyor measured the width of the clear passageway for pedestrians on the sidewalk, excluding the utility zone.

- **Width of Utility Zones:** The surveyor measured the width of the sidewalk next to the curb allotted to street facilities (such as street lights or street trees) (Figure 3.4).

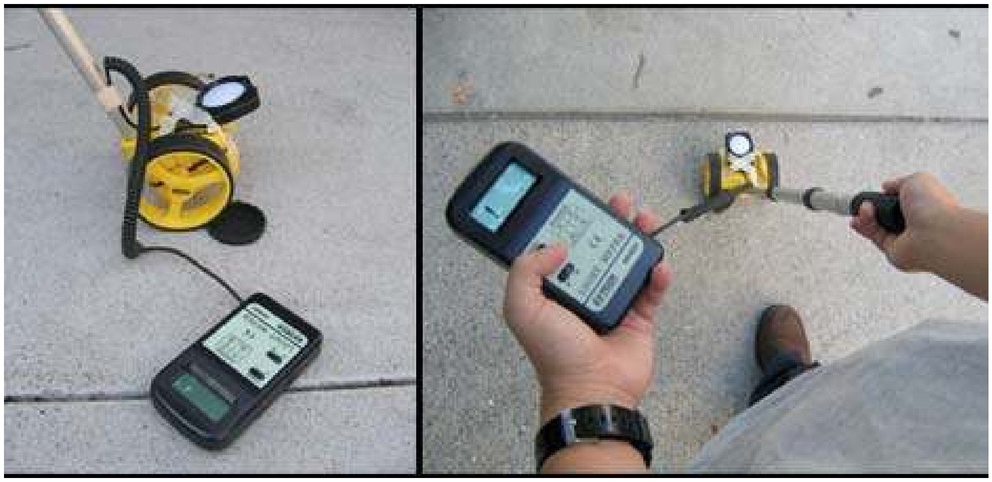
Figure 3. 4: Walking Zone and Utility Zone

- **Width of Landscaping Strips:** The surveyor recorded the width of the landscaping strips on both sides of the street.

- **Length of Sidewalks:** The surveyor measured the length of the sidewalk. A sidewalk is defined as a linear space for pedestrians separated from a traffic zone by physical devices, such as a more than 3 inches of a vertical curb, bollards, or fences. By this definition, an unpaved road shoulder doesn't count as a sidewalk, not because it is unpaved, but because it has no separating device.

- **Length of Segment:** The surveyor recorded the length between the center points of the two intersections along the street segment.

Figure 3. 5: Luminosity Measurement



- **Luminosity:** The surveyor measured light intensity (in foot candles) at six points (three on each side) on each segment (only three sample points were used if the street segment had a sidewalk on only one side, and only four sample points were selected for segments less than 150 feet long). The sample points were selected to be as evenly distributed as possible. The sample point was always the midpoint between street lightings, if there were street lights. Foot candles (fc) were measured at ground level as shown in Figure 3.5. Measuring luminosity is more informative than counting the number of street lights, because the street lighting is affected by type and height of lights as well as the uses and illumination of nearby buildings.

- **Number of Street Trees:** The surveyor counted the number of trees. This included only "street trees" planted between the traffic zones and the sidewalk passages, and excluded small trees whose girth was less than five inches and trees on a private property.

- **Lengths of Tree Canopies:** Total length of the centerline of the sidewalk walking zone covered by the tree canopies, including those planted on the private properties.

- **Amount of Street Furniture:** The number of street furniture items installed on public property only for seating (including benches, bus shelters, ledges, low retaining walls for planters, and any other devices providing potential seating.

- **Type of Sidewalk Pavement:** Most sidewalk pavement is concrete. Other varieties include colored/patterned concrete, bricks, cobblestones, asphalt, or dirt (unpaved).

- **Visual Obstacles /Nuisances:** The surveyor noted the existence of visual obstacle, such as freeway overpasses, and also noted visual nuisances, such as utility poles and hanging wires.

- **Number of Driveway Curb-Cuts:** The number of driveway curb-cuts to access private property.

- **Number of "Intermediaries":** Similar to façade transparencies, "intermediaries" are objects that connect public space on the sidewalk and indoor private space. The intermediaries counted by surveyors in this study site were small tables and chairs outside the restaurants and other businesses or on the front porches of residential buildings. The surveyor only counted those that were seen from the sidewalk.

3.2.3. Street Elements within Nearby Properties

- **Building Setbacks:** The building setback is the distance between the edge of sidewalk and the primary façade line of buildings or walls. Existence of walls kept the author from completely relying on aerial images[11], because a fence wall is not identifiable on the images, but counted as a facade. To measure this distance without trespassing on private property, the surveyor had to measure the setbacks at each end of the sidewalk. The mid-block setback was measured only when the property was not privately owned.

- **Numbers of Buildings:** The surveyor counted all the buildings on the street segment. Building structures without façades (walls) like carports are excluded. Buildings which are set back more than 70 feet from the property lines were also excluded and treated as vacant lots.

- **Heights of Buildings:** Without a practical way to measure building height, the surveyor counted the number of floors (stories) and then allotted 10 feet to each floor of residential buildings and 15 feet to each floor of commercial buildings. A half-story is assigned to attics and lofts.

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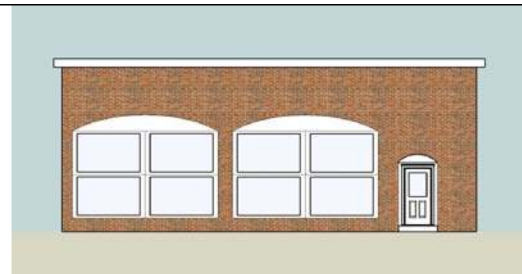
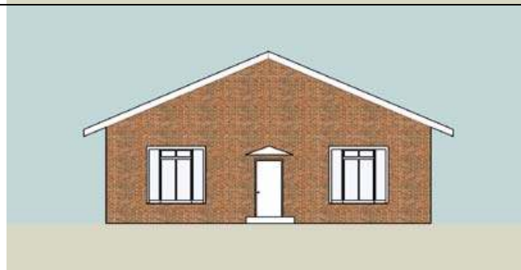
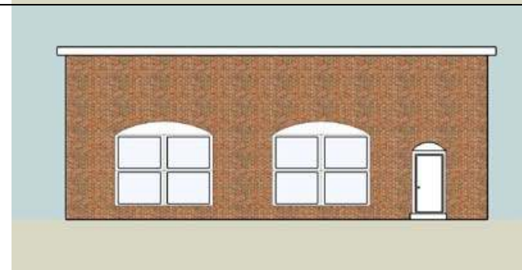
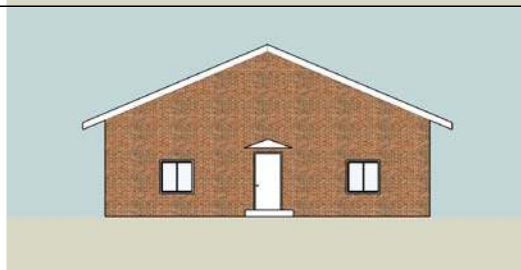
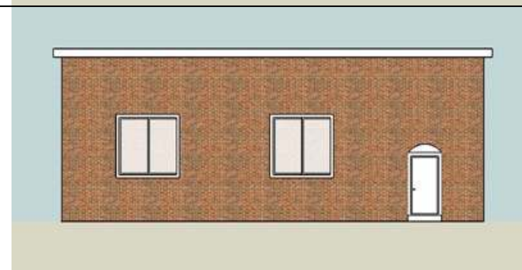
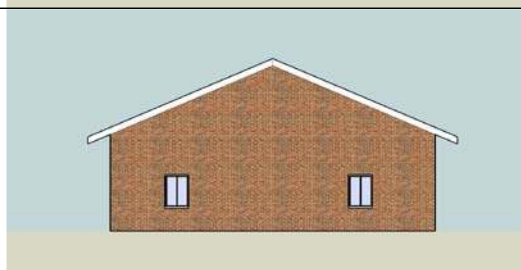
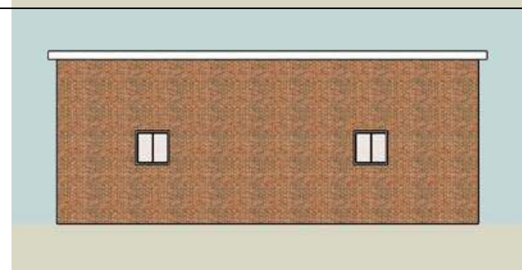
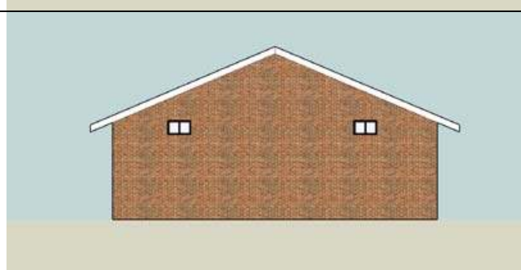
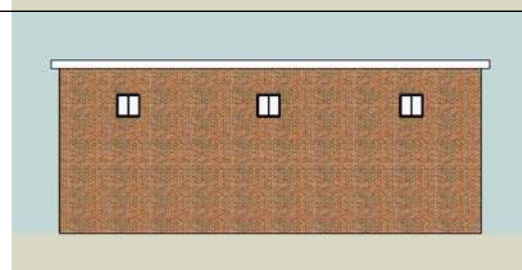
[11] A Google Earth-type computer application that helps to measure building setbacks.

- **Primary First Floor Use of Buildings:** The surveyor recorded the primary first floor use of each building in the segment: commercial, residential, office, industrial, and institutional. Additionally the surveyor recorded the specific uses of non-residential buildings, (e.g., an ice cream shop or daycare center). This detailed information will later be used to differentiate businesses, which are conducive to walking and those that are not.

- **Number of Street-Facing Entrances:** The surveyor recorded the total number of pedestrian entrances facing the street. This element relates to the orientation of the doors, not their proximity to the sidewalk, but the entrances set back from the edge of sidewalk more than 70 feet were excluded.

- **Number of Upper-Floor Windows:** The surveyor counted the number of upper-floor windows of each building facing the street in the segment. This research defines upper-floors as only the second and third floors, from which residents or other building users have good visual/ auditory access to the sidewalk. The minimum size of window was about 3 by 2 feet, this element was somewhat imprecise since there was no viable way to accurately measure the sizes of windows or know what was behind them.

Figure 3. 6: Typology of Façade Transparency

Level	**Residential**	**Commercial**
A		
B		
C		
D		
E		

- **Widths of Buildings:** The surveyor measured the widths of all buildings, including garages and other structures with walls within each property, but any building set back more than 70 feet from the property line was excluded.

- **Street-level Façade Transparency:** Transparency is defined as the degree of visual access of pedestrians into the inside space of adjacent buildings. It is mainly determined by the proportion of glass windows on the façade, but many other factors influence transparency, such as building setbacks, vegetation-blocking façades, or the elevations of the first floors. Accurate calculations of transparency could be done using a digital image of the façade, but this would have been too time-consuming and costly. Instead, this research replied on a typology designed to measure transparency in a five point scale (A – E) (Figure 3.6).

- **Types and Lengths of Fences:** The surveyor measured the lengths of fences over 4-feet height high. The types of fences were also recorded, for example chain-link, barbed wire, iron bars, or wood board.

3.3. Creating Walkability Indicators

Next step was to convert the street elements data into walkability indicators, which were standardized and thus quantitatively comparable. Most street elements could be directly converted into walkability indicators, but some indicators required further manipulation of street elements. For example, new scoring systems were developed for the walkability indicators capturing pedestrian crossings and street enclosures.

Culling potential physical/environmental attributes from the existing literature, selecting street elements through field observation and measurement, and then creating walkability indicators was not a simple linear process. Elements and indicators had to be developed interactively and incrementally through numerous trial and errors. The final 46 walkability indicators were designed to capture not only pedestrian-level design attributes, but also density (e.g. average building height, street enclosure index) and land use diversity (e.g. percentage of walking-conducive commercial uses).

3.3.1. Walkability Indicators Related to Curb-to-Curb Roadways

The following five walkability indicators were converted directly from measured street elements, and all of them were expected to have some associations with traffic speed.

(1) **Width of Curb-to-Curb Roadway:** the distance between the two curbs, which in the survey is the sum of the width of the following street elements: median/left lanes, traffic zones, bike lanes, and on-street parking lanes.

(2) **Width of Traffic Zone:** the distance between the edges of the through-traffic lanes, excluding median/left-turn lanes.

(3) **Number of Through-Traffic Lanes:** the number of traffic lanes used only for through-traffic. This was expected to be closely related to the width of the traffic zone.

(4) **Average Width of Through-Traffic Lanes:** the width of the traffic zone divided by the average number of through-traffic lanes, excluding left-turn lanes.

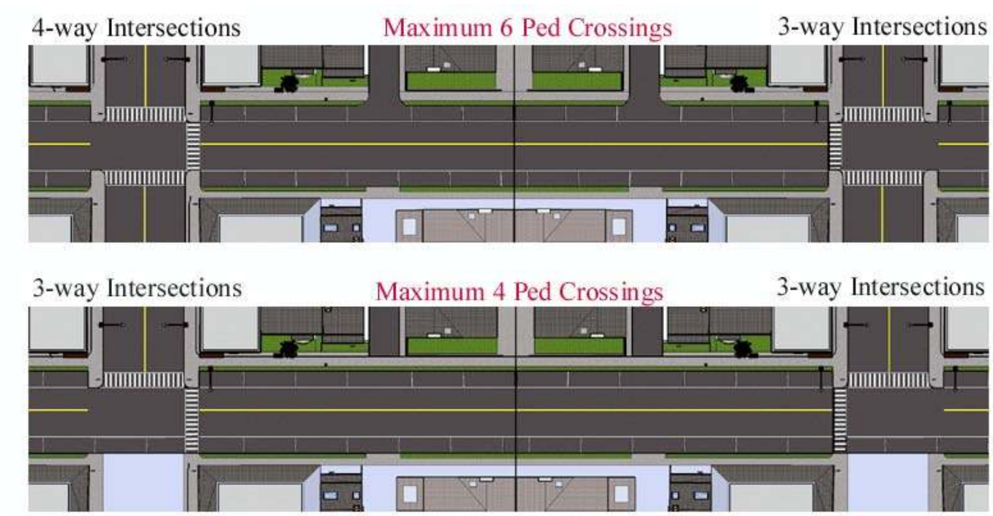
(5) **Number of Traffic Calming Elements:** this research included all ten traffic calming elements measured in the earlier subpart, weighted equally.

3.3.2. Walkability Indicators Related to Pedestrian Crossings

The existence or types of pedestrian crossings recorded on the walkability measurement instrument cannot be directly used as walkability indicators. It is difficult to convert pedestrian crossing data measured by segment into an indicator because pedestrian crossings are associated with intersections, which are also segment boundaries. That meant that one pedestrian crossing could be included in more than one segment, and the counting gets further complicated for 3-way and 5-way intersections. It was necessary to develop new scoring methods for pedestrian crossings.

To score this attribute, the author used a coverage rate. Each street segment has a maximum number of six possible street crossings (or 4 in the case of a 3-way intersection). The *pedestrian crossing coverage* indicator shows what percentage of possible crossing points have pedestrian crossings regardless of type. For example, if a street segment with 4-way stops at both ends has 4 pedestrian crossings, it has a 0.67 coverage rate (4 out of 6 potential crossings), while the segment with 3-way intersections at both ends has 3 pedestrian crossings, within an indicator of 0.75 (Figure 3.7).

Figure 3. 7: Maximum Number of Pedestrian Crossings per Segment



The author also developed two more crossing-related walkability indicators, focusing on the type of crossings. The *pedestrian signal coverage rate* is calculated in the same way as crossing coverage, but counts only those crossings with pedestrian signals. The third one, a *pedestrian crossing facility design index,* was designed to see if there was any difference in pedestrian perceptions and behavior for different types of pedestrian crossings. Each pedestrian crossing was weighted by the type of crossing: crossing with pedestrian signals = 5, crossing with markings and stop signs = 4, crossing with hatched markings = 3, crossing with markings = 2, and stop sign only =1. All weighted scores were summed for the segment and divided by the maximum number of possible crossings for the segment. Mid-block crossings were directly converted from the same name of street segment.

(6) **Pedestrian Crossing Coverage:** the total number of pedestrian crossings (regardless of type) divided by the maximum number of possible crossings. The maximum number of possible crossings depends on the street pattern. The maximum value is six for a segment that has four-way intersections at both ends, while it is four in case of two 3-way intersections.

(7) **Pedestrian Signal Coverage:** the total number of pedestrian signals divided by the maximum number of possible crossings.

(8) **Pedestrian Crossing Facility Design Index:** a total pedestrian crossing facility score divided by the by maximum number of possible crossings. The facility score was calculated by assigning values based on the type of crossing: crosswalks with pedestrian signals (5 points), crosswalks marked with stop signs (4 points), crosswalks marked with hatching patterns (3 points), crosswalks marked only with boundary lines (2 points), stop sign only (one point).

(9) **Number of Mid-block Crossings:** the number of mid-block crossings within the

segment.

3.3.3. Walkability Indicators Related to Buffer Zones

The buffer zone width and the three street elements comprising the buffer zone (landscape strips, on-street parking lanes, and bike lanes) were converted into walkability indicators. A width is a simple measurement to convert, while the existence of the three street elements yields two or more binominal dummy indicators, based on whether the segment has the element on both sides, one side, or none. Another layer is given to the on-street parking indicator by its type. It has been claimed that diagonal or perpendicular parking might have better buffering effects, or possibly slow down traffic more, than parallel parking.

(10) **Width of Buffer Zone:** average width of buffers on both sides of the street, i.e., the space between edge of the traffic lane and the clear passage of the sidewalk. In the street survey, the width of the buffer zone is the sum of the bike lanes, on-street parking, landscape strip, and utility zones.

(11) **Width of Landscape Strip:** width of the landscape strips on both sides were measured in feet and the total was averaged.

(11-1) **Existence of Landscape Strip I** (binominal dummy variable): a value of 1 was assigned if the segment had a landscape strip on at least one side; otherwise, a value of zero was given (for no landscape strip).

(11-2) **Existence of Landscape Strip II** (binominal dummy variable): a value of 1 was assigned if the segment had landscape strips on both sides; otherwise, a value of zero was given (for no or one landscape strip).

(12) **Width of Bike Lane:** width of bike lanes on both sides were measured in feet and the total was averaged.

(12-1) **Existence of Bike Lane I** (binominal dummy variable): a value of 1 was assigned if the segment had a bike lane on at least one side; otherwise, a value of zero was given (for no bike lane).

(12-2) **Existence of Bike Lane II** (binominal dummy variable): a value of 1 was assigned if the segment had bike lanes on both sides; otherwise, a value of zero was given (for no or one bike lane).

(13) **Width of On-street Parking:** width of parking lanes on both sides were measured in feet and averaged regardless of the type, but diagonal or perpendicular parking was expected to be wider.

(13-1) **Type of On-street Parking** (binominal dummy variable): a value of 1 was assigned if the segment had diagonal or perpendicular on-street parking; otherwise, a value of zero was given (for no parking or parallel parking).

(13-2) **Existence of On-street Parking I** (binominal dummy variable): a value of 1 was assigned if the segment had on-street parking on at least one side regardless of type; otherwise, a value of zero was given (for no parking).

(13-3) **Existence of On-street Parking II** (binominal dummy variable): a value of 1 was assigned if the segment had on-street parking on both sides regardless of type; otherwise, a value of zero was given (for no parking).

3.3.4. Walkability Indicators Related to Sidewalks

The following eight walkability indicators were extracted from the measured street element data.

(14) **Sidewalk Coverage Rate:** if the segment had sidewalks on both sides it had a 100% sidewalk coverage rate, and a 50% rate if it had a sidewalk only on one side. At the route-level, this indicator had a continuous range of variation.

(14-1) **Existence of Sidewalk** (binominal dummy variable): a value of 1 was assigned if the segment had sidewalks on both sides; otherwise, a value of zero was given (for a sidewalk only on one side or no sidewalk).

(15) **Width of Walking Zone:** the width of the sidewalk, excluding the utility zone. Although a small object like a fire hydrant might not be a significant obstruction, this dissertation followed the existing practice and used the entirely unobstructed passage width.

(16) **Length of Sidewalk:** the sum of the length of both sidewalks divided by two. The effect of lengthy sidewalks was unknown. A street with a lengthy sidewalk was equivalent to a longer block, which was considered a negative quality for connectivity by New Urbanists. For micro-level walkability, however, it could be good because it had less points of conflict with traffic.

(17) **Number of Driveway Curb-cuts:** the logic behind this indicator was that walkability decreases if pedestrian movement was interrupted by automobiles entering driveways. The level of interruption depended on the frequency of entering and exiting, but there was no practical way to measure this. Alternatively, the surveyor counted the number of parking spaces accessed by each driveway. If the number of parking spaces was over 20, the curb-cut scored 1.5. It scored 1.0 for 5 to 20 parking spaces, and a 0.5 for less than five parking spaces.

(18) **Existence of Special Pavement** (binominal dummy variable): Although there were many types of sidewalk surfaces, since most sidewalks were concrete, this research used a single dichotomy: concrete vs. special pavement (including colored concrete). At the segment level, a value of 1 was assigned if a half or more of the sidewalk had special pavement; otherwise, a value of zero was given. At the route-level, however, this indicator had a continuous range of variation.

(19) **Sidewalk Steepness:** the elevation difference between the end points of the segment (or route) divided by length of the segment (or route). Measuring elevation accurately was not easy. To get elevation data, this research relied on secondary data by processing DEM (Digital Elevation Model) data through a GIS program.

3.3.5. Walkability Indicators Related to Sidewalk Facilities

The six walkability indicators related to sidewalk facilities were relatively straightforward: they were directly converted from street elements without further manipulation. Later these indicators were standardized to account for segment or route length.

(20) **Existence of Visual Obstacle/Nuisance:** whether the street segment had utility poles and hanging wires, which was generally considered as a negative element.

(21) **Amount of Street furniture:** There were many different kinds of street furniture and it was assumed that all of them are not equally important. The existing literature emphasized the importance of benches and other seating facilities (Jacobs, 1993, p300; Whyte, 1980). In keeping with this, and to simplify the measurement, this research ignored all street furniture (e.g. lights, trashcans, drinking fountain) except seating facilities, including benches and seating ledges.

(22) **Number of Intermediaries:** some observers believed that the key to good walkability was to blur the boundary between the sidewalk space (the outdoors) and nearby buildings (the indoors). The author thought that the chairs and tables along store fronts and on front porches of residential buildings might play a critical role in creating a middle space between the outdoor and indoor space. In this research, the chairs and tables along store fronts and on front porches were called "intermediaries," and the surveyors counted their number within each street segment.

(23) **Number of Street Trees:** the number of street trees within each segment was counted and later used to measure tree spacing. Researchers claimed that street trees bring two major functional benefits: they work as barriers between pedestrians and traffic, and also provide shade. Tree spacing also seek to quantify the first benefit.

(24) **Sidewalk Length Covered by Tree Canopy:** This indicator seek to quantify the second benefit of street trees: providing shade. This purpose was served not only by

street trees but also by the trees on nearby properties. This research counted the length along the center line of the sidewalk that was covered by the canopy of any tree, either public or private. This indicator was expected to work somewhat better than tree spacing in reflecting the subjective arboreous quality.

(25) **Ground-level Luminosity:** Although much research has pointed out the importance of nighttime luminosity on a sidewalk, there has been little research actually measuring luminosity. How should this be measured? Illumination from nearby buildings plays a critical role in lighting, especially on commercial streets. In this case, façade transparency and building setback are as important as street light spacing and height. Because of street light height and illumination from nearby buildings, the author decided to measure luminosity instead of light spacing. The luminosity of commercial streets was not measured after 10 pm, because most stores were closed after the time. The luminosity measurement was the most difficult and time-consuming task in the entire street measurement.

Foot candle measurements would be influenced by both the elevation and location of the luminosity measuring; a protocol would have to be standardized and rigidly adhere to. Since it matters whether pedestrians had enough luminosity between sources, the author measured at the mid-points between sources. Three measurements were made for each side of the street segment that had a sidewalk. If there was no street lighting, two endpoints and a midpoint on each side were selected. For a few segments less than 150 feet long, only four samplings were made.

3.3.6. Walkability Indicators Related to Street Scale and Enclosure

While many researchers have focused only on a public space – the rights-of-way between the edges of property lines – a few have looked at a street as a whole, including nearby buildings, to assess the street scale and enclosure. Eight walkability indicators were developed to determine the scale and amount of enclosure of street segments. The four walkability indicators capturing street enclosure required manipulation of data from more than one street element.

(26) **Building-to-Building Distance:** the average distance between the building façades on the two sides of the street, which was the sum of the following street elements: medians/left-turn lanes, traffic zones, bike lanes, on-street parking lanes, landscape strips, utility zones, sidewalks, and building setbacks.

(27) **Building Height:** the average building height within the segment. The drawback of this indicator was that the value could be biased if there were only few buildings: a couple of five-story buildings have a different impact than rows of two-story buildings, but may have the similar average building height.

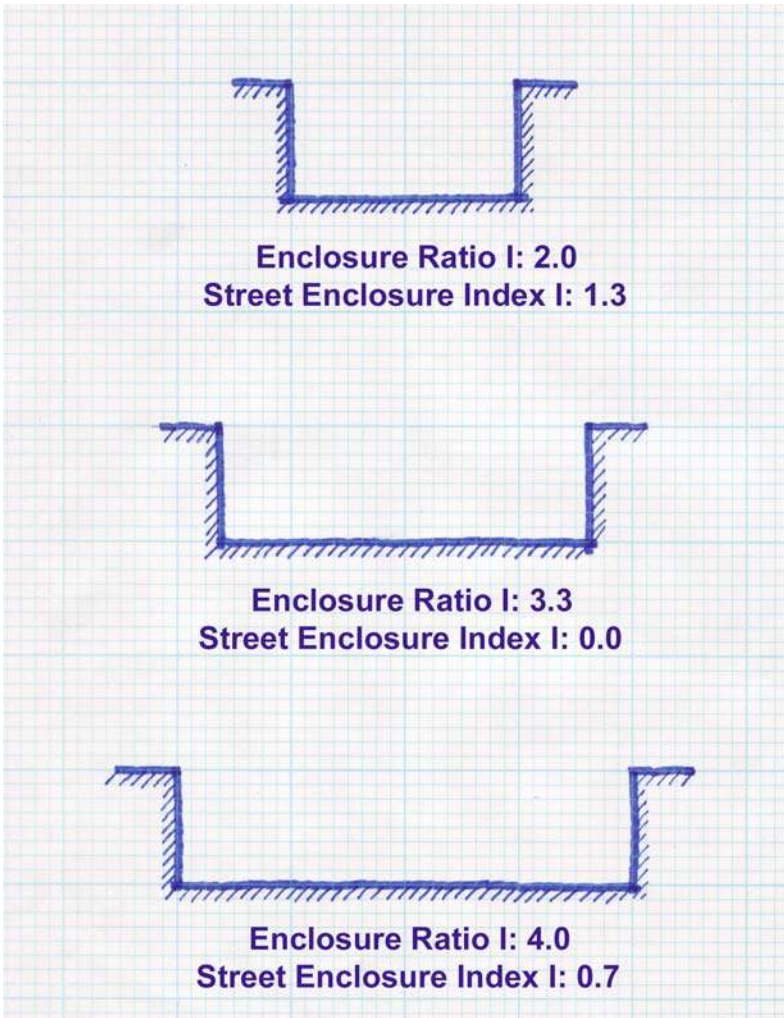
(28) **Skyline Height:** This indicator was developed to eliminate the possible bias from a small number of buildings, just as mentioned. Unlike the average building height, the skyline height included vacant lots and treated them as zero feet in height. A skyline

height was calculated by dividing the total building height by the total sidewalk length. As a result, the average skyline was always smaller than the average building height.

(29) **Enclosure Ratio in Cross Section I (Building-to-Building Distance to Building Height):** This indicator was the ratio of average building-to-building distance to average building height of the street segment. Since the average building height of most suburban transit station areas of interest are usually shorter than the average building-to-building distance in high-density urban areas, the author reversed the ratio (building height to building-to-building distance) suggested by Jacobs (Jacobs, 1993). This indicator value increases as the street segment has more openness, and decreases as the segment has more enclosure (Figure 3.8). This indicator would not be suitable for a street whose average building height is greater than its average building-to-building distance, such as Manhattan, because the value would be between 0 and 1 and it would change disproportionately within the range.

(30) **Enclosure Ratio in Cross Section II (Building-to-Building Distance to Skyline Height):** The ratio of *building-to-building distance* to *average skyline height*. This indicator is calculated in the same way as the *enclosure ratio in cross section I,* but substituted *skyline height* for *average building height* to avoid possible bias caused by vacant properties (Figure 3.9).

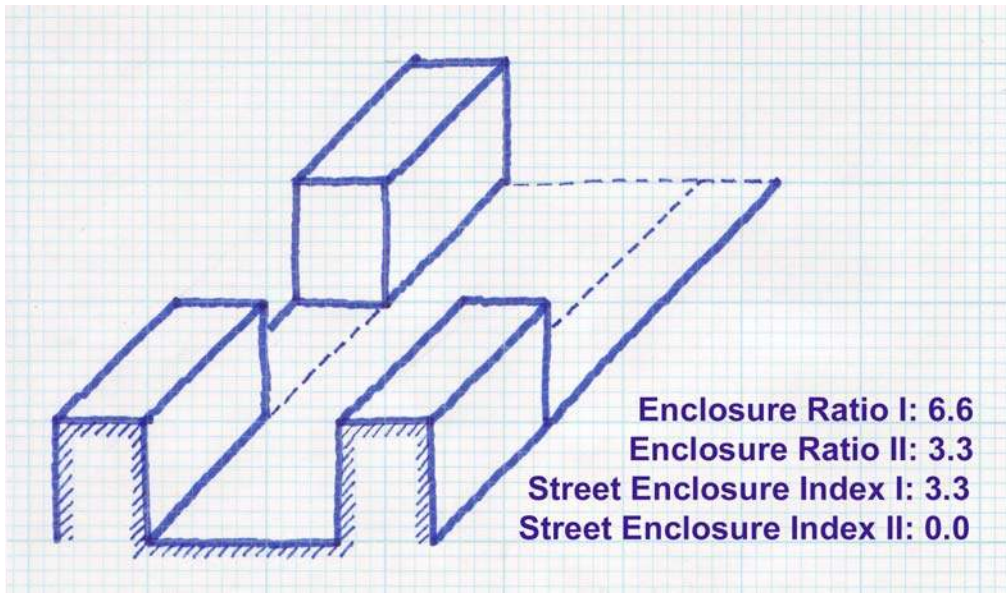
Figure 3. 8: Ratio in Section I vs. Street Enclosure Index I



(31) **Street Enclosure Index I:** the value of *enclosure ratio in cross section* is not statistically linear, which means the most desirable ratio is probably somewhere in between: not too open but not too enclosed. For the regression analyses in Chapter 7, the author mathematically modified the ratio indicator to create a new linear indicator, by subtracting 3.3 from the enclosure ratio value, and expressing this as an absolute value. This is based on Allan Jacobs' observation that a 3.3 ratio might give pedestrians the

"best" sense of enclosure. As the value of street enclosure index approaches 0, it is assumed that the enclosure of the street segment may be the most desirable (Figure 3.9).

Figure 3. 9: Ratio in Section I & II vs. Street Enclosure Index I & II



(32) **Street Enclosure Index II:** In order to account for the impact of vacant lots, this indicator is calculated in the same way as *street enclosure index I*, but using *average skyline height* instead of *average building height*.

(33) **Average Building Width:** It has been claimed that fine-grained buildings are better for pedestrians than large-scale (big box) building masses. Based on this claim, the widths of all the building façades facing the street segment were measured and the average width was calculated for the walkability indicator.

(34) **Percentage of Block Faced with Building Façade:** It has been claimed that more building façade is better for pedestrians. This indicator shows how much of a street segment has building façade.

(35) **Average Building Setbacks:** Building setback influences the scale and enclosure of a street segment, but it also determines the distance between pedestrians and nearby building façades, which might work for or against walkability. Would pedestrians prefer to walk next to some greenway, or look inside buildings? It probably depends on the characteristics and land use of both the setback space and nearby buildings.

3.3.7. Walkability Indicators Related to Nearby Buildings and Properties

This research seeks to measure the indicators capturing the two major characteristics of buildings on a segment: visual and physical access to and from the nearby buildings and the first floor land use of nearby buildings.

(36) **Pedestrian-Level Facade Transparency:** This indicator measures how easily it is for pedestrians walking on the sidewalk to see inside nearby buildings. It has often been claimed that greater façade transparency provides pedestrians with a series of interesting things and events to see, and thus makes the trip more pleasant. Since the effect of transparency has rarely been tested, the author wanted to include this indicator, although there were some objectivity issues in measuring façade transparency.

(37) **Number of Street-Facing Entrances:** This walkability indicator measures the level of direct physical access to and from nearby buildings. There has been very little research testing the effect of the number or orientation of building entrances on pedestrian perceptions or behavior. If access to the building is important as claimed, the streets with more street-facing entrances/doors should have a more desirable pedestrian environment.

(38) **Number of Upper-level Windows:** It has been claimed by many theorists that the role of natural surveillance from the users of nearby buildings could be critical for pedestrians' sense of security (Jacobs, 1963; Newman, 1973). However there has been little research testing this effect. This is difficult to measure because windows come in all different sizes and their location, transparency, and window treatments (curtains, etc.) could all influence residents' natural surveillance activity. Despite some measurement problems, the author included this walkability indicator because there is no other proxy available to measure the level of building users' surveillance.

(39) **Fence Coverage Rate:** Fences are designed to be a barrier between private and public space, and could effectively decrease the physical and visual interface between the two realms. Measurement is a problem, because there are various kinds of fences, and they come in various heights. Without any research findings regarding the effect of fences, the author decided that a 4-feet height would be the threshold to call something a

fence, because it is fairly hard to climb over 4-feet fence and thus any fence higher than 4 feet sends a clear message that you cannot cross the line. Other researchers may use different criteria.

(40) **Walking-Conducive (1st floor) Commercial Uses:** Much research has found that neighborhood land use patterns play an important role in determining the level of non-motorized travel in a neighborhood. Commercial uses within a reasonable walking distance (local shopping accessibility) especially influence level of non-motorized travel within a neighborhood (Handy and Clifton, 2000; Lamont, 2001). However, not every "commercial" use is walking-conducive; there seems to be a blurry boundary between commercial uses and office/light industrial uses. A good example might be auto repair shops and chiropractors. Auto repair shops are called commercial land uses in the general plans of many cities[12], but may not contribute to good walkability. A chiropractor is often in an office building but still attracts many visitors. The street survey of this research collected detailed information about the specific uses of non-residential buildings (e.g., an ice cream shop or a daycare center). With more detailed building-by-building land use information, however, this research was able to more narrowly define "walking-conducive" commercial uses (see Appendix 2 for a detailed list of walking-conducive uses). For this walkability indicator, only walking-conducive commercial uses were counted as commercial uses.

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[12] e.g. City of Berkeley. 2001. Berkeley Municipal Code, Subtitle Definitions, Chapter 23, p387

(41) **Residential Use (1st floor) of Adjacent Buildings:** This indicator is the percentage of the total width of the building used for residential use. Most authors studying macro-level walkability have used area footages of residential and commercial uses based on GIS zoning maps. However, this research was able to code the land use of each building and used the total width of the building used for residential use.

(42) **Mixed Land Uses of Adjacent Buildings:** According to previous research, mixed land use in a neighborhood is one of the major determinants of travel behavior by residents. But there is no consensus in measurement. To define mixed use, urban designers have intuitively assigned ranges of land use mixes for different urban settings, for example, 5 to15 percent public uses and 30 to 70 percent core/ employment uses for urban transit-oriented developments (Calthorpe and Poticha, 1993). To define mixed use, some travel behavior researchers have used the proportion and scattering of land uses (called "entropy"). Cervero used normalized entropy based on five land use categories: residential, commercial, industrial/office, public, and other (Cervero, 2001).

With route-level data, however, this research was able to look directly at the proportion of buildings widths devoted to commercial and residential use. Assuming that the essence of the mixed use effect on travel behavior is the interaction between commercial and residential uses, this research defined a route as mixed use, if (walking-conducive) commercial and residential uses each constitute more than 30% of total building width along the route. For example, a route with 35% (walking-conducive) commercial use and 35% residential use is mixed use, while one with 45% (walking-conducive) commercial use and 25% residential use is not.

To be as comprehensive and inclusive as possible, this research included over 40 walkability indicators, not all of them were used to create the operational definition of walkability. Some of them were eliminated by each operationalizing method – factor analysis for inductive operationalization and regression analysis for deductive operationalization.

3.4. Final Candidate Lists of Path Walkability Indicators

The final step in creating the candidates for walkability indicators was to convert the 46 indicators into values that should be comparable at the route level (Table 3.2). For the case study of this research (described in Chapter 4), walkability was measured on a street segment between two intersections, and the measured walkability of each street segment was integrated into an individual traveler's route (combination of multiple street segments). This walkability value of one's route is called "path walkability," which will be used as the basic unit for the disaggregated travel analysis in chapters 5 to 8.

Table 3. 2: Comparing Segment Walkability and Path Walkability

Segment	Segment 01	Segment 02	Segment 03	Segment 04
Traffic Calming (Street Element)	2	3	4	5
Length of the Segments	100 ft.	200 ft.	200 ft.	300 ft.
Traffic Calming (Walkability Indicator)	10.0	7.5	10.0	8.3
Route	**Route A**		**Route B**	
Traffic Calming Element / 500 ft (Path Walkability Indicator)	8.3		9.0	

This research used three mathematical values to convert the walkability indicators into path walkability indicators comparable at the route-level: averages, percentages, and binominal values. Most path walkability indicators based on width, length, height, and distance were averaged by the number of total measurements (Table 3.3). Other indicators associated with frequency, such as buildings entrances and driveway curb-cuts, were averaged by 500 feet of sidewalk length. The indicators associated with longitudinal street elements, such as fences or tree canopies, were divided by the total sidewalk length of each route, and converted into coverage rates. Some indicators can also be expressed in dummy values. The binominal variable merely indicates whether or not the segment has the associated characteristics; a value of 1 is given if the segment has it, 0 otherwise. When a binominal indicator is extracted from a route, this research gives a value of 1, if the route has the indicator for more than 50% of its total length, and 0 otherwise. The oversimplified binominal variable is usually statistically inferior to any average or percentage value of a similar variable.

Table 3.3 shows the final candidate list of 52 path walkability indicators. Some of them will be eliminated, if it turns out through a factor analysis that they have no correlation with pedestrian behavior (Chapter 5) or with pedestrian perception through regression analyses (Chapter 7). The eliminated indicators will not contribute to the final operational definition of walkability.

Table 3. 3: Complete List of the 52 Path Walkability Indicators

	A. Path Walkability Indicators Related to Curb-to-Curb Roadways
(1)	Average Width of Curb-to-Curb Roadway (ft.)
(2)	Average Width of Traffic Zone (ft.)
(3)	Average Number of Traffic Lanes
(4)	Average Width of Through Traffic Lanes (ft.)
(5)	Number of Traffic Calming Elements / 500 ft. Block Length
	B. Path Walkability Indicators Related to Pedestrian Crossings
(6)	Pedestrian Crossing Coverage Rate
(7)	Pedestrian Signal Coverage Rate
(8)	Pedestrian Crossing Facility Design Index
(9)	Number of Mid-block Crossings / 500 ft. Block Length
	C. Path Walkability Indicators Related to Buffer Zones
(10)	Average Width of Buffer Zone (both sides together) (ft.)
(11)	Average Width of Landscape Strip (both sides together) (ft.)
(11-1)	Existence of Landscape Strip I (binominal dummy; one or both = 1, none = 0)
(11-2)	Existence of Landscape Strip II (binominal dummy; both = 1, one or none = 0)
(12)	Average Width of Bike Lane (both sides together) (ft.)
(12-1)	Existence of Bike Lane I (binominal dummy; one or both = 1, none = 0)
(12-2)	Existence of Bike Lane II (binominal dummy; both = 1, one or none = 0)
(13)	Average Width of On-street Parking (both sides together) (ft.)
(13-1)	Type of On-street Parking (binominal dummy; diagonal or perpendicular = 1, otherwise = 0)
(13-2)	Existence of On-street Parking I (binominal dummy; both sides = 1, one side or none = 0)
(13-3)	Existence of On-street Parking II (binominal dummy; both = 1, one or none = 0)
	D. Path Walkability Indicators Related to Sidewalks
(14)	Sidewalk Coverage Rate (percentage of segment sidewalk length with sidewalk) (%)
(14-1)	Existence of Sidewalk (binominal dummy variable)
(15)	Average Width of Walking Zone (ft.)
(16)	Average Length of Sidewalk (ft.)
(17)	Average Number of Driveway Curb-Cuts / 500 ft. Sidewalk
(18)	Percentage of Sidewalk Length with Special Pavement (%)
(19)	Average Route Steepness
	E. Path Walkability Indicators Related to Sidewalk Facilities
(20)	Percentage of Sidewalk Length with Visual Nuisance (%)
(21)	Average Numbers of Street Furniture / 500 ft. Sidewalk
(22)	Average Number of Intermediaries / 500 ft. Sidewalk
(23)	Average Number of Street Trees / 500 ft. Sidewalk
(24)	Percentage of Sidewalk Length Covered by Tree Canopies (%)
(25)	Average Ground-Level Luminosity after Sunset (fc.)
	F. Path Walkability Indicators Related to Street Scale and Enclosure
(26)	Average Building-to-Building Distance (ft.)
(27)	Average Building Height (ft.)
(28)	Average Skyline Height (ft.)
(29)	Enclosure Ratio in Cross Section I (Building-to-Building Distance to Building Height)

(30)	Enclosure Ratio in Cross Section II (Building-to-Building Distance to Skyline Height)
(31)	Street Enclosure Index I (absolute value of [Enclosure Ratio I - 3.3])
(32)	Street Enclosure Index II (absolute value of [Enclosure Ratio II - 3.3])
(33)	Average Building Width (ft.)
(34)	Percentage of Sidewalk Length with Building Façades (%)
(35)	Average Building Setbacks (ft)
	G. Path Walkability Indicators Related to Nearby Buildings and Properties
(36)	Average Pedestrian-Level Façade Transparency
(37)	Average Number of Street-Facing Entrances / 500 ft. Block Length
(38)	Average Number of Upper-Level Windows / 500 ft. Sidewalk
(39)	Fence Coverage Rate (Percentage of Sidewalk Length with Fence) (%)
(40)	Percentage of Walking-Conducive (1st floor) Commercial Uses (building frontage) (%)
(40-1)	Commercial (1st floor) Use of Adjacent Buildings (commercial = 1, non-commercial = 0)
(41)	Percentage of Residential Uses (1st floor building frontage for residential uses) (%)
(41-1)	Residential (1st floor) Use of Adjacent Buildings (residential = 1, non-residential = 0)
(42)	Mixed Use (1st floor) of Adjacent Buildings (mixed use = 1, non – mixed use = 0)

4. RESEARCH DESIGN AND USER SURVEY

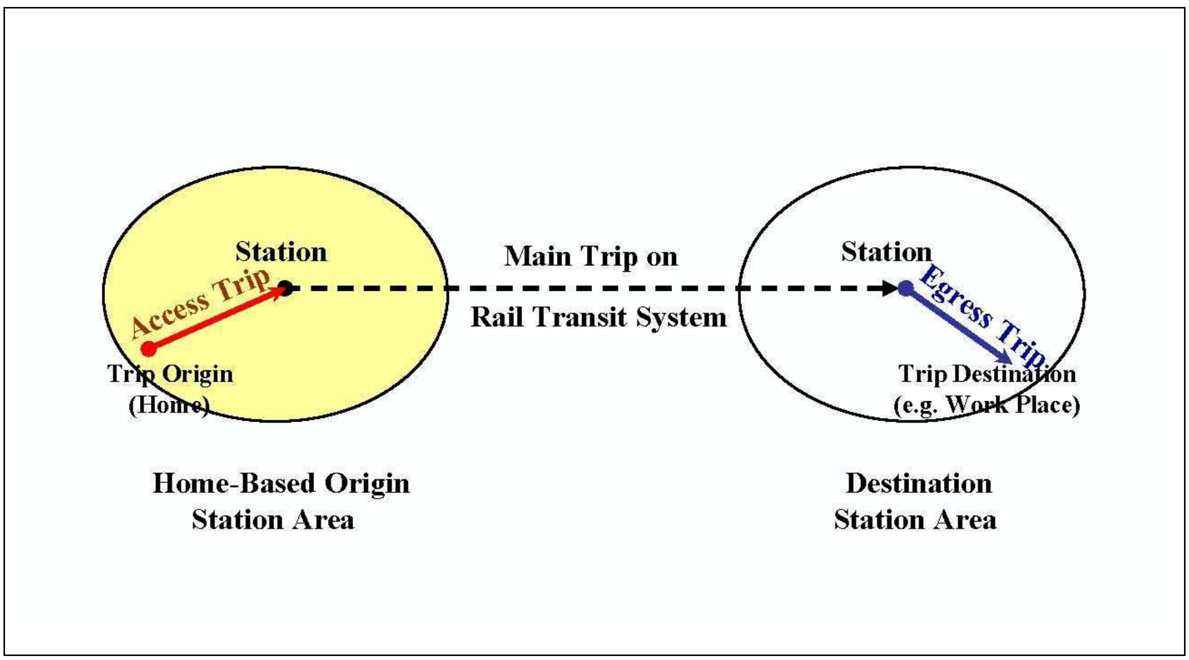
4.1. Walkability and Walking Travel Behavior in Station Areas

Today, American cities are more auto-oriented than most other cities in the world. Confronted with increasing air pollution, traffic congestion, foreign oil dependency, and increasing obesity and other health problems, planners are looking for solutions to reduce auto-dependency and to encourage more walking (Deakin, 1989). In many cases, however, it does not seem to be easy to persuade voters to spend public money on pedestrian facilities, partly because only a small fraction of travelers choose to walk to meet their daily needs. This could make it hard to justify investing in upgrading sidewalks over filling potholes. The best way to overcome this conflict may be to focus resources on the priority areas where investment in walking facilities will yield the maximum benefit. Today the top two priority areas seem to be school zones and transit station areas.

The potential for improving walkability around transit stations can hardly be overlooked, because it is likely to have positive spillover effects in the entire regional public transit system. For example, if improved walking leads to a modal shift from driving to walking to the station, the competition for parking space near the station will loosen up, attracting new transit patrons living outside a reasonable walking distance because they can easily park at the station. Transit ridership could also be increased by converting freed-up parking space into transit villages.

But for policymakers, investment in the transit station area cannot easily be justified if there is no evidence that upgraded facilities will actually encourage people to walk to the station and leave their cars at home. One of the dilemmas of planners and policymakers is that relatively little is known about transit access trips – especially about the relationship between non-motorized access trips and environmental attributes. Will improved walkability really lead to a modal shift from driving to walking as claimed? What are the real factors influencing transit users' access mode choices? If researchers can better answer those questions, it might help policymakers integrate walking improvements into future planning policies.

Figure 4. 1: Access, Main, and Egress Trips



4.2. Previous Research on Transit Access Mode Choice

With the growing importance of urban rail transit and the increasing popularity of transit-oriented development (TOD), access trips to the transit station are getting more attention from the public than ever. However, unlike research on main commuting trips, there has been relatively little research on access trips to the station, and only a few studies have included walking as a mode choice.

One of the seminal station area studies was done by Korf and Demetsky in the late 1970s (Korf et al, 1979). Based on the 1975 Bay Area Rapid Transit Passenger Profile Survey (BART, 1999), the authors tried to develop a conceptual framework of access mode choice using a multinominal logit model. They acknowledged the importance of station area characteristics and defined many potential variables, such as density and parking availability. Due to a lack of available data, however, they finally used only a limited number of socio-economic variables. They found that trip distance was a major determinant for all modes except for carpooling, and auto availability was also important to walking access trips.

Several researchers have used the 1992 BART Passenger Profile Survey to study transit access modes. Cervero studied walking trips to BART stations and the possible impacts of station area characteristics on access mode choice (Cervero, 1995). He hypothesized that walking access trips are sensitive not only to individual traveler's socio-economic backgrounds, but also to the built environment characteristics of both trip origin (home and nearby neighborhood) and destination (station area). By using aggregated socio-economic and built environment variables from each station area, Cervero conducted multivariate regression analyses to predict walking and driving mode shares to the station. His study found that a higher amount of compact residential development within a one-half mile of stations, more land use mixes, and limited parking supply at the station had great impacts on access mode choice to the station (Cervero, 1995). Tanemura elaborated Cervero's findings, focusing on the concept of "catchment" areas (Tanemura, 1996).

Using the same 1992 BART survey, Loutzenheiser tried to find determinants of walking trips to the station, by combining individuals' socio-economic characteristics and aggregated station area characteristics in his model (Loutzenheiser 1997). First, Loutzenheiser conducted a logit analysis with disaggregated travel and socio-economic data from survey respondents. His model found that walking distance, car availability, and gender were the significant determinants of choice to walk to the station. Like Cervero, his second model used a linear regression analysis, with mode share by station as a dependent variable, and the station-level aggregated built environment and socio-economic data as independent variables. His second analysis at the station level found that higher density, fewer parking spaces, and shorter distance to the nearest retail center were significant determinants that increased walking trips to the station. Finally he created a third model joining the aggregated station area characteristics data with the individual socio-economic data. He found that the disaggregated socio-economic variables dominantly entered the model, and that the aggregated built environment variables were left out. Only after controlling for the socio-economic variables did

Loutzenheiser's find that substantial parking space at the station was a deterrent to walking, while retail around the station encouraged walking (Loutzenheiser, 1997).

Based on a survey of Washington Metrorail users, Cervero created a more complete station access mode choice model. He used the 1994 Household Travel Survey of 177 Metro users in Montgomery County, Maryland, and various built environment data collected at the traffic analysis zone (TAZ) level (Cervero, 2001). His binominal logit model (walking vs. automobile uses) found that a higher intersection density and a higher ratio of roads with sidewalks significantly increased walking trips to the station. Unlike the popular perception and the research outcomes of previous research, his model did not find any significant socio-economic predictors, suggesting that the role of built environment characteristics around a station might be more critical than expected (Cervero, 2001). This is a promising outcome, because built environment attributes such as housing density, land use diversity, and design attributes around station areas have more planning implications than socio-economic determinants: policymakers are looking for built environment interventions that might encourage more non-motorized travel.

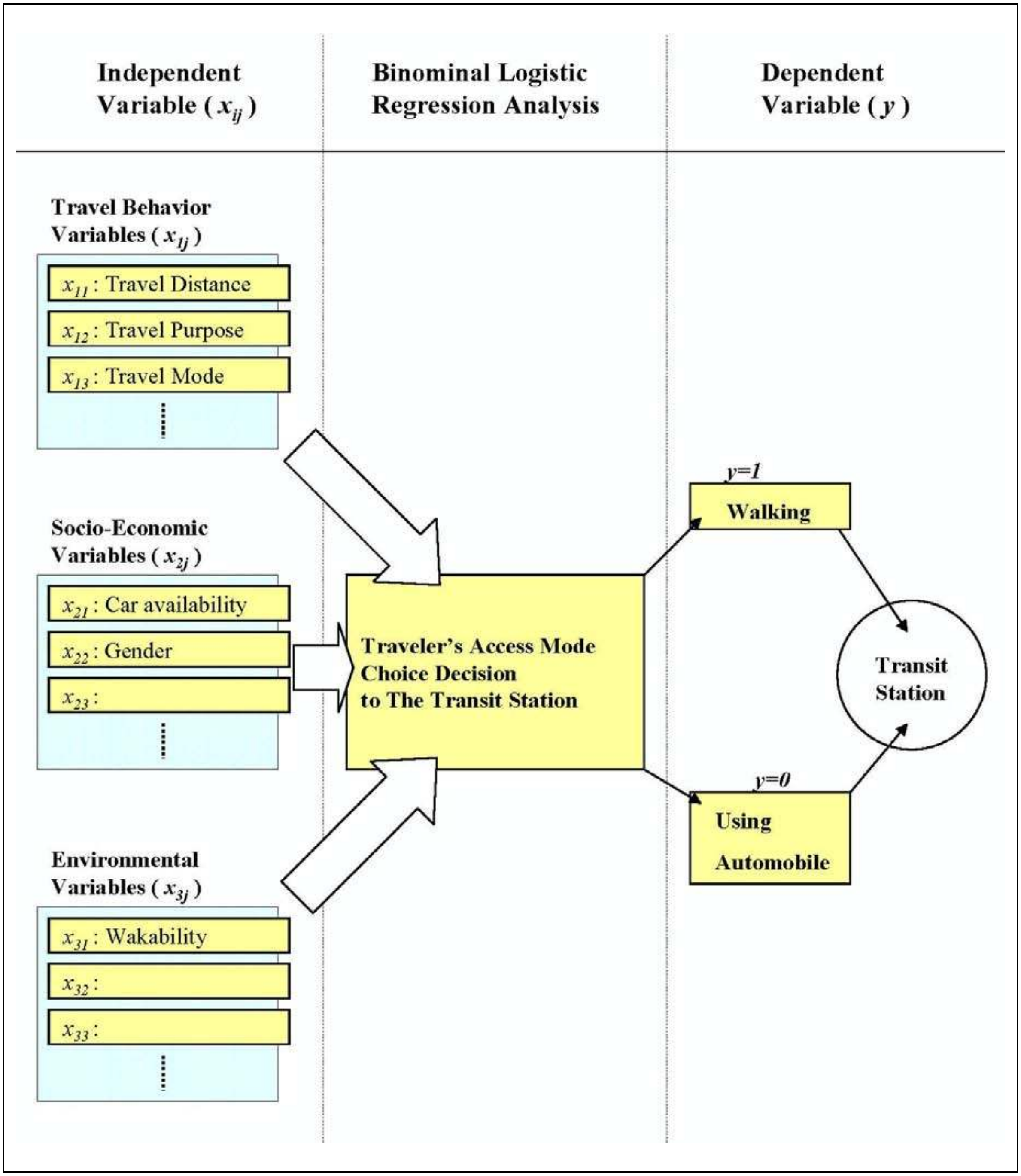
Until recently, the importance of transit access trips had been overlooked. Access mode choice studies have often relied on research designs and variables developed for analyzing main commuting trips, and have also focused primarily on motorized modes. Since the mid-1990s, researchers have paid more attention to walking access trips and tried to find built environment determinants, but station access trips remain an understudied subject in both planning and transportation. The studies mentioned above are very significant and revealing, but there is still one gaping hole in the existing literature. Without existing methods for measuring and quantifying pedestrian-level walkability, previous research was not able to test the effect of micro-level design attributes and had to rely more on aggregated macro-level urban form data. This data availability issue limited researchers' ability to conduct sensitive disaggregated analyses focusing on individual travel behaviors, and made it difficult to test any potential effect of micro-level walkability on transit users' mode choice to the station.

4.3. Research Design, Hypothesis, and Case Study Overview

The major goal of this research is to test the effects of micro-level walkability on transit users' mode choice to the station. This research hypothesizes that there could be a certain combination of micro-level walkability indicators that encourages or discourages transit users to walk for their access trips to the station.

One of the imperative tasks of this research is to include micro-level walkability that has been overlooked by previous station access mode choice models. After developing walkability measurement instruments and conducting street surveys in the sampled street segments, it became obvious that detailed walkability measurement would be costly. That meant that only a limited number of street segments could be surveyed. That led the author to the idea of surveying as many travelers as possible from a single station area, rather than sampling travelers from multiple station areas, because the former shared more street segments on their walking routes and thus reduce the number of street segments to survey.

Figure 4. 2: Constructing a Travel Behavior Model



The single station case study also provided other advantages. First it is relatively free from sampling error, if everyone entering the station received a survey without sampling. Second, it is relatively free from possible self-selection bias, given that all subjects are from one station area, which is considered as the same neighborhood. In a cross-sectional study comparing multiple neighborhoods, subtle difference in lifestyles or in environmental attitudes among neighborhoods may influence the choice of residential location and cause a "self-selection" bias (Handy et al, 2006). For example, self-selection bias could occur, if the travel behavior of transit users living in a suburban station area is compared to the travel behavior of those living in a downtown station area. If more people in the suburban station area drive to the station, it might be because those who like to use cars chose to live in suburbia rather than because they were influenced by the environmental settings of the suburban station areas after they moved into the area.

There are two drawbacks to conducting a single-station study. The first is its limited generalizability. However, the goal of this study is not to generalize an existing theory or the research findings of this dissertation. Since there is as yet no scientific research testing micro-level urban design impacts on travel behavior, this research should be considered an exploratory effort to find a piece of new evidence from this particular study site. The second drawback is the inability to test certain potential factors, which may possibly influence the mode choice, such as weather or parking availability around the station because there is no variation in term of the variables among those using the same station.

Site selection is critical for a single-station study. This research has two major site selection criteria: a significant number of transit users walking to the station, and significant variation in walkability, both of which were critical for the mode choice analyses. The station required a significant number of riders given various attrition factors. For example, to get survey responses from 150 walking transit users, a daily on-board ridership of more than 2,000 is required, even when the following favorable conditions are expected: the exclusion of 30% egress[13] /transferring transit users (if the study is focusing on home-to-station trips), a 60% non- response rate, and a 70% of non-walking transit users. The ideal station area had to have a major rail transit station located in a suburban setting because an urban station has significantly more egress trips such as station-to-office trips with a significant number of daily transit users and high share of walking access trips. The second criterion was to have a significant variation in walkability within the station area. Because walkability is the experimental variable of this research, the ideal station area required both fairly good and bad walkability around the station to have a clear analysis outcome.

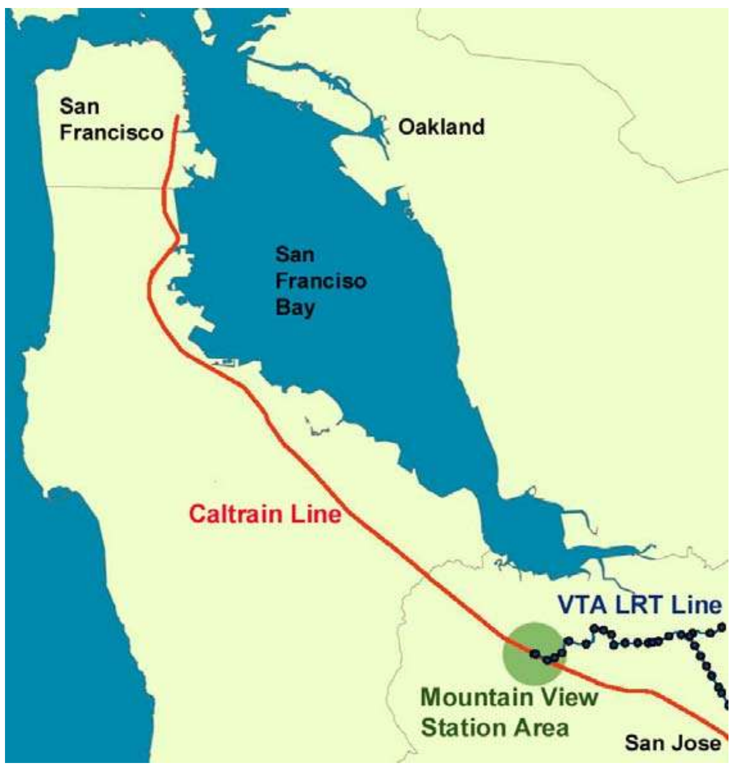
4.4. Study Site: Downtown Mountain View Station Area

To find the best study site, this research reviewed aerial photos of most transit station areas in the Bay Area and the Sacramento metropolitan area. Station areas with large-scale non-residential uses, such as big-box malls or industrial areas, around the station were excluded because they were less likely to have a significant number of transit users who make home-to-station trips by walking. Various transit ridership

[13] e.g. trips from one's destination station to his/her working place. In terms of mode choice, egress trips are expected to be significantly different from access trips.

reports, such as the BART station profile study, were consulted (Bay Area Rapid Transit, 1999). After visiting more than twenty-five potential study sites – station areas for rapid transit, commuter rail, and/or light rail systems – the downtown Mountain View station near San Jose, California was chosen. The station area was selected for the following four reasons: (1) it is located in a suburban setting, providing a high share of home-to-station trips; (2) it has a fairly large daily ridership; (3) it has a relatively large share of walking trips; and (4) it has a relatively large variation in walkability around the station.

Figure 4. 3: Location Map of Mountain View Station Area



The Mountain View station is one of the major suburban transit stations in the Bay Area. As a transfer station, it has two ground-level platforms: one serving Caltrain commuter rail and the other serving the Valley Transportation Authority (VTA) light rail. Caltrain connects San Francisco and San Jose. In 2006, the Mountain View Caltrain station had more than 2,700 weekday onboard passengers, which is the third largest daily ridership among the 30 Caltrain stations.[14] The number of light rail users at the Mountain View station is much smaller than the Caltrain users – slightly over 500 daily riders in 1998.[15] Initial observations suggested that light rail passengers are more evenly spread throughout the day, while Caltrain riders are more concentrated in commute hours. My user survey targeted transit users using the station in the morning and it was expected that less than 10% of my survey respondents would be the light rail users.

4.5. Station User Survey

The station user survey was conducted in August 2005, by distributing self-administered questionnaires to the entering transit users at the gates of the downtown Mountain View station, California. On Thursday August 18, 2005 – one week before the survey – five surveyors counted the number of entering transit users at the gates during a five-hour time period in the morning (5:30 -10:30 AM). The number of counted transit users was 1,260, and 65.7% of them were concentrated in the two-hour period between 6:30 and 8:30 AM. Based on this count, 1450 self-administered mail-back survey forms

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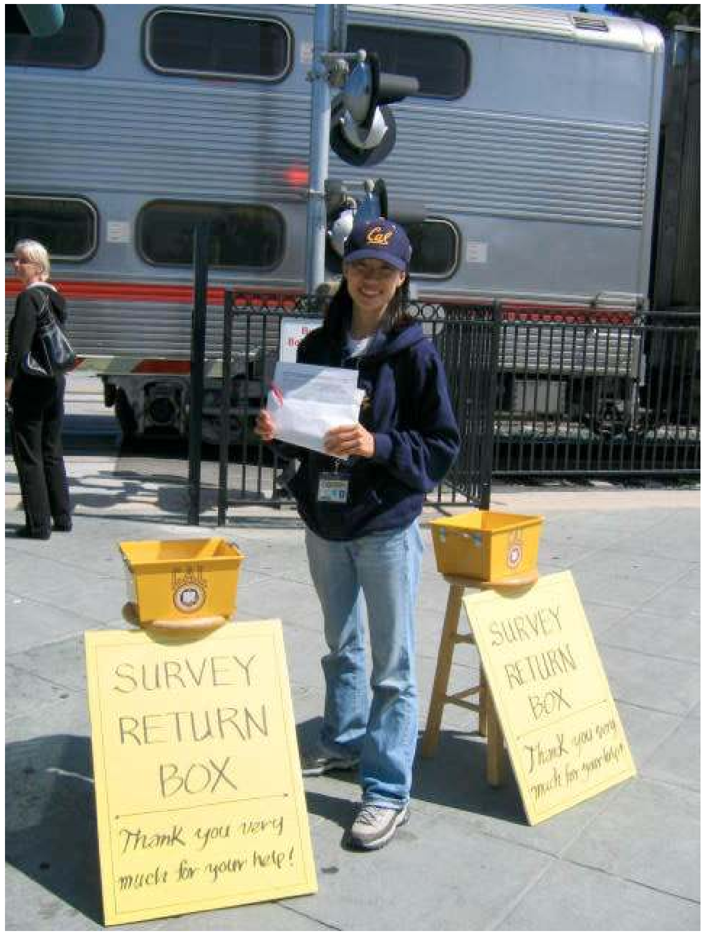
[14] Caltrain Weekday Station Passenger Boardings- 1992 & 1995 through 2007; www.caltrain.com/caltrain_ridership_2007.html. Accessed July 28, 2007
[15] the data was acquired directly from VTA

were prepared.

The survey questionnaires consisted of four pages (see Appendix 3 for the station user survey form). The first page contained questions about transit users' travel (train type, purpose, mode, and frequency). The next two pages contained a station area map to collect their trip origins and routes. It asked travelers to draw their routes on the map if they had any experience of walking to the station, regardless of frequency. The last page contained questions about the respondents' socio-economic status.

On Thursday August 25, 2005, eight surveyors handed out 1,418 survey forms with return envelopes to the entering station users from 5:00 to 11:30 AM. Survey questionnaires were handed to all onboard transit riders except a very small number of those who refused to take it. Although we provided return envelopes, three surveyors returned to the station with survey-return boxes, stationed at the three major entrance points in the morning commute time for two more days (Friday 26 and Monday 29). This was the best way to remind transit users that they had received the survey form and to solicit their participation. This pressure tactic worked fairly well – nearly 62% (877) of the questionnaires were returned. 7.8% of them (111) were collected in the on-site survey return boxes. 92% of the surveys including those into the survey box were returned within one week after the distribution, and 99.7% of them within six weeks. The last survey form was returned in February 2006.

Figure 4. 4: Survey Return Boxes



Unfortunately, 107 of them were returned without trip origins or were from either transferring or egress transit users who lived somewhere else. It was difficult to avoid handing-out questionnaires to them because when multiple trains stopped at the platforms during crowded and hurried periods, surveyors could not accurately differentiate on-boarding, off-boarding, and transferring transit users. Excluding the transferring/egress travelers, 770 surveys (54.3%) were returned from travelers who made home-to-station trips within the Mountain View station area. The majority of the survey respondents were Caltrain commuter rail users, while less than 7% were VTA light rail users. In terms of modal distribution, the major access mode choice was driving (including carpooling and drop-offs); 66.6% of respondents used automobiles to get to the station. The proportions of walking and biking were 19.5% and 11.0% respectively. The number of bus riders was fairly small (less than 3%), compared to the other modes (Figure 4.5). Figure 4.6 shows the spatial distribution of the trip origins. No walkers originated beyond a 1.5-miles radius from the center of the station, and there were very few bike origins beyond a 2-mile radius.

Figure 4. 5: Mode Shares of the 770 travelers Surveyed

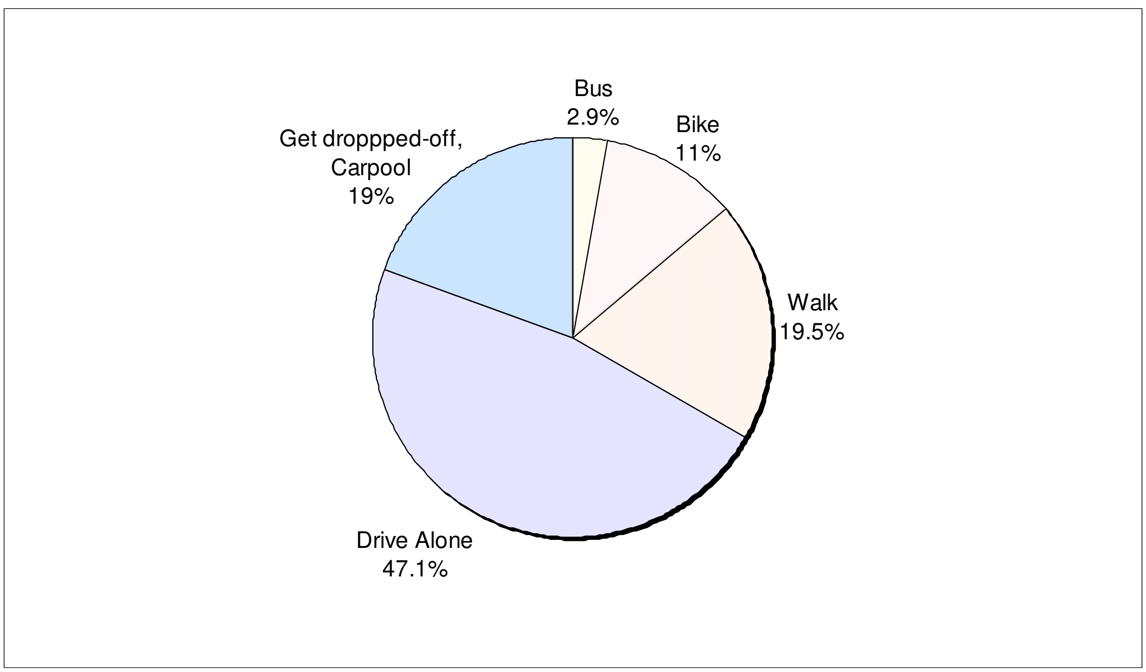
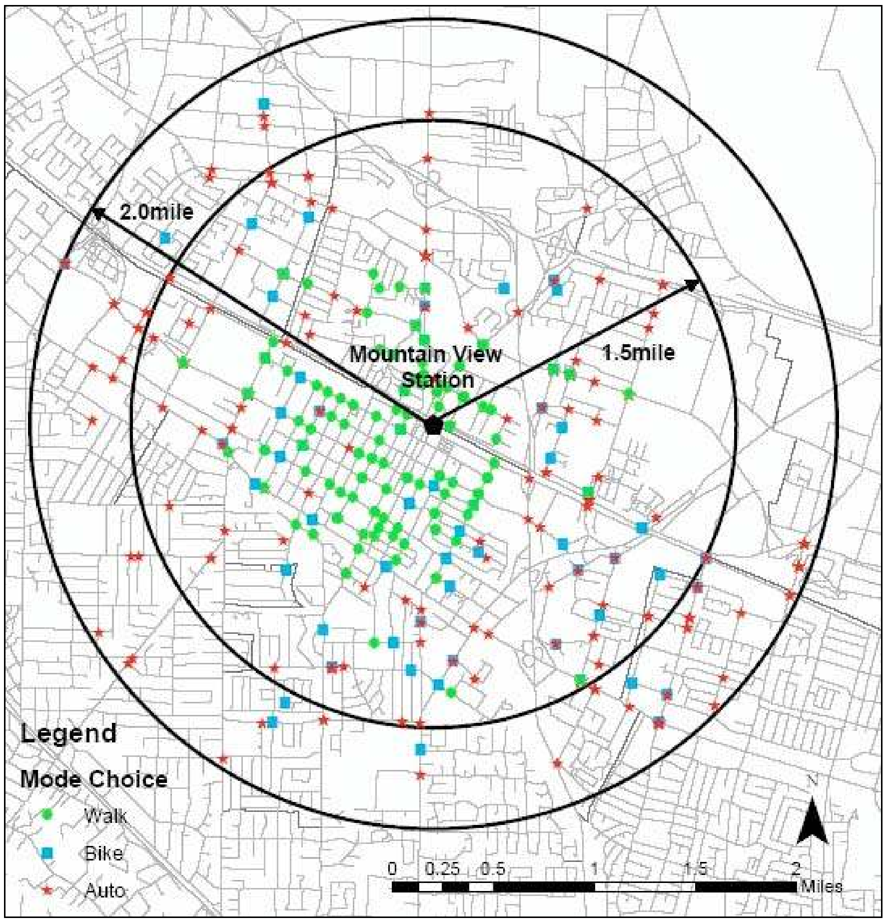


Figure 4. 6: Spatial Distribution of Trip Origins within 2 Mile Radius by Mode



Note: there are some points with multiple trip origins

Figure 4. 7: Routes of the 150 Walkers (red highlighted segments)

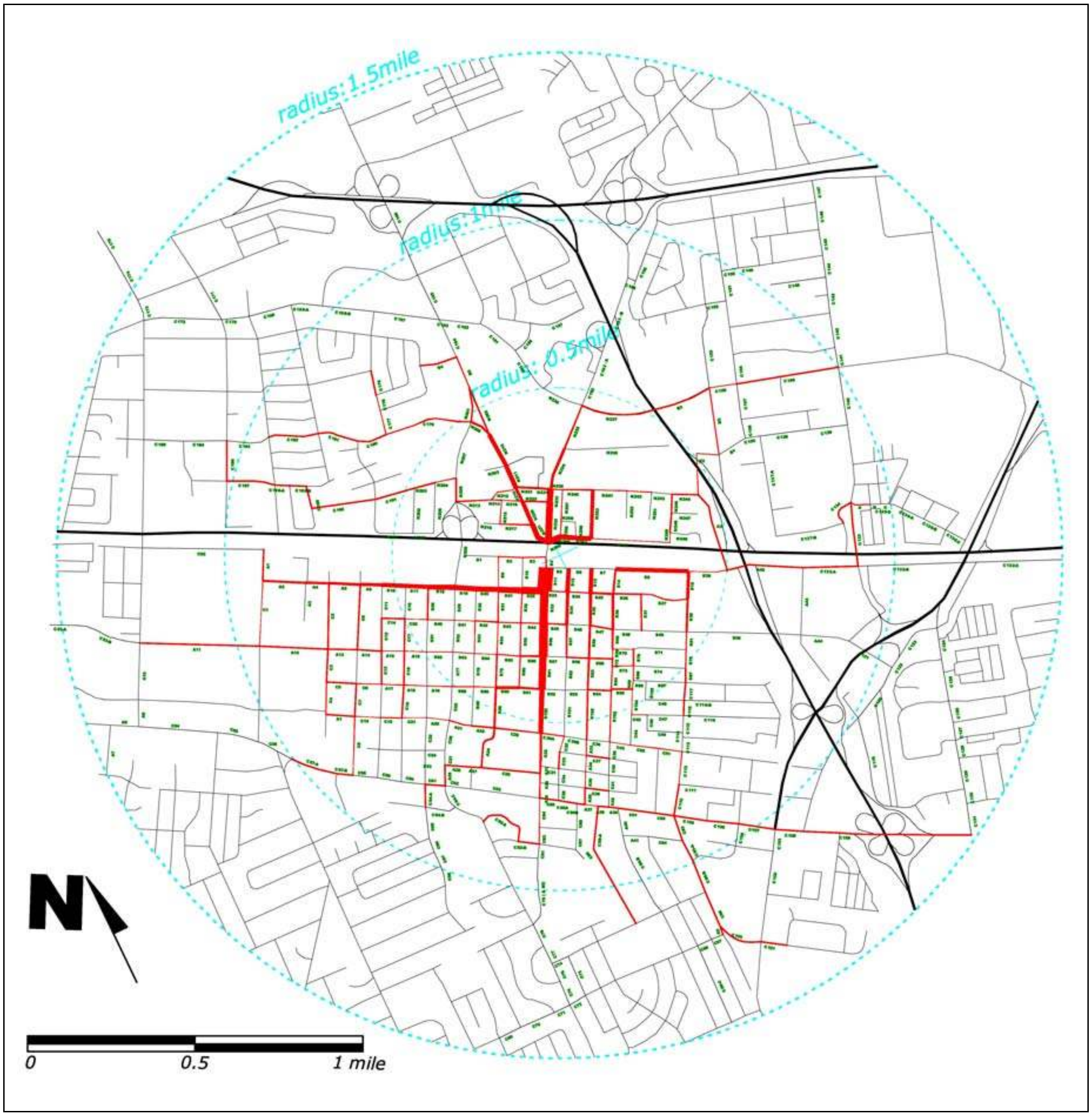
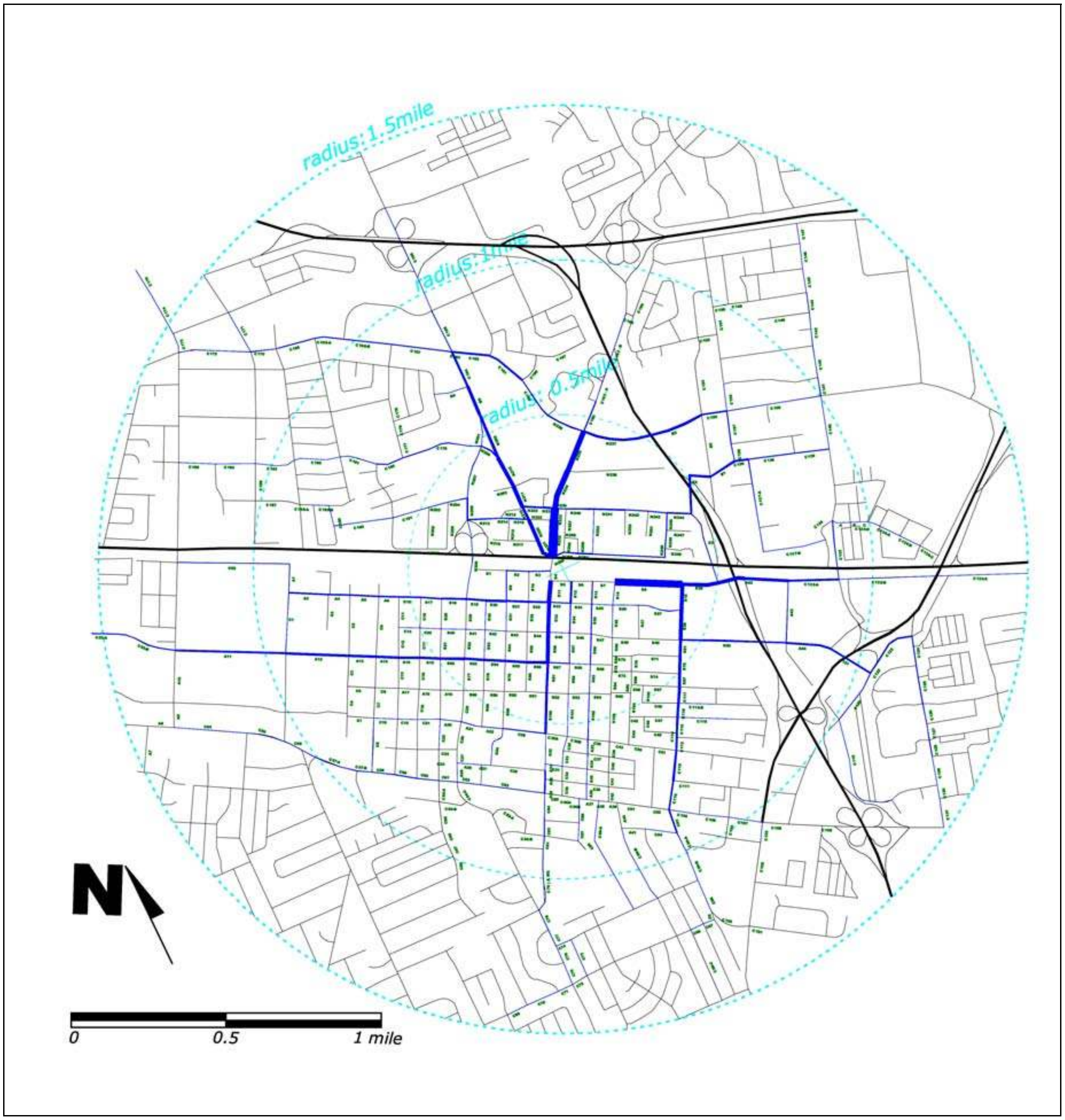


Figure 4. 8: Routes of the 99 Auto Users (blue highlighted segments)



The most important data collected from the user survey were the walking routes drawn by the 249 (150 walkers and 99 auto users) transit users who ever "experienced" walking to the station (Figure 4.7 and Figure 4.8). The survey questionnaire asked the travelers to draw the walking routes they used most, including the 99 regular auto users who had "previous experience" walking to the station. The survey asked, "Have you ever walked to the station?" If the respondent checked "yes," then the survey even asked the auto users to draw their usual walking route on the provided map (Appendix 1). It was assumed that many auto users had previous walking experience to the station, and would consider the quality of that experience the next time they decided whether to walk or drive to the station. These 249 cases are the primary data set for the access mode choice analyses in the next two chapters.

4.6. Street Survey

Using the two-page street survey instrument developed in the previous chapter, the street survey was started in the early 2005 by surveying the street segments within a half mile radius from the Mountain View station. After the two user surveys[16] were conducted in the summer of 2005, the route information from the station user survey was used as the basis of a street survey, which added new street segments outside a half mile radius. Totally 270 street segments were surveyed (Figure 4.9). Given the limited

[16] the walker perception survey will be introduced later in the chapter 7.

resources, the priority was given to the street segments that were used by survey respondents and closer to the station. The following street segments were surveyed: The first group was the 161 street segments within a half-mile (straight-line) radius of the center of the downtown Mountain View station (green segments in Figure 4.9); The second group was the 45 street segments outside a half-mile radius that were actually used by some of the 68 walkers surveyed in July 2005 (yellow segments). The walker perception survey was conducted separately a month earlier than the station user survey introduced in the previous subchapter. The walker perception survey was used to create composite a walkability index in the later subchapters (7.6). The third group was the 65 street segments that were not selected by the first two groups but used by some of the 249 respondents from the station user survey, who provided their routes (azure segments). For the third group, the segments of walking routes that were farther than 1-mile path distance (not straight-line distance) along the route from the gate of the station were not surveyed. Most of these segments were used by only one traveler. Even without those segments, conducting the street surveys was challenging, as the total length of the 270 segments was over 24 miles.

One of the critical issues in walkability measurement was a reliability test, which determines whether different surveyors who measured the same environment would end up reasonably identical results. Due to lack of research funds, however, a reliability test could not be done for this research, although some sensitive street elements were measured solely by the author to be consistent. The reliability problem was addressed in Boarnet et al. 2006 and Ewing et al. 2006, and should be addressed in future research.

Figure 4. 9: Locations of 270 Street Segments Surveyed

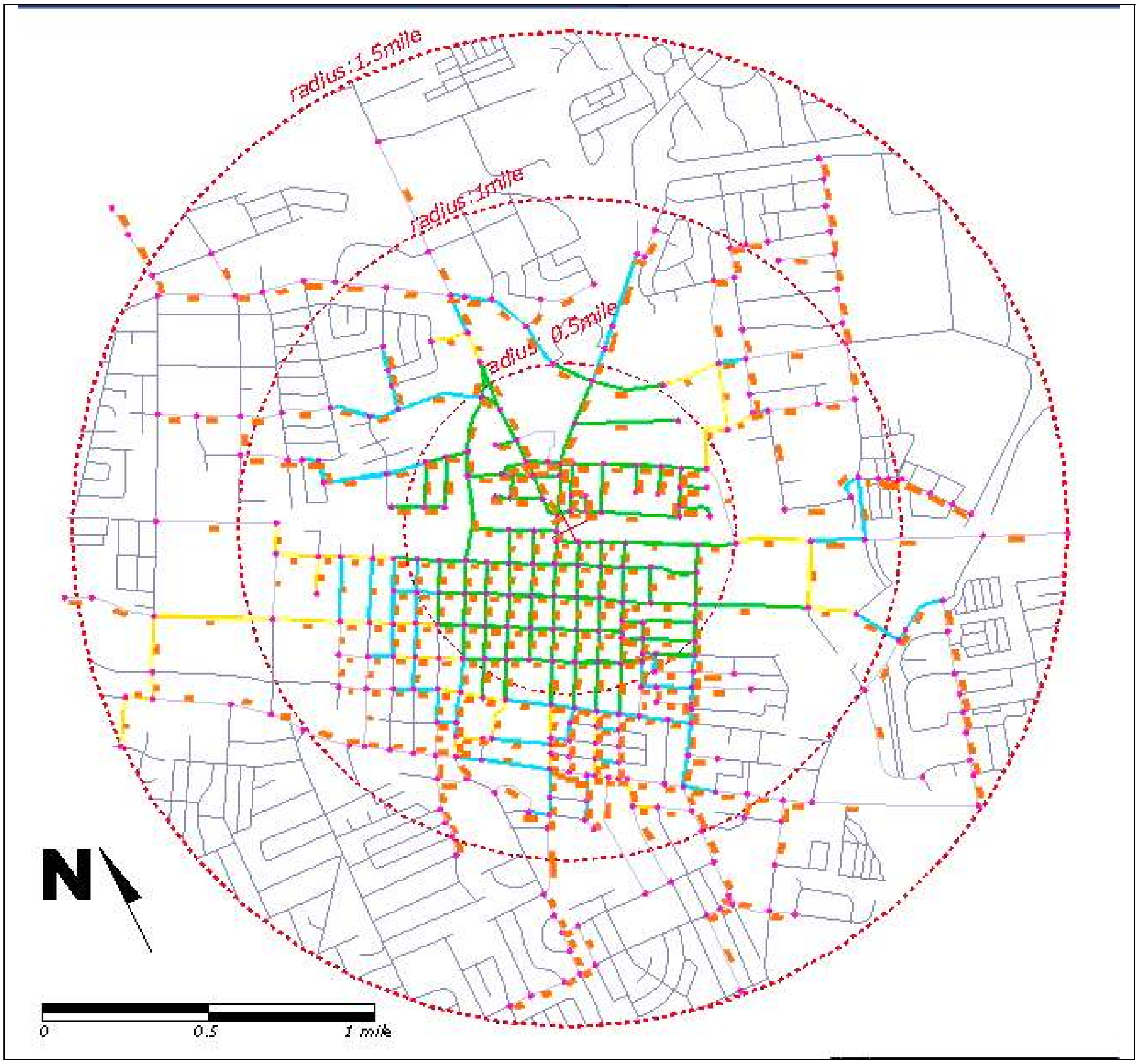


Table 4. 1: Descriptive Statistics of Path Walkability Indicators for the 270 Segments

	A. Path Walkability Indicators Related to Curb-to-Curb Roadways	Min.	Max.	Mean	Std. Dev
	Length of Segment (ft.)	75.0	1894.0	486.5	269.6
	Length of Sidewalk (ft.)	54.0	1814.5	436.2	265.2
(1)	Average Width of Curb-to-Curb Roadway (ft.)	14.5	120.0	47.9	21.7
(2)	Average Width of Traffic Zone (ft.)	7.0	100.0	33.2	21.6
(3)	Average Number of Traffic Lanes	1.0	7.0	2.6	1.2
(4)	Average Width of Through Traffic Lanes (ft.)	3.5	29.8	12.0	4.0
(5)	Number of Traffic Calming Elements / 500 ft. Block Length	0.0	10.6	0.5	1.2
	B. Path Walkability Indicators Related to Pedestrian Crossings	Min.	Max.	Mean	Std. Dev
(6)	Pedestrian Crossing Coverage Rate	0%	100%	34%	0.4
(7)	Pedestrian Signal Coverage Rate	0%	100%	18%	0.3
(8)	Pedestrian Crossing Facility Design Index	0.0	5.0	1.7	1.5
(9)	Number of Mid-block Crossings / 500 ft. Block Length	0.0	1.3	0.0	0.2
	C. Path Walkability Indicators Related to Buffer Zones	Min.	Max.	Mean	Std. Dev
(10)	Average Width of Buffer Zone (both sides together) (ft.)	0.0	26.3	11.2	3.8
(11)	Average Width of Landscape Strip (both sides together) (ft.)	0.0	17.3	2.6	3.0
(11-1)	Existence of Landscape Strip I (one or both = 1, none = 0)*			0.5	0.5
(11-2)	Existence of Landscape Strip II (both = 1, one or none = 0)*			0.3	0.5
(12)	Average Width of Bike Lane (both sides together) (ft.)	0.0	9.3	0.9	2.1
(12-1)	Existence of Bike Lane I (one or both = 1, none = 0)*			0.2	0.4
(12-2)	Existence of Bike Lane II (both = 1, one or none = 0)*			0.2	0.4
(13)	Average Width of On-street Parking (both sides together) (ft.)	0.0	21.0	6.7	3.0
(13-1)	Type of On-street Parking (diagonal or perpendicular = 1)*			0.0	0.2
(13-2)	Existence of On-street Parking I (both = 1, one or none = 0)*			0.9	0.3
(13-3)	Existence of On-street Parking II (both = 1, one or none = 0)*			0.8	0.4
	D. Path Walkability Indicators Related to Sidewalks	Min.	Max.	Mean	Std. Dev
(14)	Sidewalk Coverage Rate (%)	50%	100%	96%	0.1
(14-1)	Existence of Sidewalk (binominal dummy variable)*			0.9	0.3
(15)	Average Width of Walking Zone (ft.)	1.8	12.5	4.7	1.2
(16)	Average Length of Sidewalk (ft.)	54.0	1814.5	436.2	265.2
(17)	Average Number of Driveway Curb-Cuts / 500 ft. Sidewalk	0.0	7.0	2.5	1.4
(18)	Percentage of Sidewalk Length with Special Pavement (%)	0%	100%	24%	0.4
(19)	Average Route Steepness**				
	E. Path Walkability Indicators Related to Sidewalk Facilities	Min.	Max.	Mean	Std. Dev
(20)	Percentage of Sidewalk Length with Visual Nuisance (%)	0%	100%	54%	0.5
(21)	Average Numbers of Street Furniture / 500 ft. Sidewalk	0.0	10.5	0.4	1.4
(22)	Average Number of Intermediaries / 500 ft. Sidewalk	0.0	35.7	1.5	3.8

		Min.	Max.	Mean	Std. Dev
(23)	Average Number of Street Trees / 500 ft. Sidewalk	0.0	25.9	6.3	5.6
(24)	Percentage of Sidewalk Length Covered by Tree Canopies (%)	0%	100%	43%	0.2
(25)	Average Ground-Level Luminosity after Sunset (fc.)	0.0	1.9	0.3	0.3
	F. Path Walkability Indicators Related to Street Scale and Enclosure	Min.	Max.	Mean	Std. Dev
(26)	Average Building-to-Building Distance (ft.)	51.0	383.0	127.1	48.5
(27)	Average Building Height (ft.)	10.0	100.0	18.6	10.2
(28)	Average Skyline Height (ft.)	0.0	128.4	10.2	9.7
(29)	Enclosure Ratio I (Bldg.-to- Bldg. Dist. to Bldg. Height)	0.6	38.3	7.8	4.0
(30)	Enclosure Ratio II (Bldg.-to- Bldg. Dist. to Skyline Height)	0.6	66017.9	412.1	4633.9
(31)	Street Enclosure Index I (abs(Enclosure Ratio I - 3.3))	0.0	35.0	4.7	3.8
(32)	Street Enclosure Index II (abs(Enclosure Ratio II - 3.3))	0.1	500.0	22.3	59.4
(33)	Average Building Width (ft.)	1.0	300.0	62.6	33.7
(34)	Percentage of Sidewalk Length with Building Façades (%)	0%	98%	54%	0.2
(35)	Average Building Setbacks (ft)	0.0	134.0	30.9	19.9
	G. Path Walkability Indicators Related to Nearby Buildings and Properties	Min.	Max.	Mean	Std. Dev
(36)	Average Pedestrian-Level Façade Transparency	0.0	4.8	2.9	0.7
(37)	Average Number of Street-Facing Entrances / 500 ft.	0.0	19.2	4.5	3.2
(38)	Average Number of Upper-Level Windows / 500 ft. Sidewalk	0.0	66.1	8.3	10.6
(39)	Fence Coverage Rate (% of Sidewalk Length with Fence) (%)	0%	95%	17%	0.2
(40)	% of Walking-Conducive (1st floor) Commercial Uses (%)	0%	100%	16%	0.3
(40-1)	Commercial (1st floor) Use of Adjacent Buildings (com.= 1)*			0.2	0.4
(41)	% of (1st floor) Residential Uses (%)	0%	100%	74%	0.4
(41-1)	Residential (1st floor) Use of Adjacent Buildings (R = 1)*			0.7	0.5
(42)	Mixed Use (1st floor) of Adjacent Buildings (mixed use = 1)*			0.1	0.3

* Binominal dummy variables
** Steepness was calculated only at the route level by using secondary data (DEM)

This research relies heavily on "measurement on foot," although it selectively uses Google Earth for some measurements such as building setbacks and lengths of street segments. The resolution of aerial photos or online aerial image services was inadequate to measure micro-level street elements, such as widths of sidewalks, landscape strips, or even building frontages. Shadows of buildings and trees made it particularly hard to use aerial photos. Also, some objects were not identifiable in aerial photos. For example, they cannot differentiate building tops from parking roofs, which were not counted as buildings on my street survey. Some street elements such as intermediaries and façade transparency can only be measured on foot.

Four surveyors, including the author, measured most street elements on foot with wheel measurers (Figure 4.10). It was a painstaking task to fill in more than 60 blanks on the two-page survey form for each segment. Most burdensome was measuring the luminosity, because it had to be done separately at night.

Figure 4. 10: Wheel Measurers

4.7. Extracting Individual Route-level Walkability

The street survey provided data for 30 street elements on each of 270 street segments. Based on the walking routes drawn by travelers, this research recreated 249 individual routes, which were the combinations of surveyed street segments. The collected segment-level street data were combined into route-level data, and then the 52 path walkability indicators were recalculated for each integrated route as explained in the previous chapter 3. Table 4.2 shows the descriptive statistics of the 52 path walkability indicators extracted from the street measurements of the 249 routes. This walkability of one's route, called path walkability, will be used as a basic unit for a disaggregated travel analysis in the later chapter.

Table 4. 2: Descriptive Statistics of the Values of Path Walkability Indicators for the 249 Routes Walked by Station Users

	A. Path Walkability Indicators Related to Curb-to-Curb Roadways	Min.	Max.	Mean	Std. Dev
	Length of Route (mile)	0.09	2.10	0.76	0.46
	Length of Route (ft.)	493.0	11077.5	4003.2	2441.8
(1)	Average Width of Curb-to-Curb Roadway (ft.)	29.0	80.4	52.0	12.0
(2)	Average Width of Traffic Zone (ft.)	15.9	70.5	38.1	13.1
(3)	Average Number of Traffic Lanes	2.0	5.0	2.9	0.9
(4)	Average Width of Through Traffic Lanes (ft.)	7.7	17.7	12.6	2.0
(5)	Number of Traffic Calming Elements / 500 ft. Block Length	0.0	4.6	0.9	1.0
	B. Path Walkability Indicators Related to Pedestrian Crossings	Min.	Max.	Mean	Std. Dev
(6)	Pedestrian Crossing Coverage Rate	0%	100%	48%	0.3
(7)	Pedestrian Signal Coverage Rate	0%	100%	35%	0.3
(8)	Pedestrian Crossing Facility Design Index	0.2	5.0	2.4	1.2
(9)	Number of Mid-block Crossings / 500 ft. Block Length	0.0	1.3	0.1	0.3
	C. Path Walkability Indicators Related to Buffer Zones	Min.	Max.	Mean	Std. Dev
(10)	Average Width of Buffer Zone (both sides together) (ft.)	3.8	18.6	11.2	3.3
(11)	Average Width of Landscape Strip (both sides together) (ft.)	0.0	7.2	2.1	1.5
(11-1)	Existence of Landscape Strip I (one or both = 1, none = 0)*			0.5	0.5
(11-2)	Existence of Landscape Strip II (both = 1, one or none = 0)*			0.1	0.3
(12)	Average Width of Bike Lane (both sides together) (ft.)	0.0	5.8	1.2	1.8
(12-1)	Existence of Bike Lane I (one or both = 1, none = 0)*			0.2	0.4
(12-2)	Existence of Bike Lane II (both = 1, one or none = 0)*			0.2	0.4
(13)	Average Width of On-street Parking (both sides together) (ft.)	1.0	15.7	6.7	3.3
(13-1)	Type of On-street Parking (diagonal or perpendicular = 1)*			0.1	0.2
(13-2)	Existence of On-street Parking I (both = 1, one or none = 0)*			0.9	0.3
(13-3)	Existence of On-street Parking II (both = 1, one or none = 0)*			0.7	0.5

	D. Path Walkability Indicators Related to Sidewalks	Min.	Max.	Mean	Std. Dev
(14)	Sidewalk Coverage Rate (%)	55%	100%	96%	0.1
(14-1)	Existence of Sidewalk (binominal dummy variable)*			1.0	0.2
(15)	Average Width of Walking Zone (ft.)	2.8	7.9	5.1	1.0
(16)	Average Length of Sidewalk (ft.)	162.0	1097.5	442.4	156.1
(17)	Average Number of Driveway Curb-Cuts / 500 ft. Sidewalk	0.3	4.8	2.2	0.8
(18)	Percentage of Sidewalk Length with Special Pavement (%)	0%	100%	30%	0.4
(19)	Average Route Steepness**				
	E. Path Walkability Indicators Related to Sidewalk Facilities	**Min.**	**Max.**	**Mean**	**Std. Dev**
(20)	Percentage of Sidewalk Length with Visual Nuisance (%)	0%	100%	64%	0.3
(21)	Average Numbers of Street Furniture / 500 ft. Sidewalk	0.0	5.4	0.9	1.3
(22)	Average Number of Intermediaries / 500 ft. Sidewalk	0.0	25.0	3.2	5.2
(23)	Average Number of Street Trees / 500 ft. Sidewalk	0.7	15.0	5.9	3.3
(24)	Percentage of Sidewalk Length Covered by Tree Canopies (%)	15%	67%	39%	0.1
(25)	Average Ground-Level Luminosity after Sunset (fc.)	0.1	1.7	0.4	0.3
	F. Path Walkability Indicators Related to Street Scale and Enclosure	**Min.**	**Max.**	**Mean**	**Std. Dev**
(26)	Average Building-to-Building Distance (ft.)	0%	100%	64%	0.3
(27)	Average Building Height (ft.)	0.0	5.4	0.9	1.3
(28)	Average Skyline Height (ft.)	0.0	25.0	3.2	5.2
(29)	Enclosure Ratio I (Bldg.-to- Bldg. Dist. to Bldg. Height)	0.7	15.0	5.9	3.3
(30)	Enclosure Ratio II (Bldg.-to- Bldg. Dist. to Skyline Height)	15%	67%	39%	0.1
(31)	Street Enclosure Index I (abs(Enclosure Ratio I - 3.3))	0.1	1.7	0.4	0.3
(32)	Street Enclosure Index II (abs(Enclosure Ratio II - 3.3))	0%	100%	64%	0.3
(33)	Average Building Width (ft.)	0.0	5.4	0.9	1.3
(34)	Percentage of Sidewalk Length with Building Façades (%)	0.0	25.0	3.2	5.2
(35)	Average Building Setbacks (ft)	0.7	15.0	5.9	3.3
	G. Path Walkability Indicators Related to Nearby Buildings and Properties	**Min.**	**Max.**	**Mean**	**Std. Dev**
(36)	Average Pedestrian-Level Façade Transparency	1.6	4.5	2.9	0.7
(37)	Average Number of Street-Facing Entrances / 500 ft.	1.3	15.9	4.8	2.8
(38)	Average Number of Upper-Level Windows / 500 ft. Sidewalk	0.0	40.7	10.3	7.7
(39)	Fence Coverage Rate (% of Sidewalk Length with Fence) (%)	0%	55%	14%	0.1
(40)	% of Walking-Conducive (1st floor) Commercial Uses (%)	0%	100%	26%	0.3
(40-1)	Commercial (1st floor) Use of Adjacent Buildings (com.= 1)*			0.4	0.5
(41)	% of (1st floor) Residential Uses (%)	0%	97%	49%	0.3
(41-1)	Residential (1st floor) Use of Adjacent Buildings (R = 1)*			0.5	0.5
(42)	Mixed Use (1st floor) of Adjacent Buildings (mixed use = 1)*			0.0	0.1

* Binominal dummy variables
** Steepness was calculated only at the route level by using secondary data (DEM)

4.8. Advantage of Path Walkability and Route-level Analyses

Developing path walkability indicators required collecting both micro-level environmental data and travelers' route information, which inevitably added a huge burden to this research. However, the researcher chose to use path walkability because it enables route-level comparative disaggregate analyses. A route-level analysis has three potential advantages over conventional neighborhood comparisons relying on urban form.

The first advantage is that using walkability helps researchers avoid a mismatch between aggregated environmental data and disaggregated travel data. Most previous research relying on urban form has not been able to maximize travel survey results from individual travelers because all the environmental data are aggregated at the neighborhood level and are not available at the individual level. In much previous research without route information, the same environmental "score" was given to all the subjects living in the same neighborhood. As a result, the environmental characteristics of one's specific travel route are crudely and inaccurately averaged with the characteristics of other parts of the neighborhood outside the route (Krizek 2003). However, even within the same neighborhood, one's individual walking experience may vary based on the walking route. Not every street segment is equally important; Some pedestrian paths are more heavily used than others. Urban form approaches erroneously treat all streets in one neighborhood equally (Schlossberg 2004), while route-level walkability allows us to give weight to each street before evaluating the walkability of the neighborhood as a whole.

Second, route-level analysis can more accurately control the walking distance factor. Many previous studies insist that travel distance is the single most important determinant of walking behavior (Southworth 2005). However, without any route information, many previous travel behavior studies have used a straight-line distance (between one's trip origin and destination) instead of an actual walking distance. But a complete walking model will have many compounding determinants other than walkability, such as income or trip purposes. The success of testing the effect of walkability may depend on how accurately we can control other major determinants, especially the walking distance. By using a route-level analysis, this research is expected to control the walking distance in a more accurate way.

The third advantage of a route-level disaggregated analysis is that it reduces possible "self-selection" bias. In this case, self-selection interferes when researchers try to prove causality between neighborhood urban form (or other environmental factors) and walking behavior, because subjects might have chosen to live in the neighborhood because they prefer to walk. The causality drawn from such research design may be confounded with individual attitudes and preferences, and therefore researchers are unable to know whether it is environmental factors or human attitudes that affect walking travel behavior (Handy et al. 2006). Self-selection is one of the drawbacks of neighborhood-level comparative studies (Cervero and Duncan 2003). Route-level analysis can reduce this problem by using the individual traveler as the basic unit of analysis. For example, variation in attitude toward walking can be reduced by surveying travelers living in a single neighborhood and analyzing their individual travel data based on walking routes. A route-level analysis may not be completely free from self-selection, but could be an acceptable alternative to a high-cost longitudinal research design, which may be the only truly reliable way to avoid self-selection.

With the advantages stated above, a route-level walkability analysis has an edge over neighborhood urban form analysis, especially for studies focusing on purpose-driven, destination-specific travel (e.g., trips to the transit station, school, or neighborhood park). However, if a researcher is more interested in a "tour," which is a combination of multiple trips with different purposes, the route-level research design might not be suitable. By the same token, route-level walkability tells us little about the level of one's combined physical activity, which matters to some public health researchers.

5. QUANTIFYING PATH WALKABILITY

5.1. Dealing with Multiple Variables

The greatest challenge that this study faced was dealing with the qualitative nature of environmental design research. Complex and subtle concepts such as path walkability may not be captured by a few environmental indicators. This research embraced as much environmental information as can be measured in an objective way as possible, and yielded 52 path walkability indicators.

They are all potentially important indicators that may affect the path walkability, but some indicators are interrelated and thus may have a high degree of multicollinearity. This multivariable - multicollinearity dilemma might significantly undermine the effective model estimation (Cervero and Kockelmann 1996; Cervero and Duncan 2003).

This research avoided this problem by using factor analysis. Factor analysis is used to linearly combine the variables having multicollinearity and groups them into a smaller number of underlying dimensions that are too subtle and complex to be easily observed and measured (Cervero and Kockelman). An auxiliary benefit is that researchers can significantly reduce the number of variables.

Factor analyses have been successfully used by Cervero and other researchers in their efforts to define built environment factors (Cervero and Kockelman, 1996; Cervero and Duncan, 2003). For this research, the path walkability indicators can be grouped into a smaller number of walkability components, which represent the construct of walkability.

The factor scores extracted from the walkability components will be used as four experimental variables to test the effect of walkability on travel behavior.

5.2. Factor Analysis

From a complete list of path walkability indicators (subchapter 3.5), 38 indicators were selected for the factor analysis. Most binominal dummy variables[17] were excluded if there was a continuous variable of the same indicator available, because much detailed information was lost in the conversion to a binominal dummy variable (see Table 5.1). Table 5.2 shows the final 38 path walkability indicators selected for the factor analysis.

Table 5. 1: Continuous Variable vs. Binominal Variable

	Continuous Variable	Binominal Variable
Example	% of special pavement	Existence of special pavement
Route of Traveler A	0.49	0
Route of Traveler B	0.51	1

[17] Chatterjee et al. explained it as "qualitative variables such as sex, marital status, or political affiliation." They stated, "These variables take on only two values, usually 0 and 1. The two values signify that the observation belongs to one of two possible categories." (Chatterjee, Hadi, and Price, 2000, p123)

Table 5. 2: 38 path walkability indicators out of the list of the 52 candidates

	A. Path Walkability Indicators Related to Curb-to-Curb Roadways
(1)	Average Width of Curb-to-Curb Roadway (ft.)
(2)	Average Width of Traffic Zone (ft.)
(3)	Average Number of Traffic Lanes
(4)	Average Width of Through Traffic Lanes (ft.)
(5)	Number of Traffic Calming Elements / 500 ft. Block Length
(6)	Pedestrian Crossing Coverage Rate
(7)	Pedestrian Signal Coverage Rate
(8)	Pedestrian Crossing Facility Design Index
(9)	Number of Mid-block Crossings / 500 ft. Block Length
(10)	Average Width of Buffer Zone (both sides together) (ft.)
(11)	Average Width of Landscape Strip (both sides together) (ft.)
(12)	Average Width of Bike Lane (both sides together) (ft.)
(13)	Average Width of On-street Parking (both sides together) (ft.)
(13-1)	Type of On-street Parking (binominal dummy; diagonal or perpendicular = 1, otherwise = 0)
(14)	Sidewalk Coverage Rate (percentage of segment sidewalk length with sidewalk) (%)
(15)	Average Width of Walking Zone (ft.)
(17)	Average Number of Driveway Curb-Cuts / 500 ft. Sidewalk
(18)	Percentage of Sidewalk Length with Special Pavement (%)
(21)	Average Numbers of Street Furniture / 500 ft. Sidewalk
(22)	Average Number of Intermediaries / 500 ft. Sidewalk
(23)	Average Number of Street Trees / 500 ft. Sidewalk
(24)	Percentage of Sidewalk Length Covered by Tree Canopies (%)
(25)	Average Ground-Level Luminosity after Sunset (fc.)
(26)	Average Building-to-Building Distance (ft.)
(27)	Average Building Height (ft.)
(28)	Average Skyline Height (ft.)
(29)	Enclosure Ratio in Cross Section I (Building-to-Building Distance to Building Height)
(30)	Enclosure Ratio in Cross Section II (Building-to-Building Distance to Skyline Height)
(33)	Average Building Width (ft.)
(34)	Percentage of Sidewalk Length with Building Façades (%)
(35)	Average Building Setbacks (ft)
(36)	Average Pedestrian-Level Façade Transparency
(37)	Average Number of Street-Facing Entrances / 500 ft. Block Length
(38)	Average Number of Upper-Level Windows / 500 ft. Sidewalk
(39)	Fence Coverage Rate (Percentage of Sidewalk Length with Fence) (%)
(40)	Percentage of Walking-Conducive (1st floor) Commercial Uses (building frontage) (%)
(41)	Percentage of Residential Uses (1st floor building frontage for residential uses) (%)
(42)	Mixed Use (1st floor) of Adjacent Buildings (mixed use = 1, non – mixed use = 0)

Note: the variable numbers are consistent with the numbers in Table 3.3

Using factor analysis with varimax rotation, this research extracted principal components from 38 path walkability indicators derived from the 249 routes surveyed. Seven factors with eigenvalues larger than 1.0 were extracted and the first four factors have eigenvalues over 3.0. Table 5.3 shows 34 of the 38 walkability indicators based on the size of their factor loadings (only loadings higher than 0.30 are shown). These 34 walkability indicators were linearly grouped into the four factors. Those four factors together accounted for 72.2% of the variance among the 38 walkability indicators, which meant there was only 27.8% loss in information, while the number of variables was significantly reduced from 38 to 4.

The first 16 walkability indicators were linearly combined into "factor 1." It had the highest communality among factors (eigenvalue of 13.1), accounting for 34.5% of the total variation. Factor 1's path walkability indicators were generally related to the characteristics of both sidewalk and nearby property, therefore it was inferred that the first factor represents the quality of the street-level pedestrian sidewalk environment. This research calls it "sidewalk amenities." This factor yields intuitively expected and reasonably interpretable signs of factor loadings. For example, *(40) Percentage of Walking-Conducive (1st floor) Commercial Uses* has a plus sign while *(39) Fence Coverage Rate* has a minus sign, suggesting that if the percentage of commercial uses increases, the fence coverage rate decreases and vice versa. The walkability indicators that are expected to be conducive to walking had predominantly positive signs on this factor. Given the signs of the loadings, a high "sidewalk amenities" score represents a route with the following conditions (in order of the sizes of loadings):

Table 5. 3: Factor Analysis Results

Path Walkability Indicators	Component			
	1	2	3	4
(22) Average Number of Intermediaries / 500 ft. Sidewalk	0.97			
(9) Number of Mid-block Crossings / 500 ft. Block Length	0.97			
(21) Average Numbers of Street Furniture / 500 ft. Sidewalk	0.96			
(38) Average Number of Upper-Level Windows / 500 ft. Sidewalk	0.89			
(37) Average Number of Street-Facing Entrances / 500 ft. Block	0.88			
(25) Average Ground-Level Luminosity after Sunset (fc.)	0.87			
(28) Average Skyline Height (ft.)	0.86		-0.34	
(5) Number of Traffic Calming Elements / 500 ft. Block Length	0.86			
(40) Percentage of Walking-Conducive (1st floor) Commercial Uses	0.83			
(36) Average Pedestrian-Level Façade Transparency	0.78			0.48
(15) Average Width of Walking Zone (ft.)	0.76	0.30		
(27) Average Building Height (ft.)	0.73		-0.33	
(13) Average Width of On-street Parking (both sides together) (ft.)	0.70	-0.39		
(34) Percentage of Sidewalk Length with Building Façades (%)	0.69		-0.37	
(18) Percentage of Sidewalk Length with Special Pavement (%)	0.58		-0.34	0.36
(39) Fence Coverage Rate (Percentage of Sidewalk Length with Fence)	-0.47			
(7) Pedestrian Signal Coverage Rate	0.35	0.87		
(3) Average Number of Traffic Lanes		0.83		
(8) Pedestrian Crossing Facility Design Index	0.38	0.82		
(33) Average Building Width (ft.)		0.78		
(6) Pedestrian Crossing Coverage Rate	0.36	0.78		
(1) Average Width of Curb-to-Curb Roadway (ft.)		0.76	0.52	
(2) Average Width of Traffic Zone (ft.)		0.75	0.48	-0.32
(41) Percentage of Residential Uses (1st floor building frontage)	-0.43	-0.73		
(24) Percentage of Sidewalk Length Covered by Tree Canopies (%)		-0.71		
(12) Average Width of Bike Lane (both sides together) (ft.)		0.64	0.33	0.35
(4) Average Width of Through Traffic Lanes (ft.)	-0.36		0.79	
(30) Enclosure Ratio in Cross Section II (BB Dist to Skyline Height)	-0.55		0.66	
(29) Enclosure Ratio in Cross Section I (BB Dist to Building Height)	-0.57		0.66	
(26) Average Building-to-Building Distance (ft.)	-0.33	0.60	0.64	
(35) Average Building Setbacks (ft)	-0.49	0.42	0.61	
(23) Average Number of Street Trees / 500 ft. Sidewalk			-0.35	0.83
(11) Average Width of Landscape Strip (both sides together) (ft.)				0.83
(10) Average Width of Buffer Zone (both sides together) (ft.)	0.47			0.74
(13-1) Type of On-street Parking (diagonal or perpendicular=1)	excluded by the first four factors			
(14) Sidewalk Coverage Rate (percentage of segment with sidewalk)				
(17) Average Number of Driveway Curb-Cuts / 500 ft. Sidewalk				
(42) Mixed Use (1st floor) of Adjacent Buildings (mixed use = 1)				

Note: Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Only factor loadings larger than 3.0 are shown in the table.
Some variable names were truncated but the numbers are still consistent with the numbers in Table 3.3 and 5.2.

Table 5. 4: 34 Path Walkability Indicators and 4 Path Walkability Factors

Path Walkability Indicators	Component Name
(22) Average Number of Intermediaries / 500 ft. Sidewalk (9) Number of Mid-block Crossings / 500 ft. Block Length (21) Average Numbers of Street Furniture / 500 ft. Sidewalk (38) Average Number of Upper-Level Windows / 500 ft. Sidewalk (37) Average Number of Street-Facing Entrances / 500 ft. Block Length (25) Average Ground-Level Luminosity after Sunset (fc.) (28) Average Skyline Height (ft.) (5) Number of Traffic Calming Elements / 500 ft. Block Length (40) Percentage of Walking-Conducive (1st floor) Commercial Uses (building frontage) (36) Average Pedestrian-Level Façade Transparency (15) Average Width of Walking Zone (ft.) (27) Average Building Height (ft.) (13) Average Width of On-street Parking (both sides together) (ft.) (34) Percentage of Sidewalk Length with Building Façades (%) (18) Percentage of Sidewalk Length with Special Pavement (%) (39) Fence Coverage Rate (Percentage of Sidewalk Length with Fence) (%)	**Factor 1:** (Sidewalk Amenities)
(7) Pedestrian Signal Coverage Rate (3) Average Number of Traffic Lanes (8) Pedestrian Crossing Facility Design Index (33) Average Building Width (ft.) (6) Pedestrian Crossing Coverage Rate (1) Average Width of Curb-to-Curb Roadway (ft.) (2) Average Width of Traffic Zone (ft.) (41) Percentage of Residential Uses (1st floor building frontage for residential uses) (%) (24) Percentage of Sidewalk Length Covered by Tree Canopies (%) (12) Average Width of Bike Lane (both sides together) (ft.)	**Factor 2** (Traffic Impacts)
(4) Average Width of Through Traffic Lanes (ft.) (30) Enclosure Ratio in Cross Section II (Bldg. to Bldg. Distance to Skyline Height) (29) Enclosure Ratio in Cross Section I (Bldg. to Bldg. Distance to Building Height) (26) Average Building-to-Building Distance (ft.) (35) Average Building Setbacks (ft)	**Factor 3** (Scale & Enclosure)
(23) Average Number of Street Trees / 500 ft. Sidewalk (11) Average Width of Landscape Strip (both sides together) (ft.) (10) Average Width of Buffer Zone (both sides together) (ft.)	**Factor 4** (Landscaping Elements)

Note: Some variable names were truncated but the numbers are still consistent with the numbers in Table 3.3 and 5.2.

- plenty of chairs and tables in street cafes or front porches
- existence of mid-block crossings
- plenty of benches and other seating facilities
- more windows on the second and third floors of nearby buildings
- more street-facing entrances
- plenty of street lights or illumination from nearby businesses
- higher average building skyline (including properties without buildings)
- more traffic calming facilities
- more commercial uses on the first floor
- higher transparency between the sidewalk and the first floor of nearby buildings
- wider sidewalks
- higher average building height
- wider on-street parking spaces
- more building facades facing streets
- more sidewalks with special pavements (other than concrete pavement)
- fewer fences between sidewalks and nearby properties

The next 10 walkability indicators were linearly combined into "Factor 2." (Table 5.4) The second factor, explaining 18.8% of the total variation, included many path walkability indicators related to traffic-related roadway characteristics. Since the path indicators could collectively determine the level of traffic impact on pedestrians, this research called this factor “traffic impacts.” Given the signs of factor loadings, the conditions contributing to the high score in “traffic impacts” are expected to be found on arterials or multilane auto-oriented streets.

The walkability indicators linearly grouped under the “traffic impact” factor are reasonably interpretable in general, although there are some indicators seemingly unrelated to traffic impact, such as *(33) Average Building Width* and *(41) Percentage of Residential Uses*. But it is also true that most multilane arterials have larger office/commercial buildings and fewer residential uses at the ground level. By the same token, pedestrian crossing facilities and bike lanes are also associated with high-traffic, multilane streets, and are thus grouped with traffic impact factors, although they are sometimes considered to contribute to a good walkability. Actually, they could function in either way: Traffic signals may increase the pedestrian safety but also increase the travel time. It seems that bike lanes happen to be associated with multi-lane arterials because bike lanes are usually installed on those streets with a fairly wide curb-to-curb distance.

The least interpretable walkability indicator is the *(24) Percentage of Sidewalk Length Covered by Tree Canopies*, which could be a unique local condition. This research measured the length of tree canopies of street trees, both in the buffer zones and private properties. In the Mountain View station area, small residential streets had many private trees branching over the sidewalks while multi-lane arterials did not have much tree canopy provided by private properties. That may be why tree canopy is grouped with path walkability indicators related to “traffic impact,” but it may be different in other areas.

Given the signs of the factor loadings, the high factor score in “traffic impacts” reflects streets environment with the following attributes:

- more pedestrian crossings and signals
- multiple traffic lanes
- wider building frontages
- wider curb-to-curb roadway width
- wider width of traffic zone (excluding street parking and bike lane)
- fewer residential uses on the first floor of nearby buildings
- less tree canopy over the sidewalk
- narrower or no bike lanes

In general, the high score in “traffic impact” factor is expected to discourage walking to the station.

The next five path walkability indicators were linearly grouped into the third factor, which accounted for 10.8% of variance. Based on the five indicators, this research called it “street scale and enclosure.” All five variables were reasonably interpretable, although *average width of through traffic lanes* would be easier to interpret as a part of the second factor. Based on the signs of factor loadings, the routes with high scores in “street scale and enclosure” are expected to have the following conditions:

- wider width of each traffic lane
- lower average skyline height and longer building-to-building distance
- lower average building height and longer building-to-building distance
- longer building-to-building distance
- greater building setback from the streets

Based on environmental design theories, the high score in the "street scale and enclosure" factor is expected to be negatively associated with good walkability. The heights of most buildings in the Mountain View Station area were less than four stories, so the logic in this factor may not be applied into high-rise CBD areas, such as Manhattan.

The fourth factor includes three path walkability indicators that are related to the amount of street landscaping. This research called it the "landscaping elements" factor, and this factor explains 8.2% of variance. A high score in this factor denotes routes with the following conditions:

- more street trees between sidewalk and traffic
- wider landscape strip between sidewalk and traffic
- wider buffer zone between traffic lanes and sidewalk

It is expected that a high score in the "landscaping" factor will be associated with good walkability.

The last four path walkability indicators were not included in the first four factors with meaningful eigenvalues, and thus were excluded for the model estimation. The four excluded pathwalkability indicators are:

- *(13-1) Type of On-street Parking (binominal dummy; diagonal or perpendicular = 1, otherwise = 0)*[18]
- *(14) Sidewalk Coverage Rate (percentage of segment sidewalk length with sidewalk) (%)*
- *(17) Average Number of Driveway Curb-Cuts / 500 ft. Sidewalk*
- *(42) Mixed Use (1st floor) of Adjacent Buildings (mixed use = 1, non – mixed use = 0)*

The factor analysis was successful in general, providing distinct groups of walkability components that represented what Cervero and Kockelman call “underlying dimensions” of walkability. Overall, the relationships between the four extracted components (factors) and their path walkability indicators (variables) are logical and interpretable.

[18] Binominal dummy variables may not be suitable for factor analyses because of lack of linearity.

Note for Urban Designers

The factor analysis in this chapter did not directly test the hypothesis that path walkability influences mode choice. Rather, factor analysis transformed the walkability indicators into a form that is more suitable for the mode choice modeling in Chapter 7.

One of the problems associated with environmental design research is having a lot of variables, because in many cases, a design benefit is influenced collectively and simultaneously by a number of small variables. Urban designers like to take a "holistic" approach to these many variables. Environmental design research is more inclusive than exclusive – design researchers want to find as many causes as possible and to test their collective effect, rather than singling out a single dominant cause. But, a logit analysis, which is used for the mode choice model in Chapter 6, cannot include too many variables, usually ten at best. Given the other travel and socio-economic variables that must be tested, only a few path walkability indicators can be tested. If three path indicators are included, the other 30+ indicators must be abandoned.

Factor analysis can partly solve this problem by grouping statistically similar variables and making them into a new variable. In this chapter, many walkability indicators were condensed into a smaller number of indicator sets (called factors, later used as variables) based on the statistical correlations of the measured values. The factor analysis yielded four new variables: Sidewalk Amenities, Traffic Impacts, Street Scale and Enclosure, and Landscaping Elements. There are two important concerns in interpreting the result of factor analysis. First, the variables (walkability indicators in this research) grouped under one factor should share a quality, which can be used to name the group. Second, in the result, the signs (+ or –) of the variables indicate the relationship among the variables. The relationship should be intuitively or logically explainable. For example, two path walkability indicators, *(1) Average Width of Curb-to-Curb Roadway (ft)* and (2) *Average Width of Traffic Zone (ft.)* were grouped under the same factor "Traffic Impacts." Since in most cases, as the width of the traffic zone increases, the width of curb-to-curb roadway also increases, or vice versa, the two indicators should have the same sign (both + or both –). If they show different signs, the reason should be explainable. Otherwise, that factor should be discarded.

In reality, it is very rare to have perfectly explainable groupings and signs. And some statisticians also believe that using factor analysis to reduce the number of variables is an abuse of the method, and that factor analysis should be used only to find an unknown concept from many seemingly unrelated variables, as is done in some psychology research. Using factor analysis for environmental design research has an obvious advantage, but it should be further discussed and justified in the future.

Figure 5. 1: Difference in Factor 1 (Sidewalk Amenities)

Note: The two streetscapes are same in terms of the other three factors

Figure 5. 2: Difference in Factor 2 (Traffic Impacts)

Note: The two streetscapes are same in terms of the other three factors

Figure 5. 3: Difference in Factor 3 (Street Scale and Enclosure)

Note: The two streetscapes are same in terms of the other three factors

Figure 5. 4: Difference in Factor 4 (Landscaping Elements)

Note: The two streetscapes are same in terms of the other three factors

6. MODELING INDIVIDUAL MODE CHOICE TO THE STATION

6.1. Mode Choice Model Overview

A pair of binominal logit analyses was performed on two access mode choices (walking vs. driving) to the station. Model I (the socio-economic model) was estimated only using travel distance and socio-economic variables, while Model II (the environmental model) was constructed using new path walkability variables, as well as the same set of travel and socio-economic variables used for Model I. As four new path walkability variables, this research used the factor scores derived from the four path walkability components (factors) in Chapter 5. Both models analyzed data from the same 249 travelers, who provided their walking routes for home-to-station trips: 150 travelers who usually walk drew the routes that they were most likely to use, and 99 travelers who usually use automobiles (including solo driving, carpooling, and getting dropped-off), but who had experience walking to the station, provided the routes they had used when they walked to the station.

This research assumed that a significant number of auto users, who lived within a reasonable walking distance had previous experience walking to the station. When they walked to the station and perceived their route environments, they did not single out every walkability indicator that they liked or did not like. It was expected that they did not evaluate the walkability of their routes as they would evaluate parking cost, for example. They instead perceived their walkability in a holistic way and recognize it at a subconscious level. But this research hypothesized that travelers did consider their earlier walking experience to some extent the next time they choose an access mode to the station.

This research excluded auto users who had never walked to the station, because it was assumed that they did not make an informed decision based on experience of the environmental characteristics of any route. In other words, walkability had no influence on their mode choice decision, and therefore they are irrelevant to testing the effect of walkability on mode choice decision. One could argue that they may have some indirect perception of the walkability of possible routes to the station, for example, they might have walked similar routes for other trips and considered the previous experience in their current mode choice decision. However, the station user survey did not ask auto users who had never walked to the station whether they had any other types of walking experience on the possible routes nor to draw possible routes to the station. Would the respondent choose a possible route, or would this research use the path walkability of his or her shortest route, or the average path walkability of all the possible routes? To avoid relying on walkability data generated from hypothetical routes, and the problem of choosing a hypothetical route, the author simply excluded all auto users who had never walked to the station. To do otherwise would have introduced a new and unnecessary set of problems into the study.

Excluding those who never walked to the station also effectively eliminated those who lived far from the station, for whom walking was not a viable travel option. For example, if a traveler has to walk more than two miles in the U.S., walking might not be a competitive travel mode. One should not construct a mode choice model that includes travelers without full options, called “universal set of alternatives” (Ben-Akiva and Lerman, 1985). Since there is no research testing transit users’ acceptable walking distance, it is better to exclude those who never walk to the station than to exclude all transit users living beyond a certain arbitrary distance.

6.2. Model Specification and Variables Tested

To discover the determinants – statistically significant and interpretable explanatory variables – influencing the decision to walk or use automobiles, a pair of binominal logit models were performed on access mode choices (walk vs. auto) as dependent variables and on three types of independent variables: travel, socio-economic, and environmental variables. To estimate the probability of choosing walking over driving for access trips to the station, this research used the following binominal logit models:

$$P_{ino} = \frac{\exp(U_{ino})}{\sum_j \exp(U_{jno})}, \quad \text{for } j=1,2 \ \ all\ U_{ino}=f(T_{io}, SEV_n, EV_o)$$

P_{ino} = probability of person *n* choosing access mode *i* from home origin *o* to the Mountain View station

j = access mode choice sets available for a trip-maker

U_{ino} = utility function for a person *n* accessing by mode *i* from the origin *o* to the station

T_{io} = travel attribute for travel by mode *i* from the origin *o* to the station

SEV_n = socio-economic attributes of trip-maker *n*

EV_o = environmental attributes associated with travel route from trip origin *o* to the station

exp = exponential function

Table 6. 1: Variables Defined

Variable (*dummy)	**Description**
	Individual-Level (Disaggregated) Travel Variables
PATHDIST	Actual path (network) distance (mile)
DETOUR	Detouring ratio
PURPOSE*	Trip purpose (dummy)
FREQUENC*	Trip frequency (dummy)
T_TRAIN*	Type of transit system (dummy)
	Individual-Level (Disaggregated) Socio-economic Variables
HH_SIZE	Household size
DRVLICEN*	Possession of a valid driver's license (dummy)
N_DRLINC	Number of driver's license holders in a household
A_DRLICN	Number of driver's license per person in a household
N_CARS	Number of cars owned by a household
CAR_AVAL*	Car availability (dummy)
AVE_CARS	Number of car per person in a household
AGE	Age of a traveler
GENDER*	Gender of a traveler (dummy)
RACE*	Race of a traveler (Latino, Asian, Black; White as a reference) (dummy)
US_BORN*	Birth place of a traveler (dummy)
JOB_TYPE*	Type of occupation (dummy)
HH_INCOM	Household annual income
IN_INCOM	Individual annual income
P_C_INCM	Per capita income
	Neighborhood-Level (Aggregated) Socio-economic Variables
R_SHOUSI	Percentage of detached housing units
R_LESS4U	Percentage of housing units in buildings with 4 or less housing units
BLDG_AGE	Median age of building structure
MED_INCO	Median household income
	Individual-level (Disaggregated) Environmental Variables
SIDEWALK	**Sidewalk Amenities from Factor 1**
T_IMPACT	**Traffic Impacts from Factor 2**
SCALE	**Street Scale and Enclosure from Factor 3**
LANDSCAPE	**Landscaping Elements from Factor 4**
STEEPNESS	Average steepness between a trip origin and the station
B_HEIGHT	Height of residence
BLDG_TYP	Type of residence
APT_CON*	Type of community (dummy)
MIX_USE*	Mixed use in the residency (dummy)
	Neighborhood-Level (Aggregated) Environmental Variables
HU_DEN	Housing density (HU/acre)
POP_DEN	Population density (POP/sq. mile)
RESIDENT	Percentage of residential use
RETAIL	Percentage of retail use
USEMIX*	Percentage of retail and mixed use (dummy)

The most notable difference from previous walking travel behavior research is that this research used route-based individual data not only for socio-economic variables but also for travel and environmental variables. As experimental variables, the pair of models tested the four path walkability variables, which are the factor scores from the four path walkability components extracted from the 249 individual routes. This research also used individual path distance (network distance) instead of conventional straight-line distance, and included detour ratio as a proxy for neighborhood street patterns.

Most socio-economic variables used by previous studies were also tested. Table 6.1 lists all the variables tested, a total of 38 potential variables. Variables were selected from literature on both access mode choice and general travel mode choice studies. The variables are categorized into three types: travel, socio-economic, and environmental. The socio-economic and environmental variables are also subdivided into disaggregated and aggregated data.

6.2.1. Travel Variables

- Travel distance (PATHDIST): the actual path (network) distance along the traveler's route between a home origin and a gate of the Mountain View station. Many previous studies use a straight-line distance, but this research used path distance to more accurately measure the differences in individual trips. Travel distance is a significant predictor of choosing walking according to previous research (Korf et al 1979; Loutzenheiser 1997).

- Detour ratio (DETOUR): the ratio of traveler's straight-line distance between home origin and the station to actual path distance along the route.

- Trip purpose (PURPOSE): a dummy variable defined by the purpose of the trip. A value of 1 is assigned to a work purpose, while 0 is assigned to all other purposes.

- Trip frequency (FREQUENC): a dummy variable defined by the number of station access trips made by travelers. A value of 1 is assigned to a traveler who makes three or more trips to the station per week, 0 otherwise.

6.2.2. Socio-Economic Variables

Individual-Level (Disaggregated) Socio-Economic Variables

- Household size (HH_SIZE): the number of persons in the household.
- Possession of a valid driver's license (DRVLICEN): a dummy variable. A value of 1 is given when the survey respondent has a valid driver's license, 0 otherwise.
- Number of driver's license holders (N_DRLINC): the number of valid driver's license holders in the household.
- Average number of driver's licenses per person in household (A_DRLICN): the total number of valid driver's licenses in the household divided by the number of

persons in the household.

- Number of cars (N_CARS): the number of cars owned by the household.
- Car availability (CAR_AVAL): a dummy variable. A value of 1 is given when the survey respondent has a car available for his/her trip to the station, 0 otherwise.
- Number of cars per person (AVE_CARS): the number of cars owned by the household divided by the number of persons in the household.
- Age (AGE): the age of the traveler.
- Gender (GENDER): a dummy variable defined by the gender of the traveler. A value of 1 is given if the survey respondent is male, 0 if female.
- Race (WHITE, LATINO, ASIAN, BLACK): dummy variables defined by the race of the traveler.
- Birthplace (USBORN): a dummy variable defined by the birthplace of the traveler. A value of 1 is given to US-born travelers, 0 otherwise.
- Type of occupation (JOB_TYPE): a dummy variable defined by the traveler's employment status. A value of 1 is given to a full-time worker; all others receive 0.
- Household annual income (HH_INCOM): the annual household income before taxes in 2004.
- Individual annual income (IN_INCOM): the traveler's annual individual income before taxes in 2004.
- Per capita income (P_C_INCM): the annual household income in 2004 divided by the number of persons in the household.

Neighborhood-Level (Aggregated) Socio-Economic Variables

- Detached housing units (R_SHOUSI): the percentage of detached single family housing units in the census tract that includes the origin of the traveler.
- Housing units in buildings with 4 or fewer housing units (R_LESS4U): the percentage of housing units in buildings with 4 or fewer housing units in the census tract.
- Median age of building structure (BLDG_AGE): the median age of buildings in the census tract.
- White residents (R_WHITE): the percentage of white residents in the census tract.
- African American residents (R_BLACK): the percentage of African American residents in the census tract.
- Asian residents (R_ASIAN): the percentage of Asian residents in the census tract.
- Median household income (MED_INCO): the median household income of the census tract.

6.2.3. Environmental Attributes

Individual-Level (Disaggregated) Environmental Variables

- Steepness (STEEPNESS) is the ratio of the altitude difference between the trip origin and the center of the Mountain View station to the straight-line distance between trip origin and the center of the station. In the study area, the maximum steepness of individual access trips (home to station) is 1.2% (ascending), and the minimum is - 0.8% (descending). The steepness figures clearly show that the study area is fairly flat.

- Height of residence (B_HEIGHT): the total number of floors in the building where the traveler lives.
- Type of residence (BLDG_TYP): the number of housing units in the building of residence. Survey respondents were asked to choose one of the following four choices: detached single-family, 2 to 4 units, 5 to 9 units, and 10 or more units in the building.
- Type of community (APT_CON): a dummy variable defined by the type of community, which targets residents of large condominium projects. A value of 1 is given to a traveler living in an apartment or condominium complex that has more than 5 separate residential buildings within its boundary.
- Mixed use in the residency (MIX_USE): a dummy variable defined by the existence of retail in the building of residency. A value of 1 was given to a traveler living in a mixed-use building, 0 otherwise.

Neighborhood-Level (Aggregated) Environmental Variables

- Housing density (HU_DEN): the number of housing units per acre based on the 2000 census data (SF1) at the census tract level.
- Population density (POP_DEN): the population per square mile based on the 2000 census data (SF1) at the census tract level.

- Residential use (RESIDENT): the percentage of the total land area dedicated to residential use in the census tract.
- Retail use (RETAIL): the percentage of the total retail area dedicated to retail use in the census tract.
- Mixed use (USEMIX): a dummy variable defined by the ratios of residential and retail area in the census tract. A value of 1 was given to a traveler whose trip origin is in a "mixed use" census tract, defined in this research as consisting of 25% or more retail and 30% or more residential areas, 0 otherwise.

6.2.4. Untested Variables and Data Sources

There are two variables that might influence travel behavior, but could not be tested by a single-site study.

- **Parking availability:** Previous research has found that the amount of parking space at the station may be a significant determinant encouraging motorized travel and discouraging walking to the station (Cervero 1995; Loutzenheiser 1997). However, this research dealt with a single-station and thus could not test the influence of the parking availability.

- **Weather:** Weather is probably an important determinant of travel mode choice. A single-station study cannot test any weather variable.

Most individual-level travel, socio-economic, and built environment data came from the station user survey. Most neighborhood-level variables were derived through GIS mapping, using secondary data from various sources, including the 2000 census, ABAG land use data, and the USGS Digital Elevation Model (DEM).

6.3. Results of Two Access Mode Choice Models

Table 6. 2: Binomial Logit Results; Basic Model vs. Expanded Models, (N=249)

TABLE 1. Binomial Logit Model (Walk vs. Auto) Estimation Results, Model I &Model II (N=249)

	Model I: Basic Model Socio-Economic Model			**Model II: Expanded Model Environmental Model**		
Variables	Coefficient	Std. Err.	Sig.	Coefficient	Std. Err.	Sig.
Path Distance	-3.22	0.50	0.00	-3.78	0.65	0.00
Trip Purpose	-1.49	0.73	0.04	-1.71	0.81	0.04
Car Availability	-2.74	0.73	0.00	-2.82	0.79	0.00
Asian	-0.90	0.43	0.04	-0.69	0.53	0.19
Gender	0.39	0.37	0.29	0.97	0.45	0.03
F1: **Sidewalk Amenities**				0.84	0.26	**0.00**
F2: **Traffic Impact**				-0.82	0.22	**0.00**
F3: **Scale & Enclosureness**				-0.62	0.23	**0.01**
F4: **Landscaping Elements**				0.45	0.21	**0.03**
Constant	6.77	1.19	0.00	7.08	1.27	0.00
-2$\mathscr{L}$(c) : Log-likelihood function value: Constant only model			307.75			307.75
-2$\mathscr{L}$(beta): Log-likelihood function value: Parameterized model			203.70			158.26
Goodness of Fit (**McFadden Rho Squared**)			**0.34**			**0.49**
Number of observations			249			249
Model improvement test: $-2[\mathscr{L}$(basic model)-$\mathscr{L}$(expanded model)]		*x^2 =45.441 df=4 prob.=0.00*				

* significant at the 0.05 alpha level only in one of the two models

Model I shows the best-fitting socio-economic model with five predictors: *trip distance, trip purpose, car availability, Asian, and Gender.* All variables except *Gender* were statistically significant at the 0.05 alpha level (Table 6.2).

Path Distance entered Model I; its negative sign reflects that a longer travel distance (from home to station) will tend to decrease the utility of walking, holding other variables equal. As expected, a longer path distance discourages transit users to walk to the station. *Trip purpose* also entered the model, suggesting that when a traveler makes the trip to the station for a work purpose, the probability of walking to the station decreases. *Car availability* entered Model I also with a negative sign, suggesting that if there is a car available for a trip to the station, the probability of a traveler choosing walking over using automobiles decreases. Race also plays a significant role - Asian travelers are less likely to walk, relative to white travelers. *Gender* does not “enter”[19] Model I in a significant way, but remains to compare with Model II, which *Gender* entered at the 0.05 alpha level. All five variables have negative signs, exerting as impedance factors of walking.

Model II analyzed the same data set, but the four path walkability variables were tested. First, a walkability-only model was constructed by entering the four pathwalkability factors as variables along with *Path Distance* and *Detour Ratio*. *Detour Ratio* failed to enter the model but the other five variables – the four path walkability variables and *Path Distance* – successfully entered the model at the 0.05 alpha level.

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[19] The word “enter” was used by Cervero to explain the results of regression, logit, and factor analyses (Cervero, 1995; Cervero, 2001; Cervero and Duncan, 2003). For a logit or multiple regression model, “a variable X enters the model” means that the independent variable of X has statistically significant correlation with a dependent of Y, at a given significance level.

Based on the walkability-only model, an extended model was constructed by adding the same set of socio-economic variables used for the basic model. All variables except *Asian* entered Model II at the 0.05 alpha level. In total, the extended model (Model II) has 10 exploratory variables (including *Asian* only for a comparison with Model I).

All four path walkability variables – *Sidewalk Amenities*, *Traffic Impacts*, *Street scale and Enclosure*, and *Landscaping Elements* successfully entered the model II. Their respective signs suggest that better sidewalk amenities and landscaping increase the transit users' probability of walking to the station, while the probability of walking decreases when travelers have walking routes with higher traffic impacts, and with a larger scale and less enclosure (e.g., wide arterials with no or few buildings). *Trip distance* and the four socio-economic variables (*Trip purpose, Car availability, Asian, and gender*) all entered Model II with negative signs, influencing mode choice in the same way as they did in Model I. The final utility functions were shown below:

Basic Model:

$$P_{ino} = \frac{\exp(U_{ino})}{\sum_j \exp(U_{jno})}, \text{ for } j=1,2 \text{ all } U_{ino} = f(T_{io}, SEV_n)$$

U_{ino}=*6.77-3.22*Path Distance-1.49*Trip Purpose -2.74*Car Availability - 0.90*Asian+0.39*Gender*

Expanded Model:

$$P_{ino} = \frac{\exp(U_{ino})}{\sum_j \exp(U_{jno})}, \text{ for } j=1,2 \text{ all } U_{ino} = f(T_{io}, SEV_n, EV_o)$$

U_{ino}=*7.08-3.78*Path Distance-1.71*Trip Purpose -2.82*Car Availability -*

*0.69*Asian+0.97*Gender+0.84*Sidewalk Amenities-0.82*Traffic Impacts-0.62*Scale & Enclosure+0.45*Landscaping Elements*

Where,

Path Distance = actual path (network) distance along the person n's route between a home origin and a gate of the Mountain View station.

Trip Purpose = a dummy variable defined by the purpose of the trip. A value of 1 is assigned to a work purpose, while 0 is assigned to all other purposes.

Car Availability = a dummy variable. A value of 1 is given when the traveler respondent has a car available for his/her trip to the station, 0 otherwise.

Asian= A dummy variable defined by the race of the traveler. A value of 1 is assigned, if the traveler is Asian, while 0 is assigned to all other races.

Gender = A dummy variable defined by the gender of the traveler. A value of 1 is given if the traveler is male, 0 if female.

Sidewalk Amenity = A factor score derived from the Factor 1: Sidewalk Amenity in Chapter 5

Traffic Impacts = A factor score derived from the Factor 2: Traffic Impacts in Chapter 5

Street Scale & Enclosure = A factor score derived from the Factor 3: Street Scale & Enclosure in Chapter 5

Landscaping Elements = A factor score derived from the Factor 4: Landscaping Elements in Chapter 5

Note for Urban Designers

The logit analysis was done because the mode choice, the dependent variable in this test, had discrete data, not continuous data. If the variable had had continuous data, as occurred with housing prices, a multiple regression analysis would have been used instead. A binominal logit analysis was used because the focus of this research was a choice between two modes: walking or driving. Because the mode choice did not have an existing value like housing price (e.g., $250,000), a binominal dummy variable was artificially created. A higher score (usually 1) was given to the mode choice of interest, which is walking in this case, and a lower score (usually 0) was given to the other mode, which is driving. If a variable X entered the model with a + sign in the final result, it means that the chance of walking increases as the value of variable X increases.

The purpose of a logit model is to increase predictability. When one traveler is randomly picked from a sample including the same number of walkers and drivers, without any information about the individual traveler, the chance that the traveler is a walker is 50%. The logit analysis is a process to find meaningful variables that will increase the predictability to over 50%. If in the sample above, more male travelers chose to walk and more female travelers chose to drive, the logit analysis decides whether the tendency is significant, in light of the effects of other variables. If the tendency is significant, the variable "gender" enters the model, and improves its predictability, for example, if a traveler is male, it predicted that there is more than a 50% probability that the traveler will choose walking.

Unfortunately a logit model cannot reveal the relative importance of the variables. The major interest is in whether the variable of interest enters the model in a significant way, in view of the influence of other variables. In this chapter, the major interest was whether the four new path walkability variables entered the mode choice model, and also whether there was a significant improvement in predicting the mode choice of each traveler using the new variable. That is why the author created two models: a basic model without the new path walkability variables, and an expanded model that included the new variables.

6.4. Model Comparison and Planning Implications

To find whether path walkability influences transit users' mode choices, the basic model without a walkability factor was compared to the expanded model with the four path walkability factors. First, the pseudo R squared values of the two models were compared. McFadden rho squared of Model II (the environmental model) is 0.49, which means that the utility function model with all the estimated coefficients of variables can improve explanatory power by 49%, compared to a utility function model without coefficients. That is, this model does 49% "better job than a simple flip of a coin at predicting" (Cervero, 2001) whether a traveler will walk or drive to the Mountain View station. With a McFadden rho squared value of 0.34, Model I (the socio-economic only model) improves explanatory power by 34%, compared to Model II (the environmental model)'s 49%. Additionally, a x^2 (chi-squared) test was performed (Table 6.2). The degree of statistical improvement between a basic model and an expanded model can be measured by gauging the change in the log likelihood function $\mathscr{L}$ relative to the change in degrees of freedom (model improvement = -2 [$\mathscr{L}$ (basic model)- $\mathscr{L}$ (expanded model)]. The model improvement "follows a x^2 distribution with k degrees of freedom (where k represents the increase in parameter estimates between the basic model and expanded model)" (Cervero, 2002). A x^2 (chi-squared) test result also confirmed a significant model improvement (Table 6.2).

Based on these results, it is inferred that Model II (the environmental model), including walkability factors, better predicts transit users' mode choice to the station than the purely socio-economic model. In other words, the model's ability to predict individual transit users' mode choice to the station is significantly improved by including the four path walkability variables and micro-level path walkability influences access mode choice in a statistically significant way.

Discovering whether and how environmental factors can shift mode choice from driving to walking is very important to planners, because some other travel and socio-economic variables have relatively few policy implications. For example, trip purpose, race, and gender successfully entered the models, but they have little applicability for future policy to encourage modal shift because planners cannot control these variables. They cannot change trip purpose, race, and gender to make modal shift. Meanwhile some economic variables are related to regulation rather than incentives. For example, car availability entered both models, but probably the best way to reduce car availability is to increase auto-related taxes and parking restrictions, which are likely to face strong public opposition from transit users, transit operators, and even local businessmen. To create cities with more sustainable transportation, imposing regulations may be inevitable, but it will be more effective with complementary incentives. However, there are not many planning tools available for planners as incentives. If we can accumulate scientific evidence to prove that environmental factors such as micro-level path walkability can make a positive impact on travel behavior, policy makers will have additional planning tools to use as incentives. For example, improving path walkability near transit stations could be an effective, inexpensive approach with less public opposition.

6.5. Inductive Operational Definition of Path Walkability

Based on the signs of both the factor loadings (section 5.2) and the coefficients of the logit models (section 6.3), this research found that 34 path walkability indicators, in combination, create an inductive operational definition of (transit access) path walkability (at least for the studied transit station area). The definition of path walkability is:

The quality of the micro-level walking environments measured by the 34 path walkability indicators. Path walkability increases as each path walkability indicator has the walking-conducive condition, and the path walkability decreases as each path walkability indicator has the driving-conducive condition as shown in Table 6.3 below:

Table 6. 3: 34 Path Walkability Indicators and the Conditions Increasing and Decreasing Walkability

Factor	Path Walkability Indicators	Walking Conducive	Driving Conducive
Sidewalk Amenities	(22) Average Number of Intermediaries / 500 ft. Sidewalk	more	less
	(9) Number of Mid-block Crossings / 500 ft. Block Length	more	less
	(21) Average Numbers of Street Furniture / 500 ft. Sidewalk	more	less
	(38) Average Number of Upper-Level Windows / 500 ft.	more	less
	(37) Average Number of Street-Facing Entrances / 500 ft.	more	less
	(25) Average Ground-Level Luminosity after Sunset (fc.)	higher	lower
	(28) Average Skyline Height (ft.)	higher	lower
	(5) Number of Traffic Calming Elements / 500 ft.	more	less
	(40) Percentage of Walking-Conducive Commercial Uses	higher	lower
	(36) Average Pedestrian-Level Façade Transparency	higher	lower
	(15) Average Width of Walking Zone (ft.)	wider	narrower
	(27) Average Building Height (ft.)	higher	lower
	(13) Average Width of On-street Parking (ft.)	wider	narrower
	(34) Percentage of Sidewalk Length with Building Façades	higher	lower
	(18) Percentage of Sidewalk Length with Special Pavement	higher	lower
	(39) Fence Coverage Rate	lower	higher
Traffic Impacts	(7) Pedestrian Signal Coverage Rate	lower	higher
	(3) Average Number of Traffic Lanes	less	more
	(8) Pedestrian Crossing Facility Design Index	lower	higher
	(33) Average Building Width (ft.)	narrower	wider
	(6) Pedestrian Crossing Coverage Rate	lower	higher
	(1) Average Width of Curb-to-Curb Roadway (ft.)	narrower	wider
	(2) Average Width of Traffic Zone (ft.)	narrower	wider
	(41) Percentage of Residential Uses (1st floor frontage)	higher	lower
	(24) Percentage of Sidewalk Covered by Tree Canopies (%)	higher	lower
	(12) Average Width of Bike Lane (both sides together) (ft.)	narrower	wider
Street Scale & Enclosure	(4) Average Width of Through Traffic Lanes (ft.)	narrower	wider
	(30) Enclosure Ratio in Cross Section II (BB Dist to Skyline)	lower	higher
	(29) Enclosure Ratio in Cross Section I (BB Dist to Bldg. Ht.)	lower	higher
	(26) Average Building-to-Building Distance (ft.)	narrower	wider
	(35) Average Building Setbacks (ft)	smaller	larger
Land-scaping Elements	(23) Average Number of Street Trees / 500 ft. Sidewalk	more	less
	(11) Average Width of Landscape Strip (both sides) (ft.)	wider	narrower
	(10) Average Width of Buffer Zone (both sides together) (ft.)	wider	narrower

Note: Some variable names were truncated but the variable numbers are still consistent with the numbers in Table 3.3, 5.2, and 5.4

Table 6. 4: Recommended Conditions for Good Path Walkability

Major Factors	Conditions Creating Walking-Conducive Walkability
Factor 1: Sidewalk Amenities	• plenty of chairs and tables along store fronts and on front porches • more mid-block crossings • plenty of benches and other seating facilities • more windows on the second and third floors of nearby buildings • more street-facing entrances • plenty of lower and brighter street lights • higher buildings and less vacant properties • more traffic calming facilities • more commercial uses on the first floor • higher transparency between sidewalk and the first floor of nearby buildings • wider sidewalks • higher average building height • wider parking spaces • more building facades facing streets • more sidewalks with special (non-concrete) pavements • fewer fences between sidewalks and nearby properties
Factor 2: Traffic Impacts	• fewer signalized pedestrian crossings • fewer number of traffic lanes • fewer and simpler pedestrian crossings • shorter building frontages • fewer pedestrian crossings regardless of types • narrower curb-to-curb roadway • narrower traffic zone excluding street parking and bike lanes • more residential uses on the first floor of nearby buildings • more tree canopies over the sidewalk • narrower or no bike lanes
Factor 3: Scale & Enclosure	• narrower traffic lanes • higher average skyline relative to street width • greater building height relative to street width • narrower building-to-building distance • smaller average building setback from the street
Factor 4: Landscaping Elements	• more street trees between the sidewalk and traffic • wider landscape strip between the sidewalk and traffic • wider buffer zone between the sidewalk and traffic

Figure 6.1 and 6.2 show graphic examples of hypothetical street environments: driving-conducive vs. walking-conducive. The two pairs of opposite images are created

based on the signs of factor loadings of walkability indicators and the signs of coefficients of the logit model.

Figure 6. 1: Walking-Conducive vs. Driving-Conducive Walkability (aerial view)

Figure 6. 2: Walking-Conducive vs. Driving-Conducive Walkability (ground-level view)

7. DEVELOPING A COMPOSITE WALKABILITY INDEX

7.1. Importance of Developing a Composite Walkability Index

The two primary goals of this dissertation research were to define path walkability and to test the effect of walkability on transit users' travel behavior. The previous chapters defined path walkability through inductive operationalization, and successfully tested the research hypothesis by creating a mode choice model with new path walkability variables. The new path walkability variables were created by extracting factor scores directly from the street measurement data collected by this research (Chapter 5). The advantage of using the factor scores was that it is relatively objective, with little chance of human subjectivity in the evaluation of walkability, because the combination of factor and logit analyses allows a direct connection between measured walkability and surveyed travel behavior.

However, the inductive operationalization has a major disadvantage in its limited applicability. The factor scores extracted from the routes of the 249 survey respondents are unique values that can be used only for modeling the travel behavior of the same 249 travelers. The factor scores cannot be used to estimate the walkability scores of another set of street segments or routes. For example, to evaluate the path walkability of another station area, a researcher can use the "sidewalk amenities," one of the path walkability components defined in Chapter 5, and measure all the path walkability indicators grouped under the “sidewalk amenities” component. But there is no established formula by which the data of a multiple number of path walkability indicators can be processed. Even if the researcher conducts a new factor analysis with the same path walkability indicators, there is no guarantee that the same set of path walkability indicators will be grouped. Thus the new factor score for “sidewalk amenities” may not be comparable to the factor score for the “sidewalk amenities” derived in Chapter 5. Thus the applicability of the inductive operational definition of path walkability is limited in spite of its superiority in objectivity.

Because of the statistical limitation of factor analysis, this research also operationalized path walkability deductively and created formulas to calculate a composite walkability index. A composite walkability index is the product of the deductive operationalization utilizing regression analyses. This composite walkability index will allow other researchers to calculate a walkability index directly from their own walkability measurements, and to compare the index of one street/route to another. This means that once the formulas of the index are set (not just by this research but from the numerous replications of future research), it will allow travel behavior researchers to bypass further time-consuming walkability indexing and to apply the index to test micro-level walkability. The author believes that it is the responsibility of urban design researchers to supply travel behavior researchers with a tool to incorporate micro-level walkability into their travel models. A ready-to-use walkability index will permit travel behavior researchers to include a walkability variable in their models.

7.2. Previous Research Seeking a Composite Walkability Index

Please refer to Part1.3.2 for the literature review on measuring and quantifying walkability.

7.3. Developing a Composite Index through Deductive Operationalization

The goal of this chapter was to deductively operationalize path walkability and create a composite walkability index. The composite walkability index was actually a product of deductive operationalization, which yielded formulas and weights that could be used to calculate composite walkability scores (Figure 7.1). This research took the following five steps to achieve the goals:

(1) **Defining the Walkability Components:** Section 7.4 defines the construct of walkability by using a multiple number of smaller and concrete components that could be more easily measured. By dividing walkability into 13 smaller and tangible components, this research could avoid confusion associated with complicated concept of path walkability in scoring walkability in the next section.

(2) **Measuring the Walkers' Perception:** Section 7.5 measured real walkers' perceptions about each of the 13 walkability components by conducting an on-board transit user survey of those who walked to the station. The survey method is discussed in

detail in Part 7.5.3.

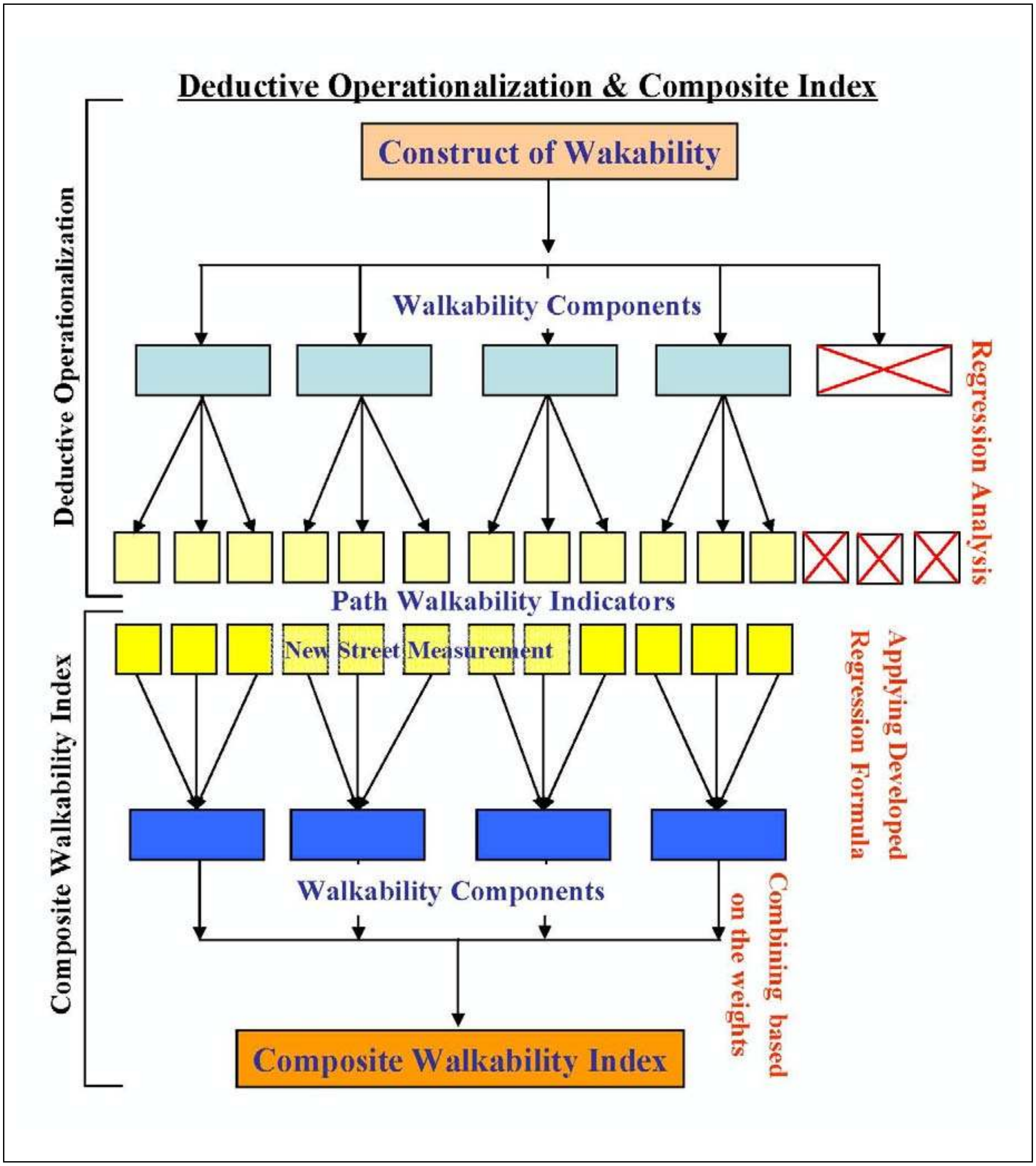
(3) **Measuring Path Walkability by Route:** Section 7.6 creates the values of the 52 path walkability indicators based on the 68 routes collected by the walker perception survey, by using the same methods developed in Chapter 3.

(4) **Finding the Statistical Association:** Section 7.7 conducts a regression analysis to find a correlation between the measured walker perception measured and the measured path walkability, for each of the 13 walkability components.

(5) **Integrating the Scores of the 12 Components:** Section 7.8 integrates the regression model results by using the weights developed based on respondents' choices out of the 13 walkability components.

These five phases will develop a composite walkability index and deductive operational definition of path walkability at the end.

Figure 7. 1: Deductive Operationalization & Creating a Composite Index



7.4. Conceptual Universe of Walkability: 5 Values and 13 Components

The first step to deductive operationalization of walkability, or developing a composite walkability index, was to divide the construct of walkability into a small number of more concrete and tangible components, which are called "walkability components" in this research. In the inductive operationalization of Chapter 5, the four factors directly extracted from measured path walkability were used as components. But for the deductive operationalization, the components were selected based on a literature review and the author's intuition. First, the author divided the construct of walkability into five walkability "values": two of them – *sense of safety* and *convenience* – represent traditional transportation values, while *sense of security*, *comfort*, and *visual interest* are urban design values (Table 7.1). Since these five values are still too general to measure, this research sliced them into smaller and more tangible 13 path walkability components, which are conceptually parallel to the four path walkability components used in the inductive operationalization. The 13 walkability components were used as the basic units to measure a walker's environmental perceptions (section 7.5). Table 7.1 shows the conceptual universe of the 5 path walkability values and their 13 components.

Table 7. 1: Five Values and 13 Components of Walkability

5 Values	13 Walkability Components
I. Sense of Safety (from traffic)	1. Sense of Safety in Pedestrian Crossing Affected by Traffic Speed 2. Sense of Safety in Pedestrian Crossing Affected by Crossing Facilities 3. Sense of Safety in Walking on the Sidewalk Affected by Traffic
II. Sense of Security (from crimes)	4. Sense of Security from Existence of Others 5. Sense of Security Affected by Visibility at Night 6. Sense of Security from Visual Surveillance from Nearby Buildings
III. Comfort	7. Sidewalk Level-of-Service & continuity 8. Buffering Negative Environmental Effects 9. Sense of Street Scale & Enclosure
IV. Convenience	10. Ease of Pedestrian Crossing 11. Easy Access to Local Stores
V. Visual Interest	12. Visual Variety 13. Visual Attractiveness

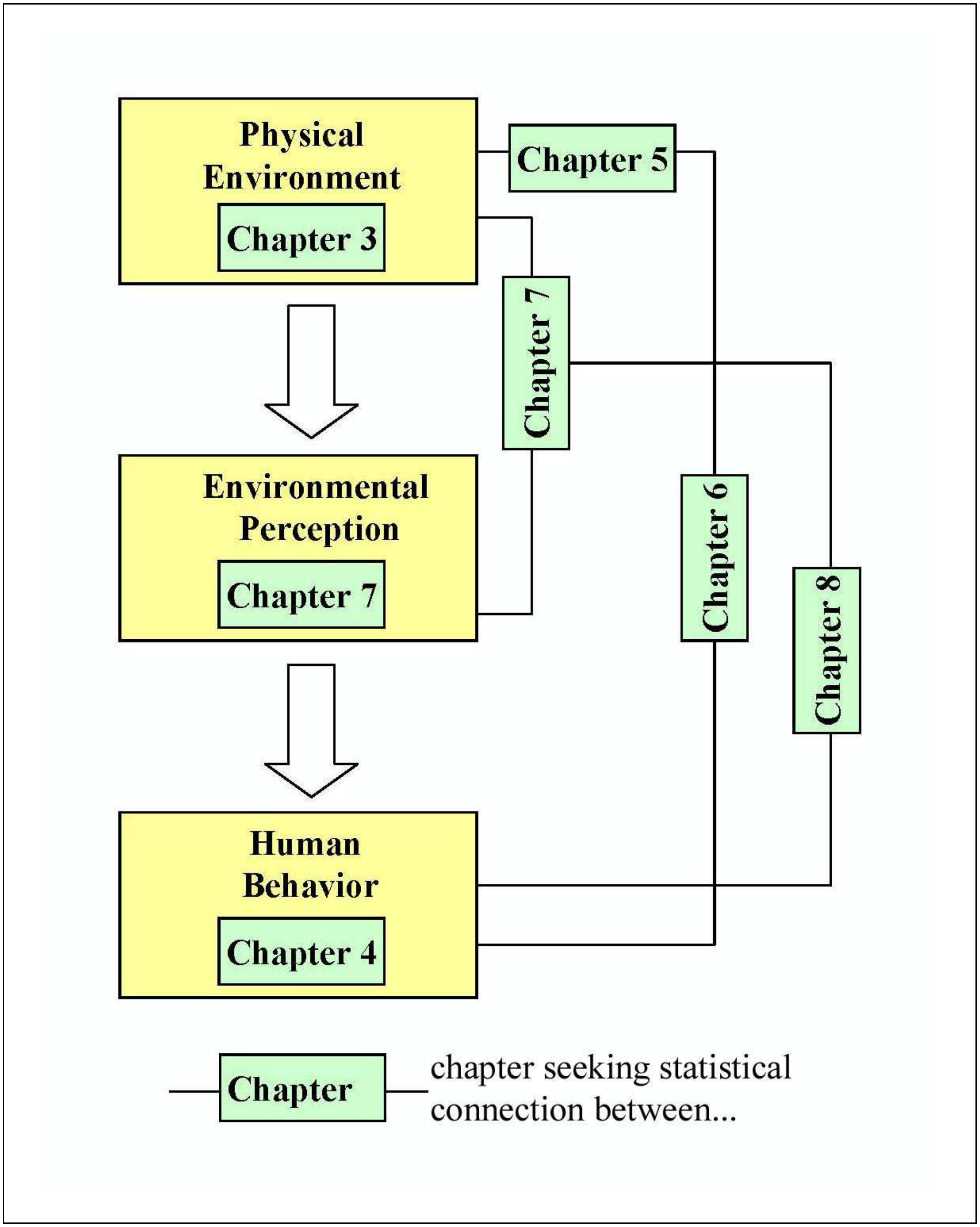
7.5. Scoring Walkability Based on User Perception

7.5.1. Perception from a Real Experience

The second step to create a composite walkability index was to score walkability. Walkability is composed of tangible qualities that are directly measurable, but the absolute values of the measurements may be less important than how the users of the space perceive the environment and how satisfied they are with it. Ultimately even more important for planners is people's behavior in the environment. For example, a 5-foot-wide sidewalk is 5 feet wide in Manhattan and Scranton, Pennsylvania. But how do walkers feel about it? It may be wide enough in Kansas City, but may not in Manhattan, because there are many more pedestrians in Manhattan. Do users like the width? and do they actually walk on it? There is no absolute walkability; it is defined by the users – their perceptions, preferences, and behavior.

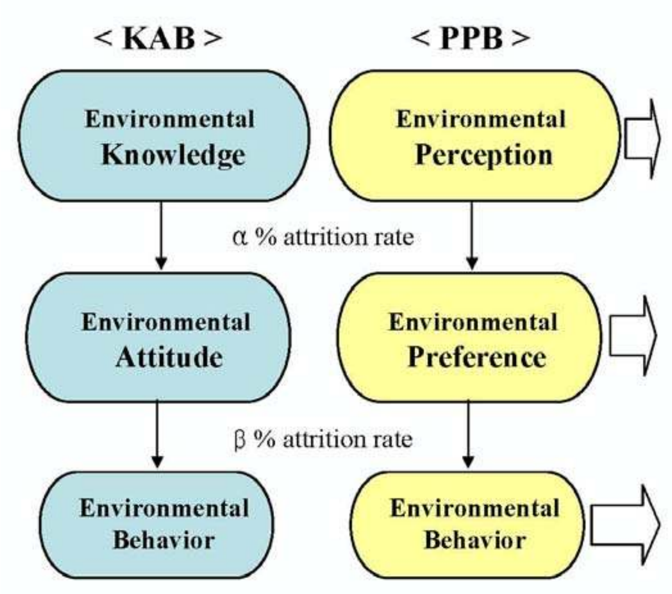
It is assumed by this research that perception and preference might be effective predictors of behavior. There is little environmental design research on this, but some revealing information comes from other fields. Some environmental behavior researchers are interested in the KAB (Knowledge – Attitude – Behavior) model: where environmental knowledge predicts an environmental attitude, predicts an environmental behavior (Kaiser et al, 1999; Flamm, 2006). For example, knowledge about global warming may predict environmental attitude toward tailpipe greenhouse gas emissions

Figure 7. 2: Physical Environment-Environmental Perception-Human Behavior



and eventually lead to walking instead of driving. In the process, there is an attribution[20]: not everyone with knowledge of global warming chooses to walk, but it might still work as an effective predictor. By the same token, if a traveler feels good about a specific walking environment, or likes it better than another walking route, it might be an effective predictor that the traveler will choose to walk (Figure 7.3).

Figure 7. 3: Predictors of Environmental Behavior



Possible Questions about the "walkability–walking" relationship

How do you feel about the route?

Do you like to walk on the route?

Did you walk on the route?

One of the most critical questions for this research is what should be used as a proxy to measure walkability. The author chose perception over preference, not because perception is a better predictor than preference, but because perception will be suitable

[20] Kaiser et al. found that "environmental knowledge and environmental values explained 40 per cent of the variance of ecological behaviour intention which, in turn, predicted 75 per cent of the variance of general ecological behaviour." (Kaiser et al., 1999)

for surveying a traveler with real experience.

Perception or preference can only be surveyed after a subject is exposed to a specific environment, and there are three levels of exposure: indirect, limited, and real experience. When you show subjects in a lab simulated images, such as 3D graphic models of streets or filmed streets, this is indirect experience. For example, Cervero and Bosselmann used 3D graphics of different residential densities to test perception of density (Cervero and Bosselmann, 1998). Ewing et al. showed filmed images of selected streets to an expert panel (Ewing et al., 2006). While using digital media is very efficient, this indirect experience is still far from reality. For example, it is hard to convey fear of crime after sunset in virtual reality. Limited experience is measured, for example, when hired subjects are brought to pre-selected street segments. Brown et al. brought subjects on guided walks of three levels of walkability (Brown et al., 2007). Surveys of limited experience have been popular, but may not be strong predictors of future environmental behavior, because a one-time visit to a limited number of streets with significantly different conditions is also far from the experience of real users, who walk routes on a regular basis and at different times. Both the indirect and limited experience methods also present the dilemma of choosing subjects – that is, do the subjects actually reflect real walkers? If a group of college students studying architecture was used, the result may not apply to the real-world walking population.

To avoid the disadvantages mentioned above, the author chose to survey real walkers' actual experiences, although this has rarely been done in walkability research. That decision forced this research to focus on perception rather than preference. To ask about preference would have required multiple options to compare, and would have entailed hypothetical questionnaires because few walkers have experienced many routes on a regular basis – Then the research also would have to assess each new route for each walker. Thus studying preference is suitable only when applied to indirect or limited experience. Having decided to measure real users' perceptions about their real walking routes, the author created and conducted a walker perception survey.

7.5.2. Walker Perception Survey

In July, 2005, roughly a month earlier than the station user survey (section 4.5), a walker perception survey was conducted in the downtown Mountain View transit station area. The survey measured walking transit users' perceptions about each of 13 walkability components along their everyday walking routes. Pretests to obtain feedback by respondents were done on two days (July 12-13, 2005) in the downtown Mountain View station, and any apparent problems were corrected before the final survey. During the four-day period from July 19-22, 2005, three to five surveyors conducted a walker perception survey in the downtown Mountain View station during the morning commute hours, from 5 to 11 A.M. They approached transit users waiting for trains on the platforms and asked them if they walked to the station, and surveyed only those who had walked to the station. Morning transit users were well aware of the train schedule and usually arrived at the station punctually, often waiting for trains less than five minutes.

This left only a small amount of time for the surveyors, barely enough to ask about access trip modes and trip origins. Therefore when the train approached, surveyors asked respondents if they could board with them to finish and collect the survey questionnaires, and with permission they traveled with the respondents while they filled out the questionnaires. Although the survey included over 40 questions and tricky route drawing on a map, this admittedly time-consuming method yielded an almost 100% response rate, and 68 usable survey responses.

The user perception survey form consisted of three parts (see Appendix): The first part asked respondents to choose the five walkability components that they valued most out of the thirteen components. Each of these was represented by a phrase, not an abstraction – for example, "streets that are observed by nearby residents and store workers, who could see and help me if I were in trouble," not "walkability component no. 4: existence of others on the streets." The respondents' five priority components were used to determine their weight to combine the 13 components into a single composite walkability index (section 7.8). The second part of the survey asked respondents to indicate their home origins and to draw the routes that they used for their walking trips to the station. This data was used to calculate the path walkability of each route (section 7.6). The third part of the survey was a series of questions asking respondents to score their experiences of walking to the station, based on scaled answers to questions related to each of the thirteen walkability components.

7.5.3. Perception Scores of the 13 Walkability Components

The questionnaires in the third part of the survey used scaled answers. This research mostly used a four-category Lickert scale rather than the more common five-category scale to provide clearer statistical outcomes, because neutral responses are not statistically helpful (Rossi et al, 1983, p252). One obvious problem of using a Lickert scale is that the collected data are discrete rather than continuous. However, because as a dependent variable continuous data works much better in a regression model than discrete data, this research used multiple questions, mostly two to four similar but slightly different questions for each walkability component. For example, the final score from a four-question set was somewhere between 4 and 16 instead of 1 and 4. This provided more variation and made the average scores closer to continuous data, and thus yielded better regression models. The author also tried to avoid semantic differentials and tried to create questions based on the scales of simple frequency adverbs.[21]

Table 7.2 showed the sets of questions asked to evaluate for the walkability component 4 (Sense of Security from Existence of Others). The remaining sets of questions for the other 12 walkability components were included in Appendix 4. The red numbers in the tables are the scores assigned to each answer.[22] The final scores were calculated to be on a 10-point scale. The figure 31 showed how to calculate the

[21] To measure human perception of environmental qualities, the Lickert scale is often coupled with a "semantic deferential," a pair of adjectives with opposite meanings, for example "very interesting-interesting-neutral-dull- very dull" (Taylor, Zube, and Sell, 1987). But semantic differentials are often problematic because people interpret adjectives differently (Bechtel, 1987).

[22] The scores were not on the original survey form and added later for the readers.

walkability perception score for each walkability component based on the traveler's choice of answers.

Table 7. 2: Survey Questionnaire and Score Formula for Walkability Component 4 (Sense of Security from Existence of Others)

26. How often do you feel like, there are people around (including other pedestrians and shop customers and workers) who could help you if you were in trouble?

During the daytime:	[ ] almost always (4)	[ ] usually (3)	[ ] occasionally (2)	[ ] rarely (1)
How about at night?	[ ] almost always (4)	[ ] usually (3)	[ ] occasionally (2)	[ ] rarely (1)

27. How often do you feel unsafe (from crime) because there are too few people on the street?

During the daytime:	[ ] almost always (1)	[ ] usually (2)	[ ] occasionally (3)	[ ] rarely (4)
How about at night?	[ ] almost always (1)	[ ] usually (2)	[ ] occasionally (3)	[ ] rarely (4)

28. How often do you feel that your walking trip to the station could be safer (from crime) if there were more people on the streets?

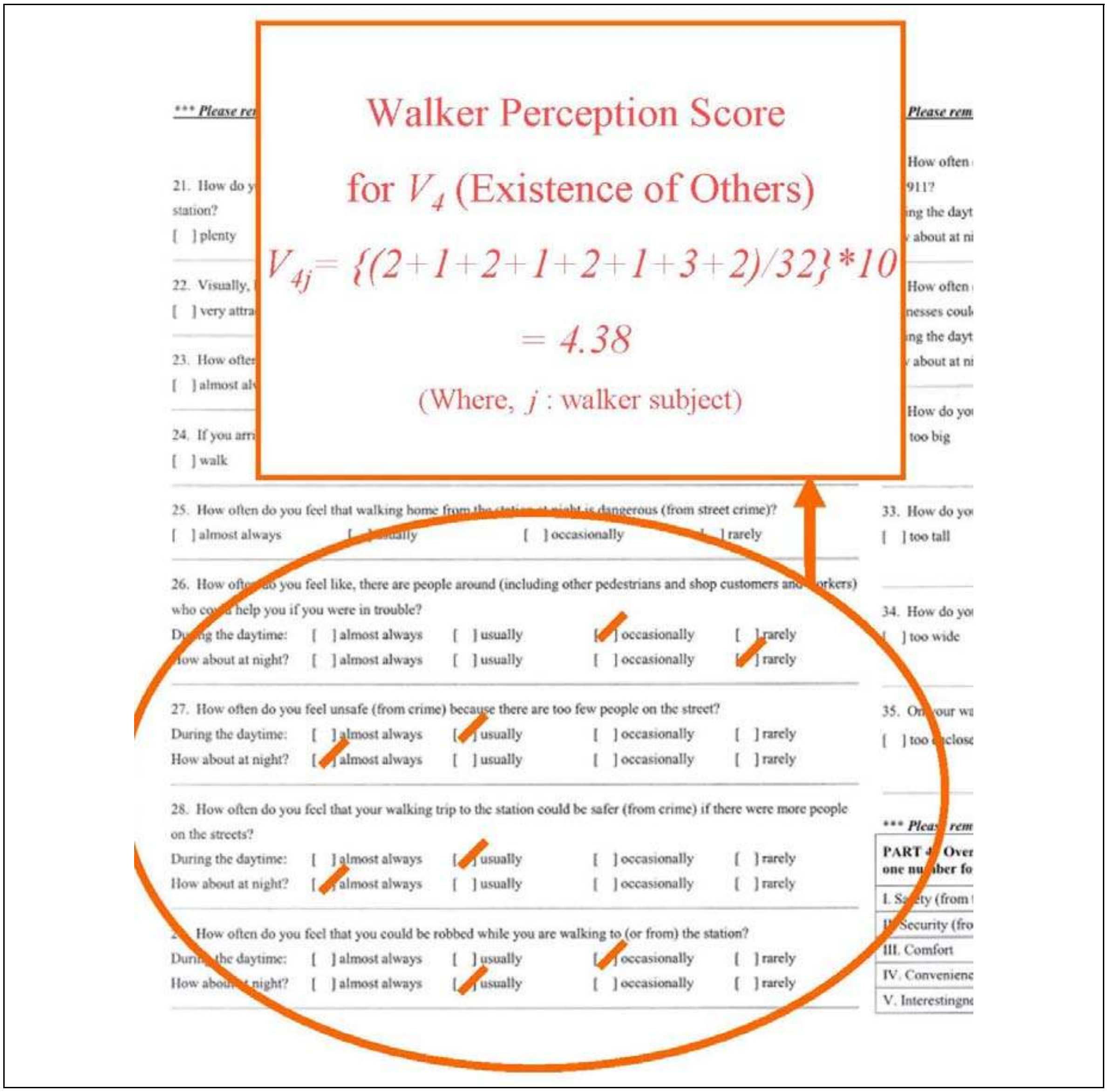
During the daytime:	[ ] almost always (1)	[ ] usually (2)	[ ] occasionally (3)	[ ] rarely (4)
How about at night?	[ ] almost always (1)	[ ] usually (2)	[ ] occasionally (3)	[ ] rarely (4)

29. How often do you feel that you could be robbed while you are walking to (or from) the station?

During the daytime:	[ ] almost always (1)	[ ] usually (2)	[ ] occasionally (3)	[ ] rarely (4)
How about at night?	[ ] almost always (1)	[ ] usually (2)	[ ] occasionally (3)	[ ] rarely (4)

Final Score of Walkability Component (Sense of Security from Existence of Others) = (Q26A + Q26B + Q27A + Q27B + Q28A + Q28B + Q29A + Q29B) * 10 / 32

Figure 7. 4: Example of Score Formula: Walkability Component 4 (Sense of Security from Existence of Others)



7.6. Measuring Path Walkability by Route

The independent variables for the regression models are the path walkability indicators extracted from the 68 walking routes of the perception survey. The 160 street segments comprising the 68 routes were surveyed in full using the walkability measurement instrument introduced in Section 3.1. Of the 160 segments, 115 had been surveyed for the 249 routes from the station user survey (4.5) and 45 new segments were surveyed especially for the 68 routes from the walker perception survey.

Based on the street survey data from the 160 surveyed street segments, the values of the 52 path walkability indicators were extracted for each of the 68 routes mapped by the survey respondents. The list of the path walkability indicators was the same as the final candidate lists of path walkability Indicators introduced in Section 3.4. Only 38 of the 52 were selected for the factor analysis in Section 5.2., but all 52 candidates were initially tested in the regression models.

Table 7. 3: Complete List of the 52 Path Walkability Indicators (same as Table 3.3)

	A. Path Walkability Indicators Related to Curb-to-Curb Roadways
(1)	Average Width of Curb-to-Curb Roadway (ft.)
(2)	Average Width of Traffic Zone (ft.)
(3)	Average Number of Traffic Lanes
(4)	Average Width of Through Traffic Lanes (ft.)
(5)	Number of Traffic Calming Elements / 500 ft. Block Length
	B. Path Walkability Indicators Related to Pedestrian Crossings
(6)	Pedestrian Crossing Coverage Rate
(7)	Pedestrian Signal Coverage Rate
(8)	Pedestrian Crossing Facility Design Index
(9)	Number of Mid-block Crossings / 500 ft. Block Length
	C. Path Walkability Indicators Related to Buffer Zones
(10)	Average Width of Buffer Zone (both sides together) (ft.)
(11)	Average Width of Landscape Strip (both sides together) (ft.)
(11-1)	Existence of Landscape Strip I (binominal dummy; one or both = 1, none = 0)
(11-2)	Existence of Landscape Strip II (binominal dummy; both = 1, one or none = 0)

(12)	Average Width of Bike Lane (both sides together) (ft.)
(12-1)	Existence of Bike Lane I (binominal dummy; one or both = 1, none = 0)
(12-2)	Existence of Bike Lane II (binominal dummy; both = 1, one or none = 0)
(13)	Average Width of On-street Parking (both sides together) (ft.)
(13-1)	Type of On-street Parking (binominal dummy; diagonal or perpendicular = 1, otherwise = 0)
(13-2)	Existence of On-street Parking I (binominal dummy; both sides = 1, one side or none = 0)
(13-3)	Existence of On-street Parking II (binominal dummy; both = 1, one or none = 0)
	D. Path Walkability Indicators Related to Sidewalks
(14)	Sidewalk Coverage Rate (percentage of segment sidewalk length with sidewalk) (%)
(14-1)	Existence of Sidewalk (binominal dummy variable)
(15)	Average Width of Walking Zone (ft.)
(16)	Average Length of Sidewalk (ft.)
(17)	Average Number of Driveway Curb-Cuts / 500 ft. Sidewalk
(18)	Percentage of Sidewalk Length with Special Pavement (%)
(19)	Average Route Steepness
	E. Path Walkability Indicators Related to Sidewalk Facilities
(20)	Percentage of Sidewalk Length with Visual Nuisance (%)
(21)	Average Numbers of Street Furniture / 500 ft. Sidewalk
(22)	Average Number of Intermediaries / 500 ft. Sidewalk
(23)	Average Number of Street Trees / 500 ft. Sidewalk
(24)	Percentage of Sidewalk Length Covered by Tree Canopies (%)
(25)	Average Ground-Level Luminosity after Sunset (fc.)
	F. Path Walkability Indicators Related to Street Scale and Enclosure
(26)	Average Building-to-Building Distance (ft.)
(27)	Average Building Height (ft.)
(28)	Average Skyline Height (ft.)
(29)	Enclosure Ratio in Cross Section I (Building-to-Building Distance to Building Height)
(30)	Enclosure Ratio in Cross Section II (Building-to-Building Distance to Skyline Height)
(31)	Street Enclosure Index I (absolute value of [inclosure Ratio I - 3.3])
(32)	Street Enclosure Index II (absolute value of [Enclosure Ratio II - 3.3])
(33)	Average Building Width (ft.)
(34)	Percentage of Sidewalk Length with Building Façades (%)
(35)	Average Building Setbacks (ft)
	G. Path Walkability Indicators Related to Nearby Buildings and Properties
(36)	Average Pedestrian-Level Façade Transparency
(37)	Average Number of Street-Facing Entrances / 500 ft. Block Length
(38)	Average Number of Upper-Level Windows / 500 ft. Sidewalk
(39)	Fence Coverage Rate (Percentage of Sidewalk Length with Fence) (%)
(40)	Percentage of Walking-Conducive (1st floor) Commercial Uses (building frontage) (%)
(40-1)	Commercial (1st floor) Use of Adjacent Buildings (commercial = 1, non-commercial = 0)
(41)	Percentage of Residential Uses (1st floor building frontage for residential uses) (%)
(41-1)	Residential (1st floor) Use of Adjacent Buildings (residential = 1, non-residential = 0)
(42)	Mixed Use (1st floor) of Adjacent Buildings (mixed use = 1, non – mixed use = 0)

7.7. Regression Models: Connecting Walkability Components to Indicators

The next step to develop the composite walkability index was to find a statistical association between the surveyed perception scores of the 13 walkability components and the measured path walkability indicators.[23] This research performed 13 regressions to yield correlations between the walkers' perception scores of each of the 13 walkability components as dependent variables and the values of the 52 path walkability indicators extracted from their routes as independent variables. Some individual sociological information, such as gender, age, and race, were also surveyed and tested as additional independent variables for the regression models, on the assumption that individual perceptions of environmental quality may vary with gender, age, or race. Gender and age successfully entered two models, and it seemed that adding gender and age improved other model results even when they did not enter the model.

Therefore the research yielded 12 successful regression models, shown in Tables 29 through 40. No statistically significant regression model was yielded for one of the thirteen walkability components – walkability component number 7: *Sidewalk Level-of-Service and Continuity*. In the end, 22 out of 52 path walkability indicators, along with gender and age, entered at least one of the 12 sub-models. More than half of the walkability indicators did not enter any model and were eventually excluded from the

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[23] With multi-set sub-models based on the 13 walkability components, this research was able to avoid the mismatch between one walkability variable and much larger number (52) of path pathwalkability indicators. Without the multi-set model approach, this research would end up losing most of street data because a single regression model usually hold less than ten (statistically significant) variables even under the best circumstance.

final formula of the composite walkability index, and also from the deductive operational definition of walkability. Four path walkability indicators – *(6) Pedestrian Crossing Coverage Rate*, *(40) Percentage of Walking-Conducive (1st floor) Commercial Uses*, *(40-1) Commercial (1st floor) Use of Adjacent Buildings (binominal dummy)*, and *(41-1) Residential (1st floor) Use of Adjacent Buildings (binominal dummy).* – each entered two different models.

Tables 29 through 40 show the results of the 12 sub-models. Only the variables that entered the models at the 0.05 alpha level remained in the models. As a result, the score of each walkability component is explained by fewer than five variables out of the full set of path walkability indicators (including gender and age).

7.7.1. Sense of Safety in Pedestrian Crossing Affected by Traffic Speed

The *sense of safety in crossing by traffic speed* was associated with *age* and four path walkability indicators (Table 7.4). The sense of safety that pedestrians feel when crossing the street increases as the route has more pedestrian crossings and higher luminosity after sunset, while the sense of safety decreases if the route has more traffic lanes and the traveler is older, and if more than half of the building frontage along the route has first-floor commercial uses. It is expected that higher traffic speed is associated with multi-lane streets and more traffic on the commercial streets. Well-lit streets seem to be perceived safer, and apparently older travelers are more easily threatened by fast moving traffic.

Table 7. 4: Regression Model for Walkability Component 1: Sense of safety in crossing by traffic speed

Summary Table: Model 1

Variables	Estimates:			
	Coefficient	Std. Err.	t	Sig.
Age (of the traveler)	-0.03	0.01	-2.35	0.02
(6) Pedestrian Crossing Coverage Rate	2.34	0.76	3.09	0.00
(3) Average Number of Traffic Lanes	-0.41	0.20	-2.10	0.04
(40-1) Commercial Uses of Adjacent Buildings*	-1.34	0.40	-3.32	0.00
(25) Average Ground-Level Luminosity (fc.)	1.29	0.61	2.12	0.04
Constant	8.16	0.73	11.19	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				8.63 (0.00)
R^2				0.435

* Binominal dummy variable; 1st floor use only; walking-conducive commercial uses = 1, Non-Commercial = 0; for walking-conducive uses, see Appendix 2

7.7.2. Sense of Safety in Pedestrian Crossing Affected by Crossing Facilities

Two path walkability variables – *pedestrian crossing coverage rate* and *existence of on-street parking* – entered this sub-model (Table 7.5). As expected, *pedestrian crossing coverage rate* and more pedestrian crossings enhanced the sense of safety. The existence of on-street parking on both sides was also associated with a greater sense of safety. Perhaps parking vehicles slow down traffic and thus increase the sense of safety.

Table 7. 5: Regression Model for Walkability Component 2: Sense of safety in crossing by crossing facilities

Summary Table: Model 2

Variables	Estimates:			
	Coefficient	Std. Err.	t	Sig.
(6) Pedestrian Crossing Coverage Rate	2.55	0.76	3.38	0.00
(13-2) Existence of On-Street Parking*	1.63	0.49	3.32	0.00
Constant	4.38	0.65	6.70	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				9.23 (0.00)
R^2				0.232

* (Both Sides = 1, One or None = 0)

7.7.3. Sense of Safety in Walking on the Sidewalk Affected by Traffic

Although most researchers focus only on the perceived danger of crossing streets, pedestrians walking on the sidewalk might also feel threatened by nearby moving traffic on the street. This sub-model shows that older travelers feel more threatened than younger travelers by nearby street traffic (Table 7.6).[24] As expected, the sense of safety increases as the width of the buffer zone increase.

[24] This study did not include children, and most of the survey respondents were over 20.

Table 7. 6: Regression Model for Walkability Component 3: Sense of safety in walking on the sidewalk

Summary Table: Model 3

Variables	Estimates:			
	Coefficient	Std. Err.	t	Sig.
Age (of the traveler)	-0.04	0.01	-2.92	0.00
(10) Width of Buffer Zone (ft.)	0.12	0.05	2.20	0.03
Constant	8.49	0.85	9.93	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				8.04 (0.00)
R^2				0.209

7.7.4. Sense of Security from Existence of Others

Travelers show a greater sense of security (from crime) when there are other pedestrians and activity. Table 7.7 shows that the level of their sense of security is associated with the first floor uses of nearby buildings in this model. It was expected, because more walking-conducive commercial uses along the route draw more people. Average building width entered the model positively, perhaps because the commercial streets in the study area tend to have relatively large buildings. Residential use also was mildly associated with greater sense of security. It seems that residential uses draw more people on the street than other non-commercial uses.

Table 7. 7: Regression Model for Walkability Component 4: Existence of others (and their activity) on the streets

Summary Table: Model 4

Variables	Estimates:			
	Coefficient	Std. Err.	t	Sig.
(40) Percentage of Commercial Uses (%)*	2.89	0.80	3.59	0.00
(33) Average Building Width (ft.)	0.04	0.01	2.91	0.01
(41-1) Residential Use of Adjacent Buildings**	1.11	0.53	2.09	0.04
Constant	3.69	1.14	3.24	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				5.60 (0.00)
R^2				0.228

* 1st floor walking conducive commercial uses only

** 1st floor only; (Residential Use = 1, Non-Residential = 0)

7.7.5. Sense of Security Affected by Visibility at Night

According to this sub-model (Table 7.8), female travelers feel more fear of crime at night and thus rates streets as less safe than male travelers, which decreases female walkability score. The *number of upper-level windows* also entered the model. This finding likely reflects that more windows on the second and third floors increases the chance of residents watching the street and thus increases the sense of security of travelers walking on the route at night.

Table 7. 8: Regression Model for Walkability Component 5: Visibility at night

Summary Table: Model 5

Variables	Estimates: Coefficient	Std. Err.	t	Sig.
Gender (of the traveler)*	1.44	0.32	4.46	0.00
(38) Number of Upper-level Windows / 500 ft.**	0.04	0.02	2.04	0.05
Constant	5.49	0.35	15.80	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				11.40 (0.00)
R^2				0.275

* (Male = 1, Female = 0)

** Number of Windows at the 2nd and 3rd Floor Only

7.7.6. Sense of Security from Visual Surveillance from Nearby Buildings

The sub-model result shows that higher buildings along the route (which means two to four story buildings in this study area) increases travelers' sense of visual surveillance from nearby buildings. The model also found that the sense of security increased if more than half of the nearby buildings had first floor residential use.

Table 7. 9: Regression Model for Walkability Component 6: Visual & physical access

Summary Table: Model 6

Variables	Estimates: Coefficient	Std. Err.	t	Sig.
(27) Average Building Height (ft.)	0.11	0.03	3.77	0.00
(41-1) Residential Use of Adjacent Buildings*	1.10	0.54	2.05	0.04
Constant	3.45	0.88	3.92	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				7.10 (0.00)
R^2				0.199

* 1st floor only; (Residential Use = 1, Non-Residential = 0)

7.7.7. Sidewalk Level-of-Service (LOS) & Continuity

This sub-model tested which path walkability indicators are associated with unobstructed walking free from conflict with other pedestrians, and with automobiles entering driveways. However, the regression analysis failed to find any interpretable variable that entered the model at a significant level. Therefore this model was excluded from the formula for both the composite walkability index and the deductive definition of path walkability.

7.7.8. Buffering Negative Environmental Effects

This sub-model was initially created to see what might influence the level of pedestrian discomfort from excessive sunlight and negative environmental effects (fume, noise, vibration) from moving traffic. But the result of this sub-model was not strong in terms of both R-squared value and the number of variables entering the model. The weak result could be blamed on the inappropriate combination of different problems caused by two different sources. As a result, only the existence of a sidewalk entered the model, suggesting that if more than half of the route does not have sidewalks on both sides, there is a higher chance for travelers to experience negative environmental effects.

Table 7. 10: Regression Model for Walkability Component 8: Buffering negative environmental effects

Summary Table: Model 8

Variables	Estimates:			
	Coefficient	Std. Err.	t	Sig.
(14-1) Existence of Sidewalk*	2.42	0.83	2.90	0.01
Constant	5.83	0.82	7.15	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				8.40 (0.01)
R^2				0.113

* (Both Sides = 1, One or None =0)

7.7.9. Sense of Street Scale & Enclosure

The purpose of this sub-model was to test how travelers feel about the scale, dimension, and enclosure of the street, and what path walkability indicators influence this sense of scale. The strongest model result was that the first floor commercial use of nearby building is associated with higher score in scale and enclosure. This may be because in this study area most commercial buildings are higher and wider than residential buildings that do not have first-floor commercial uses, and the higher and wider commercial buildings give more sense of enclosure than smaller detached houses. The Street Enclosure Index II entered the model with a negative sign, suggesting that walkers' satisfaction with scale and enclosure increases as the *ratio of building-to-*

building distance and *skyline height* (not the *average building height*) is closer to 3.3. This is a very strong sense of enclosure for a suburban station area, given the method of calculating the skyline height (Part 3.3.6). For example, a value of 3.3 could be a route with a 100-foot *building-to-building distance* coupled with rows of two-story (30-foot high) buildings on both sides without any gaps.

Table 7. 11: Regression Model for Walkability Component 9: Sense of scale & enclosure

Summary Table: Model 9

Variables	**Estimates:**			
	Coefficient	Std. Err.	t	Sig.
(40-1) Commercial Use of Adjacent Buildings*	0.56	0.25	2.23	0.03
(32) Street Enclosure Index II**	-0.03	0.02	-2.04	0.05
Constant	9.31	0.24	39.18	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				6.48 (0.00)
R^2				0.171

* 1st floor only; (Walking-conducive Commercial Use = 1, Non-Commercial = 0)
** Ratio of Average Building-to-Building Distance to Average Skyline Height

7.7.10. Ease of Pedestrian Crossing

This sub-model focused on how easy it is to cross the street, not on the sense of safety in crossing. *Average pedestrian-level facade transparency* entered the model, which was unexpected and unintuitive. A possible explanation is that the buildings in this study area, especially housing facing auto-oriented multi-lane streets, usually have a low level of façade transparency with walls between the buildings and pedestrians. This might be a unique local condition. The *length of sidewalk* was an intuitive choice because long blocks along the route minimize the need of crossing. Inclusion of *percentage of sidewalk with visual obstacles* could also result from a unique local condition, reflecting that many street segments that had undergrounded facilities instead of utility poles and hanging wires, and thus had relatively few visual obstacles, also happened to have better crossing facilities in this study area. This may not be applicable to other areas.

Table 7. 12: Regression Model for Walkability Component 10: Ease of pedestrian crossing

Summary Table: Model 10

Variables	**Estimates:**			
	Coefficient	Std. Err.	t	Sig.
(36) Average Pedestrian-level Facade Transparency*	0.80	0.27	3.02	0.00
(13-1) Type of On-Street Parking**	1.44	0.61	2.36	0.02
Constant	5.18	0.85	6.06	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				8.35 (0.01)
R^2				0.204

* On 1 to 5 Scale

** (Diagonal/ Rectangular = 1, 0 otherwise)

7.7.11. Easy Access to Local Stores

As expected, the *percentage of commercial uses of the first floor of nearby buildings* along the route was correlated with the level of *easy access to local stores*. The percentage of residential uses also entered the model, which could be explained by the fact that the routes of many travelers who gave higher scores started on residential streets but ended on commercially dominated streets near the station.

Table 7. 13: Regression Model for Walkability Component 11: Easy Access to Local Stores

Summary Table: Model 11

Variables	Estimates:			
	Coefficient	Std. Err.	t	Sig.
(40) Percentage of Commercial Uses (%)*	5.69	1.14	4.98	0.00
(41) Percentage of Residential Uses (%)**	3.23	1.21	2.68	0.01
Constant	2.92	0.88	3.34	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				12.51 (0.00)
R^2				0.294

* 1st Floor Walking-Conducive Commercial Uses Only

** 1st Floor Only

7.7.12. Visual Variety

This model was created to test what influences pedestrians' perceptions of visual interest and variety. As expected, *fence coverage rate* entered the model, reflecting that the level of visual interest and variety along the route decreased as more of the block frontage was blocked by fencing. This model also found that the *percentage of block with building façade* was correlated with the level of visual variety. Apparently buildings along the route provided more visual variety than other uses on the properties without buildings, which in the study area were often parking lots.

Table 7. 14: Regression Model for Walkability Component 12: Visual variety

Summary Table: Model 12

Variables	Estimates: Coefficient	Std. Err.	t	Sig.
(39) Fence Coverage Rate (%)	-6.92	1.67	-4.16	0.00
(34) Percentage of Block with Building Facade (%)	3.24	1.39	2.34	0.02
Constant	5.51	0.87	6.36	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				17.62 (0.00)
R^2				0.370

7.7.13. Visual Attractiveness

This sub-model tested what influences pedestrians' perceptions of visual attractiveness. According to the model, pedestrians felt that their routes are visually attractive if more than half of their route has special pavement other than plain concrete pavement. The level of attractiveness also increased when the route had more street trees between the sidewalk and the traffic zones.

Table 7. 15: Regression Model for Walkability Component 13: Attractiveness

Summary Table: Model 13

Variables	Estimates: Coefficient	Std. Err.	t	Sig.
(18) Type of Sidewalk Pavement*	0.74	0.31	2.43	0.02
(23) Number of Street Trees / 500 ft.	0.11	0.05	2.38	0.02
Constant	6.37	0.32	19.70	0.00
Summary Statistics				
Number of observations				68
F Statistic (Probability)				10.14 (0.00)
R^2				0.246

* (Special Material = 1, Concrete = 0)

7.7.14. Modeling Results and Limitations of the Sub-Models.

All variables that entered the 12 sub-models are statistically significant at the 0.05 alpha level and most of them are intuitively and logically interpretable. Those that have no apparent reasonable explanation might reflect unique local conditions, and thus might not be applicable to other areas. The R-squared values of the 12 sub-models range from 0.11 to 0.44, and more than half of them are between 0.2 and 0.3, which in general does not translate into strong explanatory power. There might be numerous reasons for the low R squared values, but the author suspects that any problems are more likely to be in the measurement of the dependent variables, the walkers' perceptions. Accurate measurement of individual perception turns out to be extremely difficult. In hindsight, and in light of the results, the questionnaire might have been improved with more questions or more specific questions. Using other survey methods, such as a focused group study, may help improve the accuracy of measuring individual perception.

The 12 regression models yielded formulas that were used to create a composite walkability index. Table 7.16 shows the final formulas:

Table 7. 16: Final Result of 12 Regression Models

- Model_01 (Safety of pedestrian crossing by slowing down traffic) = -0.03*(Age) + 2.34*(Pedestrian Crossing Coverage Rate) - 0.41*(Number of Traffic Lanes) - 1.34*(Primary Use of Adjacent Buildings) + 1.29 * (Average Luminosity) + 8.16

- Model_02 (Safety in crossing by crossing facilities) = 2.55*(Pedestrian Crossing Coverage Rate) + 1.63*(Existence of On-Street Parking) + 4.38

- Model_03 (Sense of safety in walking on the sidewalk) = -0.04*(Age) + 0.12*(Width of Buffer Zone) + 8.49

- Model_04 (Existence of Others on the Streets) = 2.89*(Percentage of Commercial Uses) + 0.04*(Average Building Width) + 1.11*(Residential Use of Adjacent Buildings) +3.69
- Model_05 (Visibility & Sense of security at night) = 1.44*(Gender) + 0.04*(Number of Upper-level Windows / 500 ft.) + 5.49
- Model_06 (Visual & Physical Access) = 0.11*(Average Building Height) + 1.10*(Residential Use of Adjacent Buildings) + 3.45
- Model_08 (Buffering negative environmental effects) = 2.42*(Existence of Sidewalk) + 5.83
- Model_09 (Sense of Scale & Enclosure) = 0.56*(Commercial Use of Adjacent Buildings) - 0.03*(Street Enclosure Index II) + 9.31
- Model_10 (Ease of Pedestrian Crossing) = 0.80*(Average Pedestrian-level Facade Transparency) + 1.44*(Type of On-Street Parking) + 5.18
- Model_11 (shopping & dinning opportunities) = 5.69*(Percentage of Commercial Uses) + 3.23*(Percentage of Residential Uses) + 2.92
- Model_12 (Visual Variety) = -6.92*(Fence Coverage Rate) + 3.24*(Percentage of Block with Building Façade) + 5.51
- Model_13 (Attractiveness) = 0.74*(Type of Sidewalk Pavement) + 0.11*(Number of Street Trees / 500 ft.) + 6.37

7.8. Integrating Components into a Single Composite Index

The next task was to combine the 12 formulas into a single composite walkability index. However, combining scores from a multiple number of components has been a dilemma for many studies. In many cases, researchers simply add scores without weighting, as seen in the Pedestrian Environmental Factor (PEF) or Ewing et al.'s sprawl index (1000 Friends of Oregon. 1993; Ewing et al., 2002). This is a dilemma for this research as well. All 12 models produced individual scores on the same 10-point scale, but their influences on the final walkability are probably not same – for example, is the *existence of others* more important than the *visual variety*? If so, how much?

To address weighting, this research once again turned to the opinions of real users. Part 1 of the walker perception survey form (Figure 7.5) asked respondents to choose five hypothetical conditions that they value most out of thirteen statements representing thirteen walkability components. The 12 sub-models were weighted in proportion to the respondents' preferences to calculate a single composite walkability index (Figure 7.6 and Table 7.17).

With the 12 formulas and 12 weights, a composite walkability score of any street segment can be calculated if the research has the 22 path walkability indicators measured on the segment. A composite walkability score of one's route can also be calculated with the 22 path walkability indicators along with the age and gender of the traveler. By using the formulas and weights, this research calculated the composite walkability scores of the 270 street segments and the 249 routes surveyed in Section 4.6. The test result showed that the composite walkability scores were heavily clustered between 5 and 10. To spread them out evenly on a 10-point scale, the walkability scores were mathematically rescaled by the following formula: (X-4)*10/6. The formula was created based on the composite walkability scores of the 270 street segments, because the walkability scores of the segments are supposed to have greater variation than the walkability scores of the routes. This research did not use (X-5)*10/5, because the general walkability of the Mountain View station area is expected to be better than the average station areas in the U.S., and thus the author wanted to shift the range of the scores a little upward. The rescaled scores were statistically identical with the pre-scaled scores, and did not affect the results of the ensuing statistical modeling in Chapter 8 and 9.

Figure 7. 5: Survey Questionnaires for Weighting the Results of 12 Walkability Models

PART 1. Please imagine that you have to walk for five minutes to a station everyday. What kind of walking environment do you want to have on your (imaginary) walking trip to the station. Please check the five phrases below that best describe what you value most for your walking trips.

Model 11

[ ] plenty of street lighting on the sidewalk at night. **> Model 05**

[ ] shops and restaurants on the streets that allow me to do errands or get a bite to eat while I'm out.

[ ] streets that are observed by nearby residents and store workers, who could see and help me if I were in trouble. **> Model 06**

[ ] other pedestrians, bikers, and shop customers on the streets. **> Model 04**

[ ] small buildings and blocks, and narrow streets with fewer than four lanes. **> Model 09**

[ ] streets with a variety of things to see. **> Model 12**

[ ] streets that are shaded in summer and wind-free in winter. **> Model 08**

[ ] visually attractive streets. **> Model 13**

[ ] wide and continuous sidewalks (without interruption by vehicles entering driveways). **> Model 07**

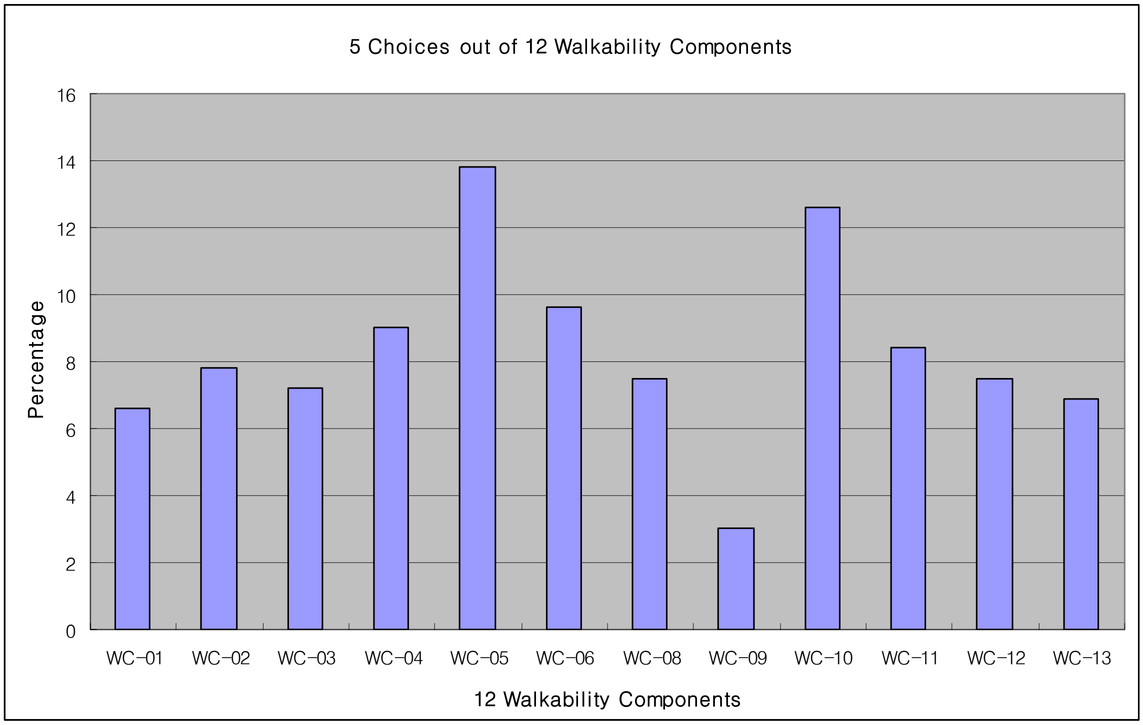
[ ] relatively slow-moving traffic on the streets. **> Model 01**

[ ] conspicuous pedestrian crossing signs and signals. **> Model 02**

[ ] minimal noise, fumes, and vibrations from nearby traffic. **> Model 03**

[ ] easy street crossings with minimum delays. **> Model 10**

Figure 7. 6: Travelers' Choices of Walkability Components



Note: the walkability component 7 was excluded in calculating the proportions

Table 7. 17: Final Weight Values (from the proportion of each answer)

Model	Walkability Components	weight
M 01	Sense of Safety in Pedestrian Crossing Affected by Traffic Speed	0.066
M 02	Sense of Safety in Pedestrian Crossing Affected by Crossing Facilities	0.078
M 03	Sense of Safety in Walking on the Sidewalk Affected by Traffic	0.072
M 04	Sense of Security from Existence of Others	0.090
M 05	Sense of Security Affected by Visibility at Night	0.138
M 06	Sense of Security from Visual Surveillance from Nearby Buildings	0.096
M 08	Buffering Negative Environmental Effects	0.075
M 09	Sense of Street Scale & Enclosure	0.030
M 10	Ease of Pedestrian Crossing	0.126
M 11	Easy Access to Local Stores	0.084
M 12	Visual Variety	0.075
M 13	Visual Attractiveness	0.069
Total		1.000

Note: the weight values were calculated from the proportion of the respondents' choices for each walkability component, excluding the component 7.

7.9. Deductive Operational Definition of Path Walkability

Based on the regression formulas and weightings, this research created a deductive operational definition of (transit access) path walkability with the 22 path walkability indicators, along with a traveler's age and gender. The deductive definition of path walkability is:

The quality of the micro-level walking environment measured by the 22 path walkability indicators and additionally the traveler's age and gender. Path walkability increases as the composite walkability score approaches 10, and decreases as the score approaches 0. The composite walkability index is calculated using on the formulas shown in Table 7.18 below:

Table 7. 18: Final Formulas for Mountain View Walkability Index

Rescaling	Weight	Model formulas & Variables
=10/6*[-4	+(0.07*	(-0.03*(Age) + 2.34*(Pedestrian Crossing Coverage Rate) - 0.41*(Number of Traffic Lanes) - 1.34*(Primary Use of Adjacent Buildings) + 1.29 * (Average Luminosity) + 8.16))
	+ (0.08*	(2.55*(Pedestrian Crossing Coverage Rate) + 1.63*(Existence of On-Street Parking) + 4.38))
	+ (0.07*	(-0.04*(Age) + 0.12*(Width of Buffer Zone) + 8.49))
	+ (0.09*	(2.89*(Percentage of Commercial Uses) + 0.04*(Average Building Width) + 1.11*(Residential Use of Adjacent Buildings) +3.69))
	+ (0.14*	(1.44*(Gender) + 0.04*(Number of Upper-level Windows / 500 ft.) + 5.49))
	+ (0.10*	(0.11*(Average Building Height) + 1.10*(Residential Use of Adjacent Buildings) + 3.45))
	+ (0.08*	(2.42*(Existence of Sidewalk) + 5.83))
	+ (0.03*	(0.56*(Commercial Use of Adjacent Buildings) -0.03*(Street Enclosure Index II) + 9.31))
	+ (0.13*	(0.80*(Average Pedestrian-level Facade Transparency) + 1.44*(Type of On-Street Parking) + 5.18))
	+ (0.08*	(5.69*(Percentage of Commercial Uses) + 3.23*(Percentage of

	Residential Uses) + 2.92))
+ (0.08*	(-6.92*(Fence Coverage Rate) + 3.24*(Percentage of Block with Building Façade) + 5.51))
+ (0.07*	(0.74*(Type of Sidewalk Pavement) + 0.11*(Number of Street Trees / 500 ft.) + 6.37))]

7.10. Mountain View Index

The final set of formulas, including its selected variables (path walkability indicators along with age and gender), coefficients, constants, weights, and a rescaling formula, are valid within the Mountain View station area, and may be useful for similar transit station areas, but might not be applicable to other places. Therefore this research named the final walkability index "Mountain View Index" or MVI. Future researchers could use the Mountain View Index (MVI) if their study sites have similar physical conditions – that is, if they are in medium-to-low density urban or suburban areas. The MVI would be most suitable for measuring the walkability of suburban transit station areas with mixed land uses.

Using the MVI, researchers can calculate a walkability score for any street segment or combination of segments, if they measure the same 22 path walkability indicators. They can calculate more accurately individual walkability scores if they also have individual travelers' ages and genders. For example, Figure 7.7 compares the two composite walkability scores calculated from the routes of two sampled travelers surveyed using the station user survey. Another example is shown in Figure 7.8. This GIS thematic map represents the walkability scores of the 270 street segments surveyed by this research. The composite walkability score and GIS data base could be combined

Figure 7. 7: Comparison of Composite Walkability Index (CWI)

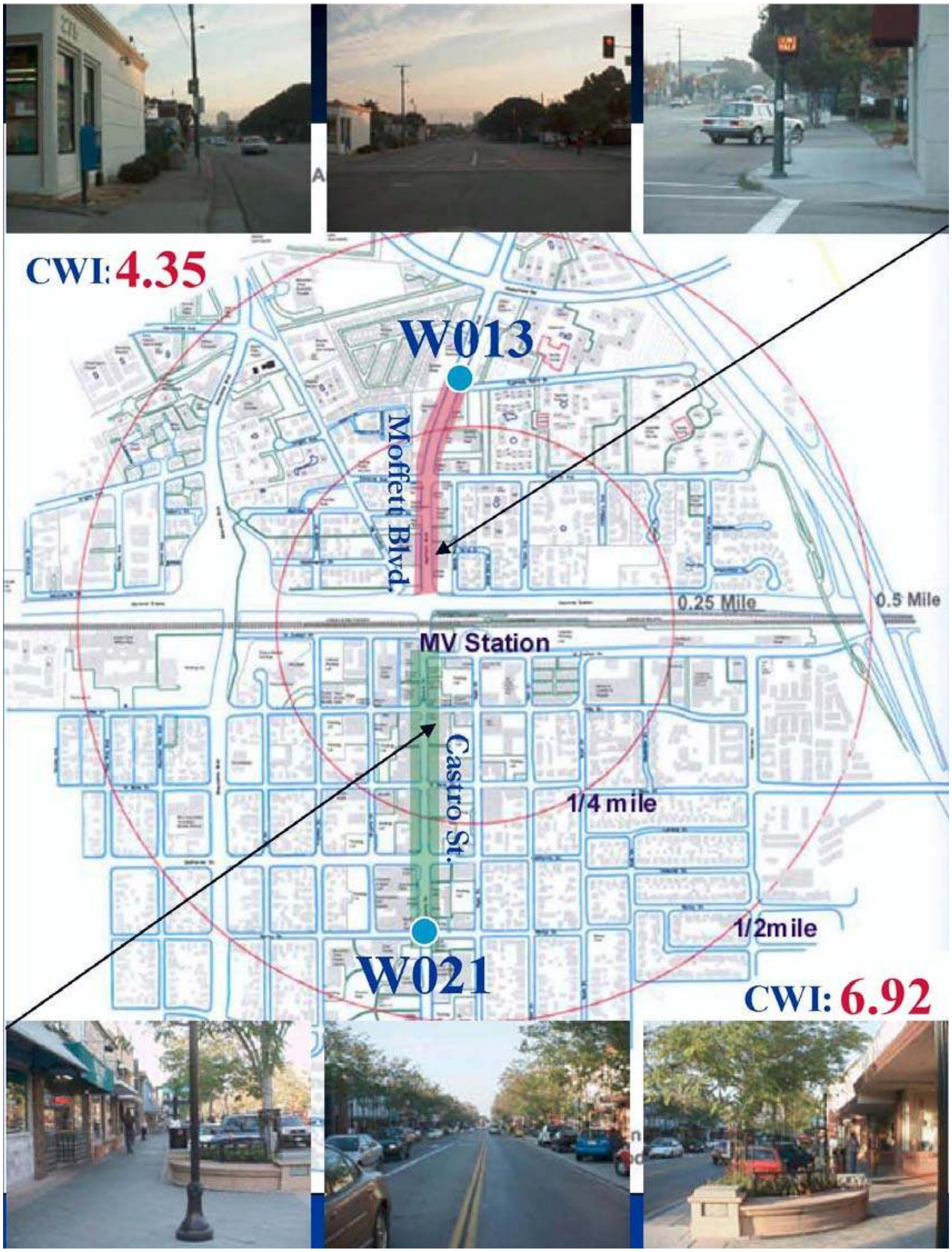
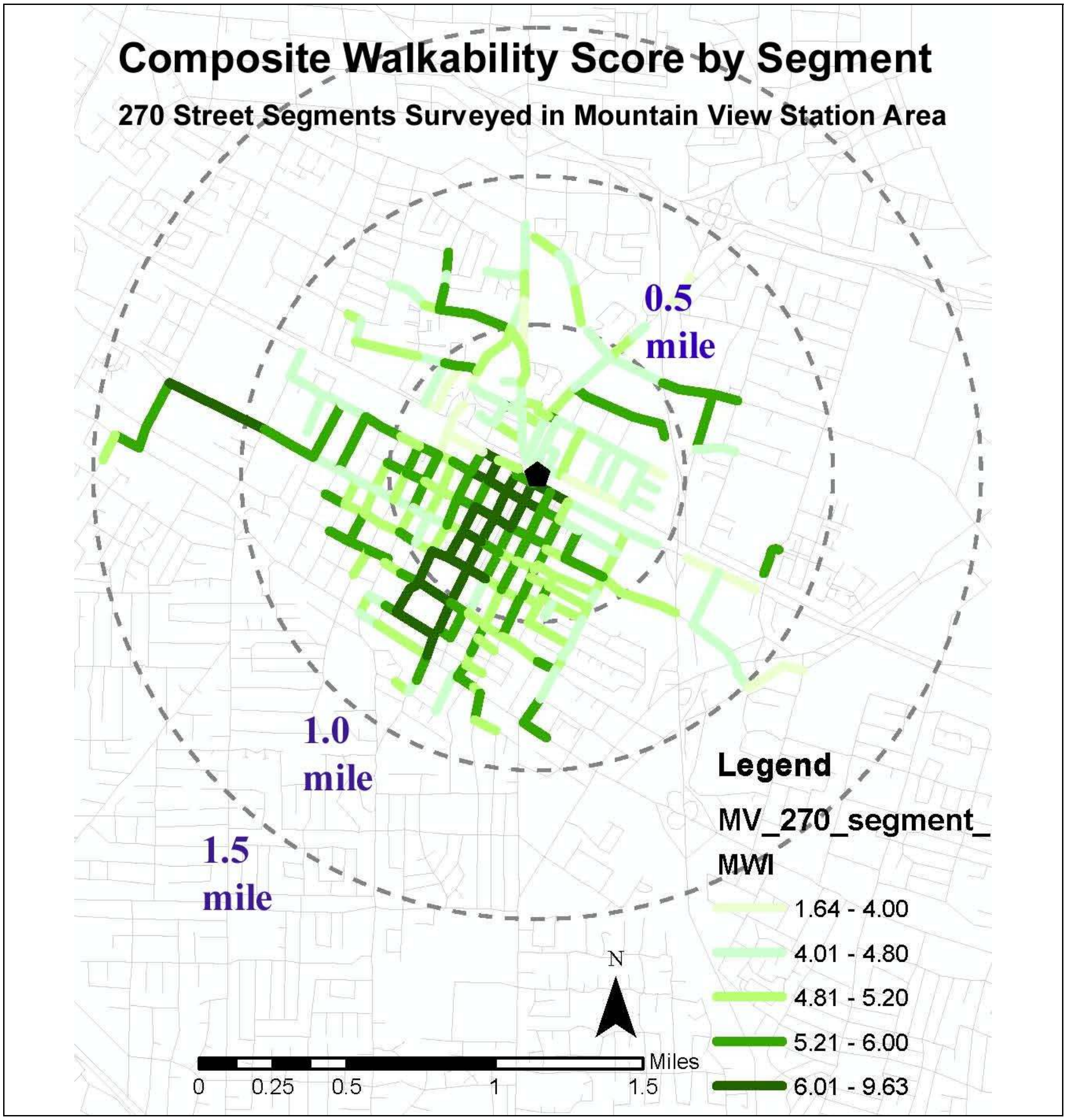


Figure 7. 8: GIS Thematic Map based on Walkability Index



to evaluate and compare the walkability of specific corridors or neighborhoods for future travel behavior research. The data base could also be applied to more complicated GIS spatial analyses.

8. MODELING BEHAVIOR WITH A COMPOISTE WALKABILITY SCORE

8.1. Modeling Transit Users' Access Mode Choice

The primary hypothesis of this research was successfully tested in Chapter 6. By using four new path walkability variables derived from the factor analysis in Chapter 5, this research constructed a binominal logit model, proving that all four path walkability variables influenced travelers' access mode decisions about whether to walk or use automobiles to the station, and the influences were statistically significant. In this chapter, the primary hypothesis was revisited and tested again using a composite walkability score instead of the four path walkability variables.

This part of the study analyzed data from the same set of 249 travelers, 150 travelers who usually walk, and 99 travelers who usually use automobiles, but who had experience walking to the station. A pair of models was constructed: one used only socio-economic variables and the other was constructed using a full set of variables, including a new path walkability variable that was the composite walkability scores derived from the 249 routes drawn by the station user survey respondents. The set of variables developed in Chapter 6 for the socio-economic and environmental models was used for the analyses.

To estimate the probability of choosing walking over driving for access trips to the Mountain View station, this research used the following forms of binominal logit models:

Basic Model:

$$P_{ino} = \frac{\exp(U_{ino})}{\sum_j \exp(U_{jno})}, \quad \text{for } j=1,2 \ \ all\ U_{ino}=f(T_{io}, SEV_n)$$

Expanded Model:

$$P_{ino} = \frac{\exp(U_{ino})}{\sum_j \exp(U_{jno})}, \quad \text{for } j=1,2 \ \ all\ U_{ino}=f(T_{io}, SEV_n, EV_o)$$

Where,

P_{ino} = probability of traveler *n* choosing access mode *i* from home origin *o* to the Mountain View station

j = access mode choice sets available for a travler

U_{ino}= utility function for a traveler *n* accessing by mode *i* from the origin *o* to the station

T_{io} = travel attribute for travel by mode *i* from the origin *o* to the station

SEV_n= socio-economic attributes of traveler *n*

EV_o= environmental attributes associated with traveler's route from trip origin *o* to the station

exp = exponential function

Table 8. 1: Binomial Logit Results; Basic Model vs. Expanded Models, (N=249)

	Model I: Basic Model Socio-Economic Model			**Model II: Expanded Model Environmental Model**		
Variables	Coefficient	Std. Err.	Sig.	Coefficient	Std. Err.	Sig.
Path Distance	-2.97	0.47	0.00	-3.71	0.55	0.00
Car Availability	-2.62	0.69	0.00	-2.46	0.72	0.00
Trip Purpose*	-1.57	0.71	0.03	-1.24	0.72	0.08
Asian*	-0.93	0.41	0.02	-0.83	0.46	0.07
Composite Path Walkability				1.26	0.26	0.00
Constant	6.72	1.15	0.00	0.31	1.64	0.85
-2Log-likelihood (beta)			207.87			176.53
-2Log-likelihood (c)			307.75			307.75
Goodness of Fit (McFadden Rho Squared)			**0.32**			**0.43**
Number of observations			249			249
Model improvement test: -2[$\mathscr{L}$(basic model)-$\mathscr{L}$ (expanded model)]			x^2 =31.33 df=1 prob.=0.00			

* not significant at the 0.05 alpha level in Model II

Table 8.1 shows the result of the pair of binominal logit models. Both models included the same set of travel and socio-economic variables that entered the mode choice models in Chapter 6: *Path Distance*, *Car Availability*, and *Trip Purpose*. The composite walkability score successfully entered the environmental model as a new variable (Model II). However, when the walkability variable was introduced, *Trip Purpose* and *Asian* were no longer significant at the 0.05 level. Unlike the previous environmental model, *Asian* entered the model significantly at the 0.05 level. The final utility functions were shown below:

Basic Model:

$$P_{ino} = \frac{\exp(U_{ino})}{\sum_j \exp(U_{jno})}, \quad \text{for } j=1,2 \text{ all } U_{ino}=f(T_{io}, SEV_n)$$

U_{ino}*=6.72-2.97*Path Distance-1.57*Trip Purpose -2.62*Car Availability -0.93*Asian*

Expanded Model:

$$P_{ino} = \frac{\exp(U_{ino})}{\sum_j \exp(U_{jno})}, \quad \text{for } j=1,2 \text{ all } U_{ino}=f(T_{io}, SEV_n, EV_o)$$

U_{ino}*=0.31-3.71*Path Distance-1.24*Trip Purpose -2.46*Car Availability -0.83*Asian +1.26*CPW (Composite Path Wakability)*

Where,

Path Distance = actual path (network) distance along the traveler n's route between a home origin and a gate of the Mountain View station.

Trip Purpose = a dummy variable defined by the purpose of the trip. A value of 1 is assigned to a work purpose, while 0 is assigned to all other purposes.

Car Availability = a dummy variable. A value of 1 is given when the traveler has a car available for his/her trip to the station, 0 otherwise.

Asian= dummy variables defined by the race of the traveler. A value of 1 is assigned, if the traveler is Asian, while 0 is assigned to all other races.

Composite Path Walkability = A composite walkability score derived from the route of the traveler based on the formula defined in Chapter 7

To compare the effectiveness of the two models, the pseudo-R squared values were compared. The environmental model has a McFadden rho squared value of 0.43, which means that with all the variables including the composite walkability score, the environmental model increased its ability to predict one's access mode choice (walk vs. auto) by 43% over a flip of the coin. The degree of statistical improvement between a basic model and an expanded model can be measured by gauging the change in the log likelihood function $\mathscr{L}$ relative to the change in degrees of freedom (model improvement = –2 [$\mathscr{L}$ (basic model)- $\mathscr{L}$ (expanded model)]. The model improvement "follows a x^2 distribution with k degrees of freedom (where k represents the increase in parameter estimates between the basic model and expanded model)" (Cervero, 2002). A x^2 (chi-squared) test result also confirmed a significant model improvement (Table 8.1).

Judging by both the McFadden rho squared values and the chi-squared test, it was obvious that the expanded model outperformed the basic model and adding the walkability score as a new variable significantly improved the model's predictability. Compared to the environmental models in Chapter 6, however, the McFadden Rho squared value dropped slightly from 0.49 to 0.43. Although the four walkability factors in the previous model outperformed the single composite walkability score in the model, this could be considered a minor drawback, given the greater applicability of the composite walkability index.[25]

This model proves again that walkability plays a significant role in transit users' decisions about whether to walk or use automobiles to access the station. The important point is that two tested models yielded very similar results, although the primary experimental variables of walkability were developed using completely different methods. This means that the two methods lend credibility to each other – especially proving that the deductive operationalizing process was generally appropriate for creating a composite walkability index, although some evaluations were made subjectively.

8.2. Testing Transit Users' Walking Distance to the Station

With the path walkability score derived from the Mountain View Index, this section analyzes the transit users' walking distance to the station. The model used the same 150 transit users (analyzed by the logit model in Section 8.1), who walked to the station and provided their walking routes. A regression analysis was performed to test a correlation between path walking distance as the dependent variable and a set of independent variables (the new composite walkability score and the variables from Section 6.2).

[25] With the composite walkability index, this research was able to conduct a series of model analyses in Section 8.2, 8.3, and 8.4.

Table 8. 2: Regression Modeling of Transit Users' Walking Distance (N=150)

Variables	Estimates:			
	Coefficient	Std. Err.	t	Sig.
Population Density*	0.07	0.01	12.26	0.00
Median Household Income*	0.00	0.00	8.07	0.00
Percentage of Asian*	4.06	0.68	6.00	0.00
Path Walkability Index	**0.12**	**0.03**	**4.53**	**0.00**
Gender (male=1, female=0)	-0.10	0.04	-2.63	0.01
Constant	-5.13	0.46	-11.13	0.00
Summary Statistics				
Number of observations				150
F Statistic (Probability)				50.01 (0.00)
R^2				**0.69**

* Aggregated data measured at the census tract level (U.S. Census 2000).

Table 8.2 shows a best-fitting regression model, explaining 69.3% of the variation in walking distance of the 150 station users. According to the model, the path walkability variable significantly influenced transit users' walking distance. A traveler is likely to walk farther if he or she has a route with a higher path walkability score. This might mean that good walkability could compensate for a longer travel distance. Controlling for other explanatory variables, a traveler's walking distance increased by 314 feet for every 0.5-point increase in the composite walkability score. Gender also had an impact on walking distance: male travelers had shorter routes than female travelers.[26] This result was somewhat unexpected, given that the chance of walking increases in mode

[26] This result was somewhat unexpected, given that the chance of walking increases in mode choice models. Within 1500 feet (0.28 mile) path distance from the station, the travelers were predominantly male (with an average gender of 0.73). Between 1500 feet (0.28 mile) and 4,420 feet (0.84 mile) path distance, the travelers were predominantly female (with average gender of 0.27). Beyond 4,420 feet (0.84 mile) path distance, the traveler were predominantly male (with an average gender of 0.72), but they had significantly higher population density, median income, and path walkability, compared to the travelers living within 1,500 feet.

choice models. Within 1500 feet (0.28 mile) path distance from the station, the travelers were predominantly male (with an average gender of 0.73). Between 1500 feet (0.28 mile) and 4420 feet (0.84 mile) path distance, the travelers were predominantly female (with average gender of 0.27). Beyond 4420 feet (0.84 mile) path distance, the traveler were predominantly male (with an average gender of 0.72), but they had significantly higher population density, median income, and path walkability, compared to the travelers living within 1500 feet.

In the two mode choice models for Section 6.3 and 8.1, individual-level variables (based on disaggregated data) dominated, with no neighborhood-level variables (based on aggregated data) significantly influencing mode choice. However, this model revealed three census tract-level variables that correlated with walking distance: population density, median income, and percentage of Asian population. If a traveler lives in a census tract that has a higher population density, a higher average median income, and/or a greater percentage of Asians, the traveler is likely to walk a longer distance to get to the station. The three variables related only to the origins of the travelers, not their routes. All five variables entered the model with statistical significance at the 0.05 alpha level.

8.3. Quasi-Experimental Design Approach: Two-Group Comparison

To further investigate the influence of path walkability on travelers' walking distance, this research also conducted a quasi-experimental, two-group comparison by dividing the 150 walking transit users into two groups based on their home origins. Of the 150 walkers, 56 travelers walked from the north area and 94 travelers from the south

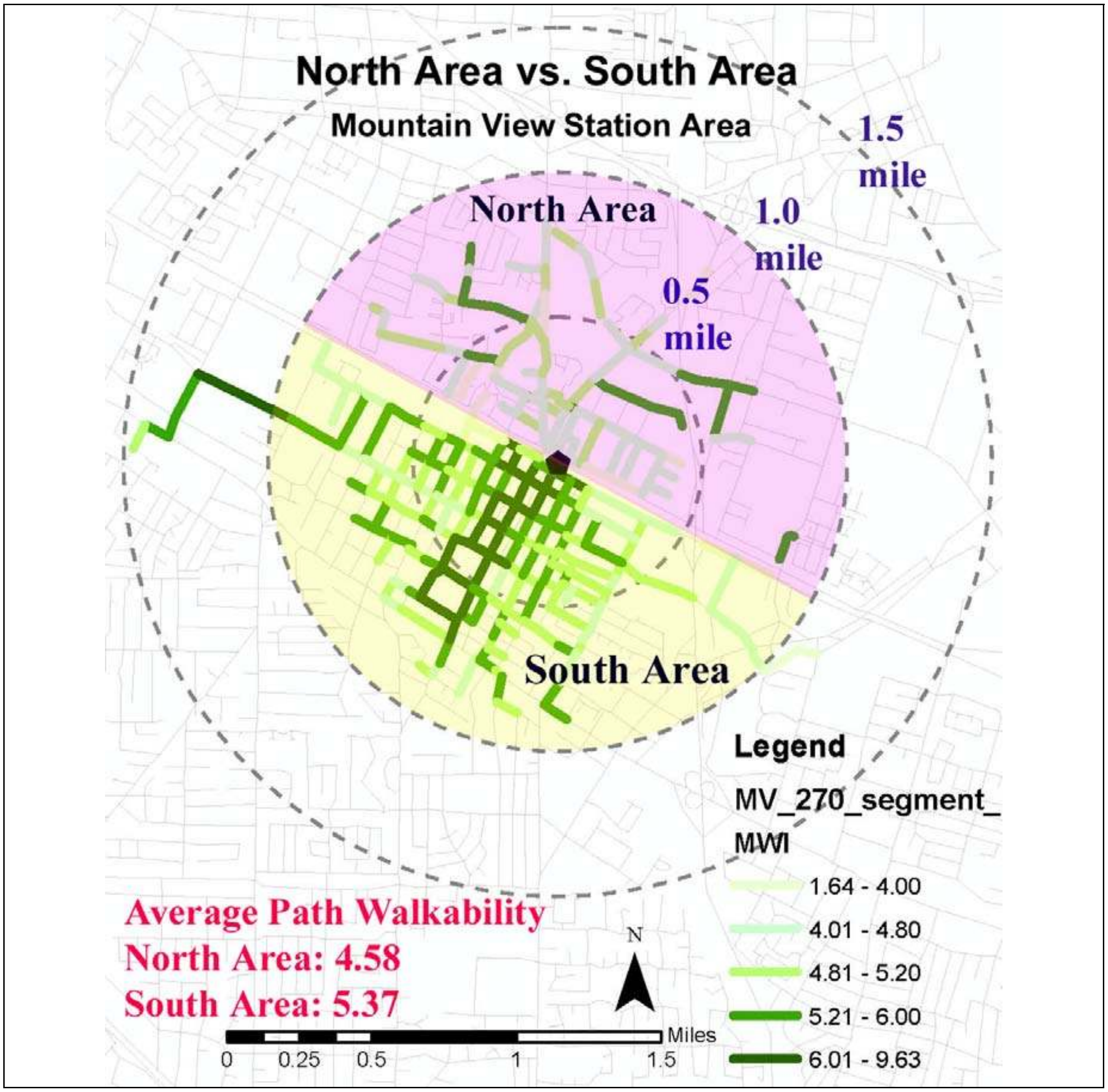
(Figure 8.1 and 8.2).

First, path walking distances between those two areas were compared. In general, the travelers living in the south area had longer routes than those living in the north: the average path walking distances of the north and south areas were 2,274 ft. and 3,444 ft. respectively (Table 8.3). An analysis of variance (ANOVA) test was conducted to see if the difference is statistically significant (Appendix 5). The result showed that walking distances between north and south areas were significantly different.

Second, this research compared the north and south areas in terms of the five variables that entered the regression model shown in Table 8.2: population density, median household income, percentage of Asian population, path walkability score, and gender. The average values of the five variables are presented in Table 8.3. To test if each difference between north and south is statistically significant, a series of ANOVA tests were conducted with the five explanatory variables (Appendix 5). The result showed that the north travelers and the south travelers are not different in a statistically significant way in terms of four of the variables. Only the path walkability scores differed. The path walkability score of the south area was higher than the north, and the difference was significant.

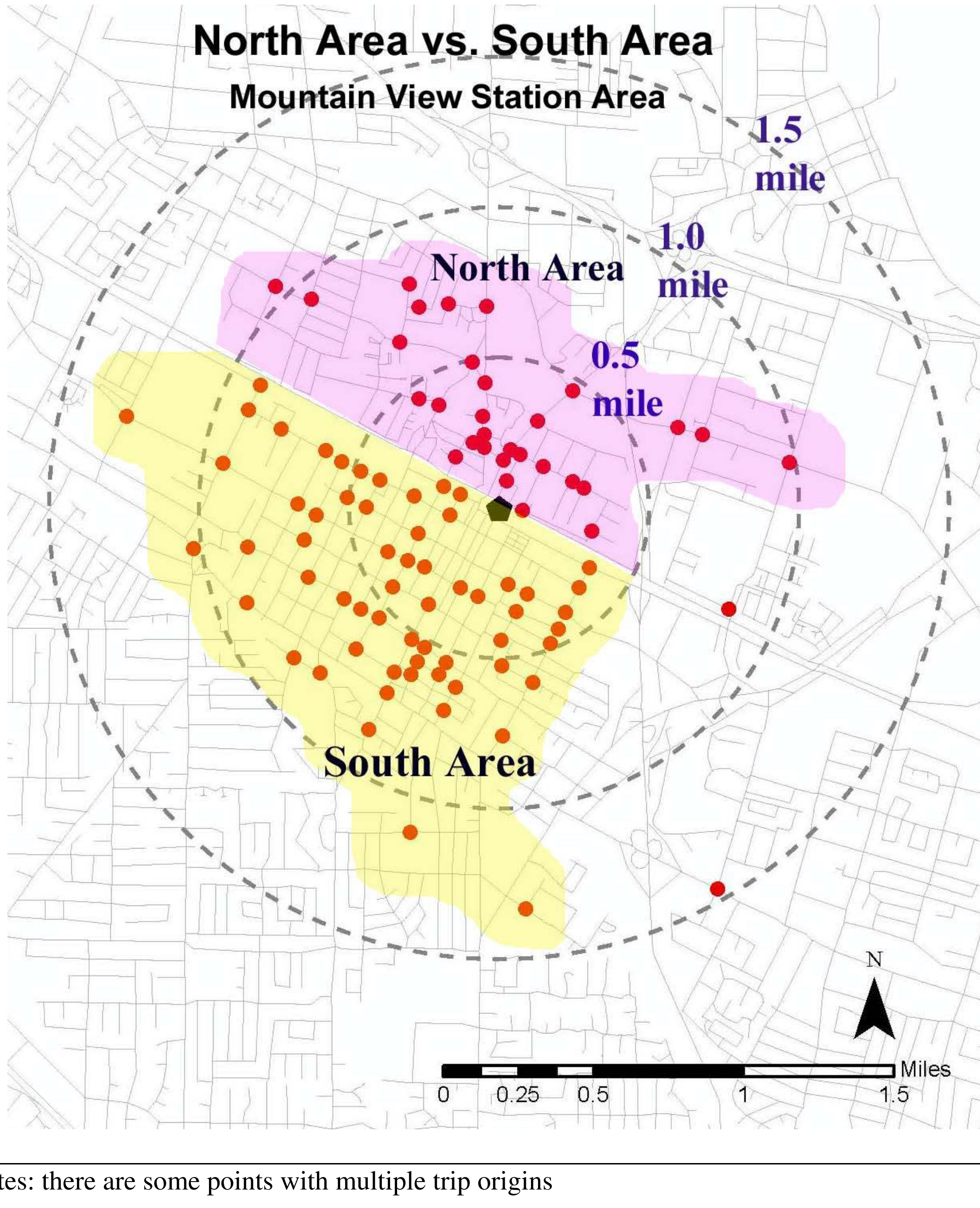
The result illustrates that the difference in path walkability creates a significant difference in travelers' walking distances. In other words, creating good walkability might be an effective means of encouraging people to choose longer walking distances rather than driving.[27]

Figure 8. 1: North and South Areas with Composite Walkability Scores



[27] The result of the quasi-experimental aggregate analysis (Section 8.3) and the multi-nominal disaggregate analysis (Section 8.2) are independent each other; one cannot overrule the other.

Figure 8. 2: North vs. South Areas with Trip Origins



Notes: there are some points with multiple trip origins

Table 8. 3: Comparing the average values of path walking distance and the five explanatory variables

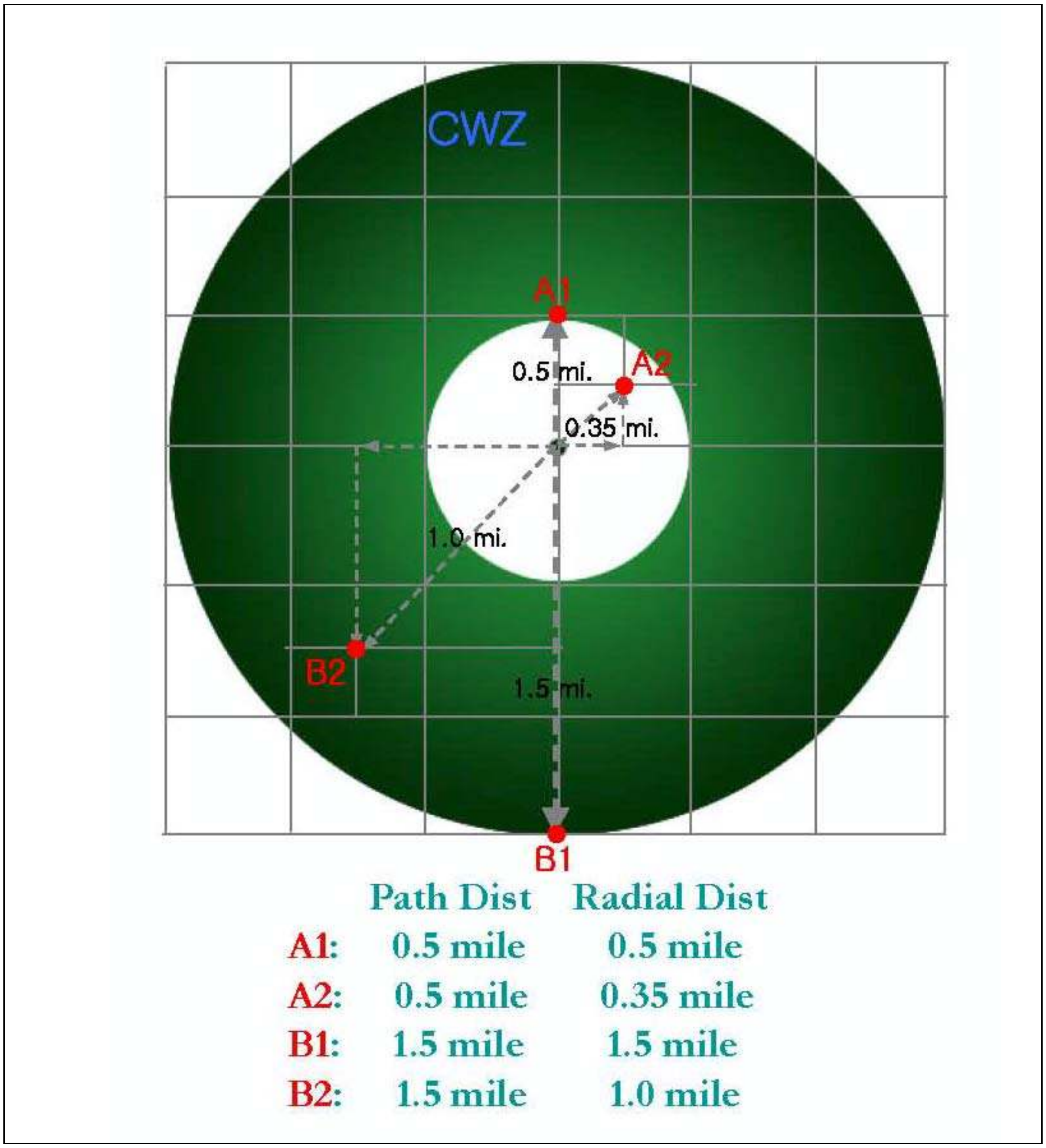
Variables	Average Value for Each Variable	
Area	North Area	South Area
Path Walking Distance	0.43 mile (2274 ft.)	0.65 mile (3444 ft.)
Population Density*	9.8 person/acre	11.8 person/acre
Median Household Income*	$70,885	$76,802
Percentage of Asian*	22.2%	19.3%
Path Walkability Score	4.53	5.36
Gender (male=1, female=0)	0.49	0.46

* Census tract-level data from 2000 U.S. Census; The North Area included the census tract 509303, 509202, 509201, 509108, 509109, 509302, 509304; The South Area included the census tract 509500, 509600, 509700, 509403, 509105, 509802, 509801, 510400, 509902, 509901.

8.4. Defining a Critical Walking Zone

This section investigated whether there is a "critical walking zone" within which path walkability plays a greater role in transit users' access mode decision. From the original 249 travelers, a subset of 131 travelers was extracted of those who live between a 0.5-mile path distance and 1.5-mile path distance from the gate of the station. On a true grid pattern, a 0.5-mile path distance is equivalent to a minimum 0.35 and a maximum 0.5-mile straight-line distance (or radial distance). A 1.5-mile path distance is equivalent to a minimum 1.0-mile and a maximum 1.5-mile straight-line distance (or radial distance) (Figure 8.3).

Figure 8. 3: Critical Walking Zone (CWZ)



With this new subset, a new binominal logit regression was performed[28], with mode choice as the dependent variable, and the path walkability as the independent variable along with other independent variables developed in Chapter 7. Table 8.4 below shows the result of the new mode choice model with the 131 travelers (Model III), and the result compared to the previous environmental model of the 249 travelers (Model II). Unlike Model II, only *Path Walkability* entered the new model in a statistically significant way at the 0.05 alpha level. *Asian* also entered, but at slightly over the 0.05 level. The predictability of the new model was decreased as its McFadden rho squared value was reduced from 0.42 to 0.35. For a model with only one variable entered at a significant level, however, this rho squared value is still quite impressive.

Table 8. 4: Comparing Two Logit Models: 249 Travelers vs. 131 Travelers from CWZ

	Model II: Environmental Model **249 Travelers**			Model III: Environmental Model **131 Travelers from CWZ**		
Variables	Coefficient	Std. Err.	Sig.	Coefficient	Std. Err.	Sig.
Path Distance	-3.71	0.55	0.00	-3.51	1.04	0.00
Asian*	-0.83	0.46	0.07	-1.05	0.57	0.06
Car Availability	-2.46	0.72	0.00			
Trip Purpose*	-1.24	0.72	0.08			
Path Walkability	1.26	0.26	0.00	1.60	0.33	0.00
Constant	0.31	1.64	0.85	-5.01	1.78	0.00
-2Log-likelihood (beta)			176.53			110.63
-2Log-likelihood (c)			307.75			167.73
McFadden Rho Squared			**0.43**			**0.34**
Number of observations			249			131

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[28] This showed an example of superior applicability of taking deductive approach and creating a composite walkability index. The research was able to derive composite walkability scores from the reduced number of cases and plug them into a new model with as an experimental variable. The path walkability scores derived from the factor scores through the inductive operationalization in Chapter 5 could not be used in this way. Instead a new factor analysis with the 131 cases would yield a different set of factors. It might even have yielded no result, because of the number of cases was reduced and factor analysis is very sensitive to number of cases.

To further investigate the relationship between mode choice and path walkability in the critical walking zone, another model was constructed using only the path composite walkability score, and the result was compared to a walkability-only model (Model II-1) based on the 249 travelers (Table 8.5). The McFadden Rho squared value of 0.28 for the 131-traveler model (Model III-1) is significantly greater than the value of 0.07 for the 249 travelers (Model II-1).

Table 8. 5: Comparing Two Logit Models only with Path Walkability Scores

	Model II-1: **249 Travelers**			Model III-1: **131 Travelers from CWZ**		
Variables	Coefficient	Std. Err.	Sig.	Coefficient	Std. Err.	Sig.
Path Walkability	0.75	0.17	0.00	1.67	0.30	0.00
Constant	-3.43	0.88	0.00	-8.85	1.57	0.00
-2Log-likelihood (beta)			312.60			130.69
-2Log-likelihood (c)			334.67			181.60
McFadden Rho Squared			**0.07**			**0.28**
Number of observations			249			131

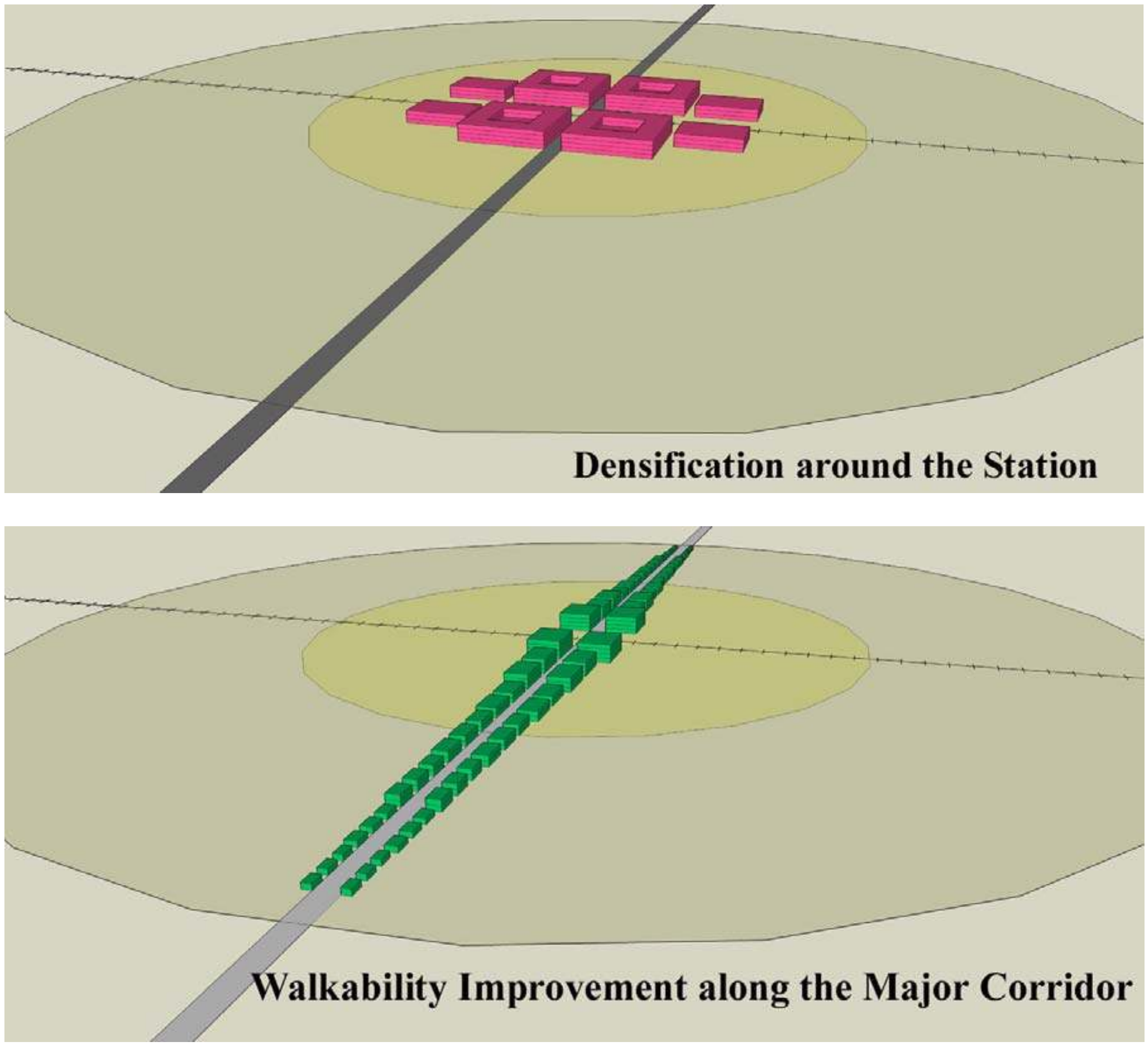
The influence of the path walkability variable on the transit users' access mode choice is greater in the model based on the 131 travelers whose (home-based) trip origins were within the critical walking zone. Path walkability also plays a much greater role than other variables within the critical walking zone. It is supposed that transit users living close to the station would walk regardless of their path walkability, simply because the station is so close to their homes, and that those who live beyond a certain distance from the station will not walk regardless of path walkability, because they live too far from the station. The significant point is that walkability matters most in a donut-shaped middle area between two threshold distances. In the Mountain View station area, this "critical walking zone" was predefined as the zone with straight-line distance between 0.35 ~ 0.5 mile and 1.0 ~ 1.5 mile from the center of the station.

8.5. Planning Implications for Future TOD Policies

This research found that path walkability influences transit users' access mode choice decisions, and their walking distances to the station, in a statistically significant way. This means that it may be possible to encourage transit users to choose walking over driving and also to encourage them to walk farther, by improving path walkability in the station area. This research also found that the influence of path walkability on mode choice is even greater in a critical walking zone between 0.5 and 1.5 mile path distance from the station.

Today's transit-oriented development (TOD) practices often focuses on increasing density near transit stations and thereby decreasing walking distances to the station (Figure 8.4). This might increase transit ridership, because indeed travel distance matters. But many transit-oriented developments fail to grow as vibrant "transit villages" because potentials of a station area were not fully utilized. However, the findings of this research suggest that both in frequency and length, walking trips to the station could be increased by improving path walkability especially in the critical walking zone.

Figure 8. 4: Densification around the Station vs. Walkability Improvement



This could be achieved at relatively low-cost and perhaps with relatively little public opposition. The author believes that increased walking trips to the station can stimulate a more dispersed synergy in which more people walking to the station boost local business, thriving restaurants and stores attract more people to the area, and more customers encourage public investment to improve walkability. This benevolent circle eventually helps create the vibrant transit villages and increases transit ridership.

Based on the research findings, the first priority would be to improve walkability along the major pedestrian corridors leading to the station (Figure 8.4). Attention should be paid not only to the portion of the corridor near the station, but even more so to the portions of corridor within the critical walking zone. This corridor improvement could be coupled with densification around the station to maximize the benefit, but large-scale housing projects that surround the station and function as psychological barriers would not be recommended. Even though it is accessed by foot, the walking paths within the housing projects often give travelers the perception that they are within someone else's territory. Desirable path walkability defined by this research is more likely to be a public street with a certain amount of walking-conducive, first-floor commercial uses.

8.6. Lessons for Future Street Design Guideline

The purpose of this dissertation was to test the collective effect of walkability indicators, not to create desirable street design guidelines. But, if good walkability means a walking-conducive environment, which increases both the chance of walking and walking distance, walkability might be improved by following the five principles below.[29]

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[29] These five principles are based on the results of this research. However, some specific suggestions of how to express three principles in design are the author's opinion based on the author's personal experience in the study site. Any design conclusions need to take into account all the research limitations and constrains mentioned throughout this dissertation.

(1) Buffering Traffic Impacts: As pointed out by many previous studies, traffic impact discourages walking. Multi-lane streets attracting fasting-moving traffic are not desirable. A street with fewer through-traffic lanes is better than a street with more lanes. Traffic impacts can be reduced by buffer zones. The width of the buffer zone (space between the edge of the outer traffic lane and edge of the sidewalk) seems important. Wider is better, but a minimum of 10 feet, including on-street parking, may be desirable. The role of on-street parking turns out to be critical. Unlike stationary elements such as lawn strips, on-street parking slows down traffic and provides more customers, pedestrians, and "eyes on the street." The combination of a 7-foot parking lane and a 3-foot lawn strip between the sidewalk and the street would be more effective than a 10-foot lawn strip.

(2) Improving the Sidewalk Environment: Three sidewalk elements are more important than others: more street trees, brighter luminosity, and special pavements create good walkability. More trees are better – it is probably desirable to have at least 20 trees (including both sides) on a 500-foot street. Well-lit streets are important, though this could be achieved in many ways. More and lower street lightings improve luminosity. It appears desirable to have 0.3 or higher foot candles at the midpoints between two light posts. Commercial streets are superior in terms of luminosity, because light from the windows are often intense, and help fill the gap between streetlights, whose effectiveness drops sharply as one moves away from the sources. Special pavements, other than common concrete pavement, may also increase path walkability. This research did not test specific types of pavement, but in the study site special pavements were mostly colored and patterned concrete.

(3) Reducing Barriers between Public and Private Spaces: Like the buffer zone dividing the traffic zone and the walking zone, the boundary between the public sidewalk and private buildings and properties is also important. Unlike the buffer zone, however, less of a barrier between the two spaces seems more desirable. More visual access from the outside to the inside of the building at the ground level (façade transparency) and more visual access from the inside to the outside space from the second and third stories (upper-level windows) are critical. More, larger, and more transparent windows with lower window sills increase both types of visual access. By the same token, a fence works as a barrier between the walking zone and private properties. The walkability decreases as more sidewalk frontage is blocked by a 4-foot or higher fence.

(4) Finding the "Right" Scale and Enclosure: The ratio of building-to-building distance to building height is important, or more accurately, the building-to-building distance relative to the average building skyline height, which is influenced by vacant lots and surface parking lots. Walkability increases when the street frontage contains more building façade. A 3.3 enclosure ratio, which means a 66-foot building-to-building distance and a 22-foot average building height, seems fine based on this research, but the author personally thinks that an optimum ratio for TOD might be closer to 2.0 than 3.3. For example, a 2.0 ratio could be created by a 60-foot building-to-building distance and rows of 30-foot buildings on both sides. Walkability also increases with wider buildings, which can be related to the percentage of block face with building façade and commercial uses.

(5) Having the "Right" Combination of Building Uses: Walking-conducive commercial uses, such as groceries and snack shops, on the first floors of buildings increase walkability. Auto and construction-related businesses do not help. Residential use on the first floor is better than non-commercial uses, such as parking lots and industrial uses. Buildings with ground-level commercial space and second- and third-floor residential space seem to make sense from a walkability perspective.

8.7. Limitations and Future Research

Both the definition of path walkability and the composite walkability index were derived from a limited number of street measurements and perception surveys, and thus may not be applicable to other areas. More research replicating similar methods of measuring and evaluating walkability need to be done.

Due to lack of research funds, reliability tests could not be done on the walkability measurements used in this research, although some sensitive street elements were measured solely by the author to be consistent. The reliability problem was addressed in Boarnet et al. 2006 and Ewing et al. 2006, and should be addressed in future research.

This research gathered travel data from only one transit station area and the findings may not be generalizable. More comprehensive explanations of access mode choice require more surveys at other stations and other rail systems across the nation. The possibility that the subject group has some unknown socio-economic uniqueness also needs to be considered.

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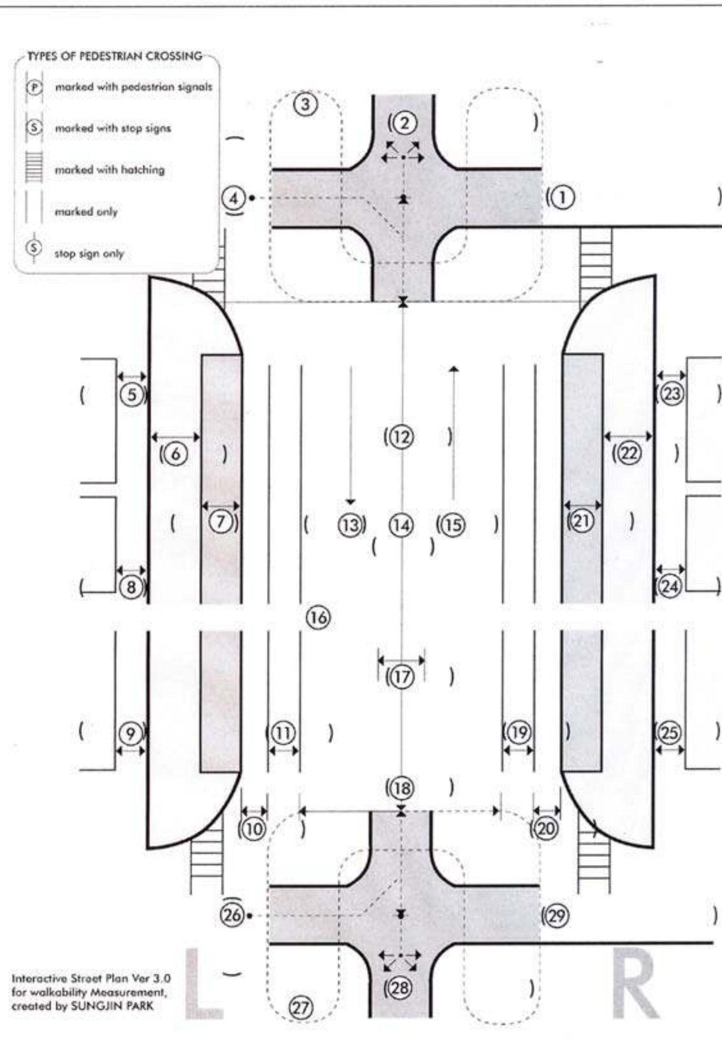
Appendix 1-A. Path Walkability Measurement Instrument, Page-1

Walkability Survey Form (Oct 1, 2005) Sungjin Park, Ph.D. Candidate, UC Berkeley

Station Area: *Mountain View*	Time of Survey:	Surveyor:
Segment No.: Street Name:	Between	&
Indicators	Left	Right

Indicators
1) upper crossing street name
2) # of upper ped connection
3) type of upper ped xing
4) upper ped xing distance (ft.)
5) upper left setback (ft.)
6) left-side walking zone (ft.)
7) left-side utility zone (ft.)
8) mid-left setback (ft.)
9) lower left setback (ft.)
10) left-side on-street parking
11) left-side bike lane (ft.)
12) length of Sidewalk (ft.)
13) # of downward traffic lanes
14) # of left turn lane
15) # of upward traffic lanes
16) mid-block crossing
17) median / left turn lane (ft.)
18) width of traffic zone (ft.)
19) right-side bike lane (ft.)
20) right-side on-street parking
21) right-side utility zone (ft.)
22) right-side walking zone (ft.)
23) upper right setback (ft.)
24) mid-right setback (ft.)
25) lower right setback (ft.)
26) lower ped xing distance (ft.)
27) type of upper ped xing
28) # of lower ped connection
29) lower crossing street name



30) Street-level Luminosity	#1:	#2:	#3:	#4:	#5:	#6:
31) # of Trees			32) Total Canopy	ft.	ft.	
33) # of Street Furniture			34) Pavement type			
35) Altitudes	Up:	Lo:	36) Walking Barriers	(Y / N)		
37) Visual Obstacles	(Y / N)	38) # of Traffic Calming:				

Types of Traffic Calming (SB: Speed Bump/ CH: Choker/ BO: Bulb-Out/ CC: Chicane/ SC: Street Closing/ RC: Raised Crosswalk/ PT: Paving Treatment/ DV: Divert/ CI: Crossing Islands/ MC: Mini-Circle);
Location of Parking (**PK:** on-street parking **PB:** parking bay); Types of Parking (**PLL**: Parallel, **DIA:** Diagonal, **PK (REC):** Rectangular) (BK: Bike Lane, LSS: Landscape Strip, UTZ: Utility Zone)

Appendix 1-B. Path Walkability Measurement Instrument, Page-2

Building ID	
Building Height	
Use (1st floor / Upper-levels)	
# of street facing doors	
# of upper-level windows	
Building Width	
(Ped-level) Transparency	
# of Driveway Curb-Cuts	
# of Intermediaries	
Fence Type / Length	
Setback Use	
Retail Uses & Other Specifics	

Time of Survey:
Segment # : **083**
Surveyor:
Survey Area:
Mountain View
Street segment:
View St.
between
Mercy St. &
California St.

Mercy St.

California St.

Building ID	
Building Height	
Use (1st floor / Upper-levels)	
# of street facing doors	
# of upper-level windows	
Building Width	
(Ped-level) Transparency	
# of Driveway Curb-Cuts	
# of Intermediaries	
Fence Type / Length	
Setback Use	
Retail Uses & Other Specifics	

Appendix 2. List of Walking-Conducive and Non-Walking-Conducive First-Floor Uses

Walking-Conducive Commercial Uses Found in My Study Site • Retail Offices: (banks, Insurance agencies, travel agencies, law firms, real estate agencies) • Non-Academic Classes: (aerobics, gymnastics, martial arts, ballet, yoga) • Beauty & Style: (hair salons, nail shops, skin cares, barbers) • Home improvement and house wares: (kitchenware, carpet, coin-laundry, furniture) • Specialty Shops: (quilts, antiques, souvenir, gift shops, cigar shops, pet shops, Jewelers) • Health Services: (dentistry, acupunctures, fitness, opticians/eye clinics/ vision cares/ glasses, chiropractics) • Restaurants: (fast foods, cafes, coffee shops, restaurants, pizzas, pubs) • Food-related Retail: (liquor stores, convenient stores, groceries, supermarkets, bakeries, ice cream stores) • Other Small Retail Stores: (photo shops, locksmiths, flowers, watch repairs, computer stores, copy shops, book stores, cell phones)
Non-Walking-Conducive Commercial Uses Found in My Study Site • Construction-Related Businesses: (building materials, construction equipments, paint stores, glass shops, construction consultants) • Auto-related businesses: (car washes, body shops, auto dealers, rental cars, oil changers, parking structures, gas stations) • Warehouses and Storage Buildings

Appendix 3-A. User Survey Form Page 1, 2, 3, and 4

Survey of Transit Users' Trip to the Station

Thank you very much for your participation. This is a survey on transit users' trips to the station administered by researchers at the UC Berkeley Department of City and Regional Planning. Your answers will be used to understand the way of improving the quality of access to Bay area transit stations. In this survey, no personal information (such as your name, address, or telephone number) will be asked. All the data collected through this survey will be kept confidential. You may have completed a similar survey in July 2005, but this is a new survey with a different purpose, so we hope you will help us again by completing this survey form.

1. Which train do you most often take at the downtown Mountain View Station?
[ ] Caltrain [ ] VTA Light Rail

2. What is usually the major purpose of your trip by using the train selected above? (please check only one)
[ ] working
[ ] shopping
[ ] going to school
[ ] social gathering
[ ] recreational activities
[ ] other (please specify) _______________

3. How many round trips (between your home and the downtown Mountain View Station) do you make?
[ ] three or more times a week
[ ] one or two times a week
[ ] once every two weeks
[ ] once a month
[ ] less than once a month

4. How do you usually **get (from home) to the downtown Mountain View station**? Please select only one, **your most frequently used**, method.
[ ] drive and park
[ ] carpool or get dropped off
[ ] walk only
[ ] bicycle
[ ] ride the bus
[ ] others (please specify) _______________

5. How do you usually **return back home** (from the downtown Mountain View station)? Please select only one, **your most frequently used**, method.

[ ] drive
[ ] carpool or get picked up
[ ] walk only
[ ] bicycle
[ ] ride the bus
[ ] other: (please specify) _______________

6. In either Question 4 or 5 above, did you select "drive" or "carpooled or get dropped off or picked up" for your most frequently used method?
[ ] yes (go to Question 7)
[ ] no (skip to Question 8)

7. If you selected "yes" on Question 6, what are your reasons for using a car rather than walking between your home and the station? (Please check all that apply.)

[ ] The station is too far from my home.
[ ] I am very busy, so I drive to save time.
[ ] I am not healthy enough to walk to the station.
[ ] My walking trip to the station is boring.
[ ] Walking is dangerous because of traffic
[ ] Walking is dangerous because of crime,
[ ] Other reason (please specify)_________
____
____

8. Do you live in the San Francisco Bay Area?
[ ] yes (go to Question 9)
[ ] no (skip to Question 15)

9. Which city do you live in?
[ ] Mountain View
[ ] Los Altos
[ ] Sunnyvale
[ ] Other (please specify)_____________

Continue on Reverse

Appendix 3-B. User Survey Page 2 and 3 (originally printed on 11 by 17 size paper)

10. Please write down the street intersection closest to your home (This is any intersection, not just a major intersection).
The closest intersection to my home is the intersection of (______________________) and (______________________)
(Example: …the intersection of Castro St. and Villa St.)

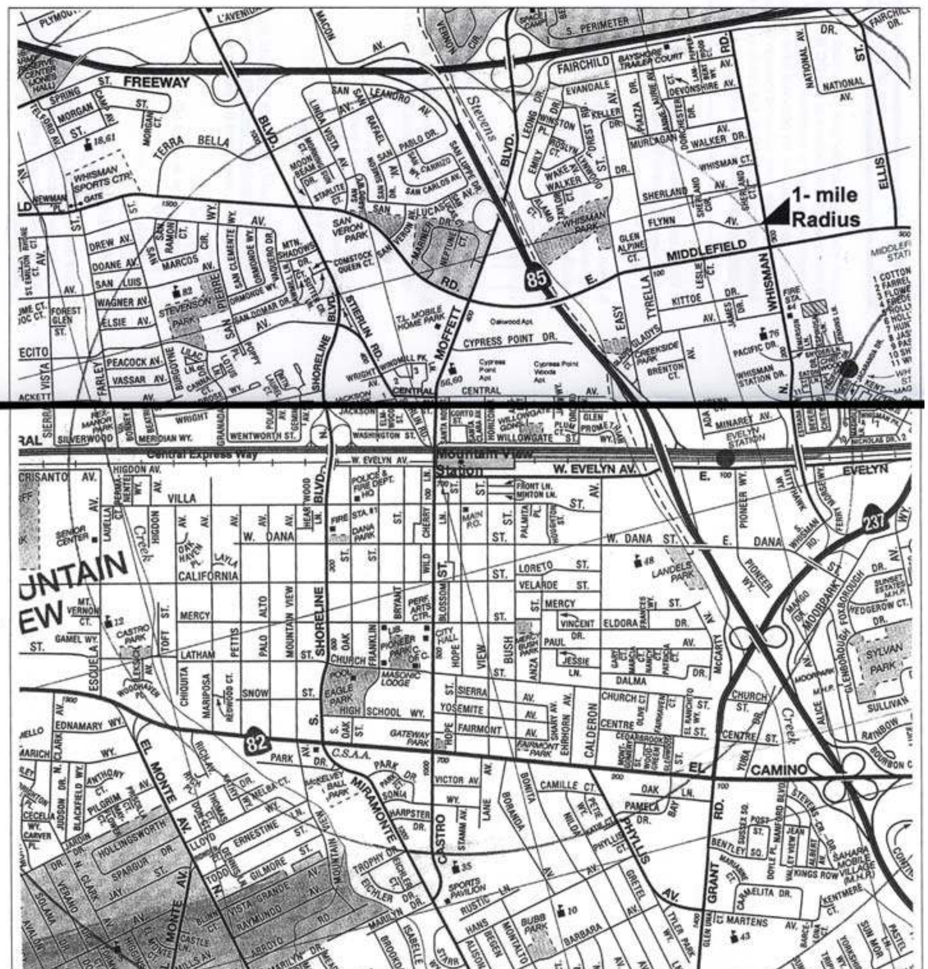
OR

If you don't remember the street name, you could also give us the address range and the name of street you live on.
(____________) block of (__________________________) / (Example: 200 block of Castro St.)

11. The map below shows the Mountain View neighborhood (approximately within a 1-mile radius from the downtown Mountain View station).
Is your home within this map?
[ ] yes (go to Question 12) [ ] no (skip to Question 15)

12. Have you ever walked from your home to the station (or from the station to your home)?
[ ] yes (go to Question 13) [ ] no (skip to Question 15)

13. By using the red ball pen given to you, please draw the walking route to the station that you use most frequently on the map below.
First, indicate the location of your home and draw the line to the downtown Mountain View station located at the center of the map below.
(If you use different routes for your home-to-station and station-to-home walking trips, please draw both of them and label them so we can differentiate those two routes). If you prefer, you may describe your route in words below (e.g. I walk down Main street, then turn left on 1st street, and then I…) : ____



Sources: California State Automobile Associatio

14. Overall, how do you rate your walking experience on the route you drew above? Please circle one number for each of the five values.

I. Safety (from **traffic accident**)	Safe	1	2	3	4	5	Unsafe
II. Security (from **street crime**)	Safe	1	2	3	4	5	Unsafe
III. Comfort	Comfortable	1	2	3	4	5	Uncomfortable
IV. Convenience	Convenient	1	2	3	4	5	Inconvenient
V. Interestingness	Interesting	1	2	3	4	5	Uninteresting

Appendix 3-C. User Survey Form Page 4

15. How many people, including yourself, live in your household?
[ ] one [ ] two [ ] three
[ ] four [ ] five [ ] six or more

16. Do you have a valid driver's license?
[ ] yes
[ ] no

17. How many people in your household, including yourself, hold valid driver's licenses?
[ ] one [ ] two [ ] three
[ ] four [ ] five [ ] six or more

18. How many cars (including trucks and vans) are available for use to your household?
[ ] one [ ] two
[ ] three [ ] four or more

19. Do you usually have a car (or a truck or a van) available for your trip to the downtown Mountain View station?
[ ] yes
[ ] no

20. What is your age? (___________)

21. What is your gender?
[ ] male [ ] female

22. What is your race or ethnic identification?
[ ] White/ Caucasian
[ ] Hispanic/ Latino
[ ] Asian/ Asian-American
[ ] Black/ African-American
[ ] Other (please specify) ______________

23. Were you born in the United States?
[ ] yes (skip to Question 25)
[ ] no (please specify the name of country you were born in) ____________________

24. If "no" above, how many years have you lived in the United States? _________ years

25. What describes you best?
[ ] Full-time worker
[ ] Part-time worker
[ ] Homemaker/Retired/Unemployed
[ ] Student

26. What was **your household's** annual income in 2004 before taxes?
[ ] less than $20,000
[ ] $20,000 to 29,999
[ ] $30,000 to $39,999
[ ] $40,000 to $49,999
[ ] $50,000 to $74,999
[ ] $75,000 to $124,999
[ ] 125,000 to 199,999
[ ] $200,000 or more

27. What was **your** annual income in 2004 before taxes?
[ ] less than $20,000
[ ] $20,000 to 29,999
[ ] $30,000 to $39,999
[ ] $40,000 to $49,999
[ ] $50,000 to $74,999
[ ] $75,000 to $124,999
[ ] 125,000 to 199,999
[ ] $200,000 or more

28. What is the height of building you currently live in?
[ ] 1 story
[ ] 2 story
[ ] 3 story
[ ] 4 or more story

29. What type of building do you currently live in?
[ ] detached single family housing
[ ] 2 to 4 unit building
[ ] 5 to 9 unit building
[ ] 10 or more unit building

30. Do you live in an apartment/condominium complex, which has more than 5 separate residential buildings within its boundary?
[ ] yes [ ] no

31. Do you live in a "mixed-use" building, that is, in a building whose lower floors are used for office or commercial uses?
[ ] yes [ ] no

Thank you very much for your participation!

(By using the envelope and stamp given to you, please return this survey to S.J. Park, Dept of City & Regional Planning, UC Berkeley, 228 Wurster Hall, #1850, Berkeley, CA94720)

Appendix 4.

Appendix 4-A. Survey Questionnaire and Score Formula for Walkability Component 1 (Sense of Safety in Pedestrian Crossing Affected by Traffic Speed)

Survey of Walking Condition for Transit Users' Trip to the Station

Please complete the remaining part of the survey and mail it to us by using the return envelope given to you. (if you lose the envelope, please send it to S.J. Park, 228 Wurster Hall, #1850, Berkeley CA 94720)
Thank you very much again for your participation.

PART 3. Please answer the following questions based on your walking trip to the station (on the route you just drew). Please check one response to each question.

1. On the streets you walk on, how fast does the traffic move?

[ ] very fast 1 — [ ] somewhat fast 2 — [ ] somewhat slow 3 — [ ] very slow 4

2. When you try to cross the street without a pedestrian light, how often do drivers stop their cars and let you cross the street first?

[ ] almost always 4 — [ ] usually 3 — [ ] occasionally 2 — [ ] rarely 1

3. While you are walking to the station, how often do you feel that crossing the streets is dangerous?

[ ] almost always 1 — [ ] usually 2 — [ ] occasionally 3 — [ ] rarely 4

4. On the streets you walk on, how often do you feel that crossing streets is dangerous because of fast-moving automobiles on the streets?

[ ] almost always 1 — [ ] usually 2 — [ ] occasionally 3 — [ ] rarely 4

Final Score of Walkability Component 1 (Sense of Safety in Pedestrian Crossing Affected by Traffic Speed) = (Q1 + Q2 + Q3 + Q4) * 10 / 16

Appendix 4-B. Survey Questionnaire and Score Formula for Walkability Component 2 (Sense of Safety in Pedestrian Crossing Affected by Crossing Facilities)

5. On the street you walk on, how often do you feel that having more pedestrian crossings and pedestrian light signals will make crossing the streets safer?

[ ] almost always 1 [ ] frequently 2 [ ] occasionally 3 [ ] rarely 4

6. Overall, how do you feel about crossing the streets?

[ ] very dangerous 1 [ ] slightly dangerous 2 [ ] relatively safe 3 [ ] very safe 4

Final Score of Walkability Component 2 (Sense of Safety in Pedestrian Crossing Affected by Crossing Facilities) = (Q5 + Q6) * 10 / 8

Appendix 4-C. Survey Questionnaire and Score Formula for Walkability Component 3 (Sense of Safety in Walking on the Sidewalk Affected by Traffic)

7. How often do you feel that it is still dangerous walking on the sidewalk because of cars entering driveways?

[ ] almost always 1 [ ] frequently 2 [ ] occasionally 3 [ ] rarely 4

8. How often do you feel that a fast moving car could lose control and swerve into you while you are walking on the sidewalk?

[ ] almost always 1 [ ] frequently 2 [ ] occasionally 3 [ ] rarely 4

9. How often do you feel that putting waist-high barriers between sidewalks and traffic lanes will make sidewalks safer to walk?

[ ] almost always 1 [ ] frequently 2 [ ] occasionally 3 [ ] rarely 4

10. How often do you feel some danger from moving cars on the streets while you are walking on the sidewalk?

[ ] almost always 1 [ ] frequently 2 [ ] occasionally 3 [ ] rarely 4

Final Score of Walkability Component 3 (Sense of Safety in Walking on the Sidewalk Affected by Traffic) = (Q7 + Q8 + Q9 + Q10) * 10 / 16

Appendix 4-D. Survey Questionnaire and Score Formula for Walkability Component 5 (Sense of Security Affected by Visibility at Night)

24. If you arrive at the downtown Mountain View station at 10 pm, how would you return home from the station?

[ ] walk 4	[ ] call someone for a ride 1	[ ] use bus transit 2	[ ] call a taxi 1

25. How often do you feel that walking home from the station at night is dangerous (from street crime)?

[ ] almost always 1	[ ] usually 2	[ ] occasionally 3	[ ] rarely 4

29. How often do you feel that you could be robbed while you are walking to (or from) the station?

During the daytime:	[ ] almost always 1	[ ] usually 2	[ ] occasionally 3	[ ] rarely 4
How about at night?	[ ] almost always 1	[ ] usually 2	[ ] occasionally 3	[ ] rarely 4

30. How often do you feel, if you were mugged, that someone in the nearby houses or businesses could see you and call 911?

During the daytime:	[ ] almost always 4	[ ] usually 3	[ ] occasionally 2	[ ] rarely 1
How about at night?	[ ] almost always 4	[ ] usually 3	[ ] occasionally 2	[ ] rarely 1

Final Score of Walkability Component 5 (Sense of Security Affected by Visibility at Night) = [Q24 + Q25 + (4 – (Q29A – Q29B)) + (4 – (Q30A – Q30B))] *10 / 22

Appendix 4-E. Survey Questionnaire and Score Formula for Walkability Component 6 (Sense of Security from Visual Surveillance from Nearby Buildings)

30. How often do you feel, if you were mugged, that someone in the nearby houses or businesses could see you and call 911?

During the daytime:	[ ] almost always 4	[ ] usually 3	[ ] occasionally 2	[ ] rarely 1
How about at night?	[ ] almost always 4	[ ] usually 3	[ ] occasionally 2	[ ] rarely 1

31. How often do you feel, if you lose your consciousness on the sidewalk, that someone in the nearby houses or businesses could find you immediately and come out to help you?

During the daytime:	[ ] almost always 4	[ ] usually 3	[ ] occasionally 2	[ ] rarely 1
How about at night?	[ ] almost always 4	[ ] usually 3	[ ] occasionally 2	[ ] rarely 1

Final Score of Walkability Component 6 (Sense of Security from Visual Surveillance from Nearby Buildings) = (Q29A + Q29B + Q30A + Q30B + Q31A + Q31B) * 10 / 24

Appendix 4-F. Survey Questionnaire and Score Formula for Walkability Component 7 (Sidewalk Level-of-Service & continuity)

11. How often do you have to step out of the way to avoid other pedestrians moving on the sidewalk?

[ ] almost always	[ ] frequently	[ ] occasionally	[ ] rarely
1	2	3	4

12. How often do you have to stop to avoid cars entering driveways?

[ ] almost always	[ ] usually	[ ] occasionally	[ ] rarely
1	2	3	4

13. How often do you feel uncomfortable because the sidewalk is crowded?

[ ] almost always	[ ] usually	[ ] occasionally	[ ] rarely
1	2	3	4

Final Score of Walkability Component 7 (Sidewalk Level-of-Service & continuity) = (Q11 + Q12 + Q13) * 10 / 12

Appendix 4-G. Survey Questionnaire and Score Formula for Walkability Component 8 (Buffering Negative Environmental Effects)

14. How often do you feel uncomfortable because of too much direct sunlight?

[ ] almost always	[ ] usually	[ ] occasionally	[ ] rarely
1	2	3	4

15. How often do you feel uncomfortable because of noise, fumes, or vibrations from street traffic?

[ ] almost always	[ ] frequently	[ ] occasionally	[ ] rarely
1	2	3	4

Final Score of Walkability Component 8 (Buffering Negative Environmental Effects) = (Q14 + Q15) * 10 / 8

Appendix 4-H. Survey Questionnaire and Score Formula for Walkability Component 9 (Sense of Street Scale & Enclosure)

32. How do you feel about the sizes of buildings on your route?

[ ] too big	[ ] somewhat big	[ ] I like them just way they are	[ ] somewhat small	[ ] too small
1	3	5	3	1

33. How do you feel about the building heights on the streets you walk?

[ ] too tall	[ ] somewhat tall	[ ] I like them just way they are	[ ] somewhat short	[ ] too short
1	3	5	3	1

34. How do you feel about the street width (more accurately "building to building across the street")?

[ ] too wide	[ ] somewhat wide	[ ] I like it just way it is	[ ] somewhat narrow	[ ] too narrow
1	3	5	3	1

35. On your walk to the downtown Mountain View station, how do you feel about the streetscapes?

[ ] too enclosed	[ ] somewhat enclosed	[ ] I like it just way it is	[ ] somewhat expansive	[ ] too expansive
1	3	5	3	1

Final Score of Walkability Component 9 (Sense of Street Scale & Enclosure)
= (Q32 + Q33 + Q34+ Q35) * 10 / 20

Appendix 4-I. Survey Questionnaire and Score Formula for Walkability Component 10 (Ease of Pedestrian Crossing)

16. How often do you feel that you have to wait too long at intersections to cross?

[ ] almost always	[ ] usually	[ ] occasionally	[ ] rarely
1	2	3	4

17. Overall, how do you feel about crossing streets?

[ ] very difficult	[ ] somewhat difficult	[ ] pretty easy	[ ] very easy
1	2	3	4

Final Score of Walkability Component 10 (Ease of Pedestrian Crossing)
= (Q16+ Q17) * 10 / 8

Appendix 4-J. Survey Questionnaire and Score Formula for Walkability Component 11 (Easy Access to Local Stores)

18. Along the route you walk, do you have stores or other services available for errands (either in your trip to the station or your return trip to home)?

[ ] Yes, plenty 4   [ ] Yes, enough 3   [ ] No, not enough 2   [ ] No, hardly any 1

Final Score of Walkability Component 11 (Easy Access to Local Stores)
= (Q18) * 10 / 4

Appendix 4-K. Survey Questionnaire and Score Formula for Walkability Component 12 (Visual Variety)

19. Along your route to the station, are there interesting things to see?

[ ] Yes, plenty 4   [ ] Yes, enough 3   [ ] No, not enough 2   [ ] No, hardly any 1

20. How do you feel about the streetscape you see while you walk to the station?

[ ] very dull 1   [ ] somewhat dull 2   [ ] somewhat interesting 3   [ ] very interesting 4

Final Score of Walkability Component 12 (Visual Variety) = (Q19 + Q20) * 10 / 8

Appendix 4-L. Survey Questionnaire and Score Formula for Walkability Component 13 (Visual Attractiveness)

21. How do you feel about the amount of landscaping of the streets (trees, grass, and planters) on your walk to the station?

[ ] plenty 4   [ ] enough 3   [ ] not enough 2   [ ] hardly any 1

22. Visually, how do you feel about the streetscapes you see on your walk to the station?

[ ] very attractive 4   [ ] somewhat attractive 3   [ ] unpleasant 2   [ ] ugly 1

Final Score of Walkability Component 13 (Visual Attractiveness)
= (Q21 + Q22) * 10 / 8

Appendix 5. Result of the Analysis of Variance (ANOVA) Test

ANOVA Results **North Area vs. South Area**

Path Distance

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.72	1	1.72	14.91	**0.00**
Within Groups	17.10	148	0.12		
Total	18.82	149			

Population Density

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	32.03	1	32.03	0.53	0.48
Within Groups	906.51	15	60.43		
Total	938.54	16			

Median Household Income

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	247607114.93	1	247607114.93	1.06	0.32
Within Groups	3506792454.96	15	233786163.66		
Total	3754399569.88	16			

Percentage of Asian Population

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.00	1	0.00	2.03	0.17
Within Groups	0.03	15	0.00		
Total	0.04	16			

Gender

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.05	1	0.05	0.18	0.67
Within Groups	58.30	232	0.25		
Total	58.35	233			

Composite Walkability Score

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	35.19	1	35.19	47.56	**0.00**
Within Groups	198.33	268	0.74		
Total	233.53	269			