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A Multi-~Procedural Approach to Evaluating Walkability and Pedestrian Safety

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A MULTI-PROCEDURAL APPROACH TO EVALUATING WALKABILITY AND PEDESTRIAN SAFETY

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ABSTRACT

Walking has sound health benefits and tends to be a pleasurable experience requiring no fuel, fare, license, nor registration. Whilst walking is recommended as part of physical activity, it is necessary to provide a conducive and safe walking environment. In an effort to determine an optimum combination of infrastructure that would create walkable, transit-oriented neighborhoods eliminating unnecessary motorized trips; various approaches evaluating an assortment of features in the walking environment have been implemented. However, some factors such as crash risk which have an essential contribution to the suitability of the walking environment have yet to be considered. Therefore the objective of this study was to quantify the walking environment, by developing a comprehensive walkability index which reflects the condition of the walking environment as well as pedestrians' perceptions of the walking environment. Developing the walkability index included three sub-objectives as follows:

1. Incorporate crash risk in the development of walkability indices which has not been done in previous walkability studies. An overall safety index was designed to estimate safety in the built environment in a more complete form.
2. Analyze the impact of features in the built walking environment on walking for recreational or utilitarian purposes. The analyses also determined whether sampled residents' perception of their walking facilities is comparable to the objective audit observations in various categories.
3. Identify features in the built environment that influence resident perception of their walking environment. This involved analyzing patterns and relationships between features in the walking environment and resident perceptions. Results would relate resident perceptions and walking environment features using calibrated statistical models.

The study methodology included conducting a resident survey, an audit of objectively measured features in the walking environment and a pedestrian safety analysis. The survey collected residents' perceptions of their walking environment expressed using natural language. A perception quality grade of walkability based on resident perceptions was developed from the survey data. An audit of survey neighborhoods was performed by a trained auditor using Google earth, maps, and site visits. Features in the walking environment such as driveways, signals, and crosswalks among others, were measured on a segment by segment basis. Using the various features measured on a segment, an audit quality index for walkability was developed for each neighborhood. A crash index was also developed as a function of population and commercial land use within the survey neighborhoods.

The findings of this study are expected to enhance evaluation of walking environments. The safety index incorporating crash risk and objectively measured safety elements provides a more representative indicator of safety levels within the walking environment. In addition, crash data increases objectivity to neighborhood audits depending on how audit scores are estimated. The fuzzy logic approach to estimating resident perceptions of the walking environment enables analysis of imprecise information to obtain logical output through computing with words. As such, residents' opinions which are analyzed in an approximate framework similar to the human ability to manipulate and reason with perceptions are more consistent with initial resident evaluations. With improved walkability estimation, decision makers are better equipped during planning to select appropriate strategies that encourage walking in a safe environment for recreational and utilitarian purposes.

Comparison of developed audit quality walkability indices, with and without crash data indicates significant differences in walkability indexes. Neighborhoods with initial high walkability indexes ranked much lower after crash data integration. Even without statistical significance, crash data provides more objectivity to audit quality indexes based on depending on data collection and reduction.

The study used multinomial logit to identify parameters that influence walking frequency. Results indicate that land use, and aesthetic and amenities perceptions have a significant relationship with walking frequency. This is intuitive because more varied land uses not only attract more pedestrians, but also provides opportunities for trip chaining. As expected, better aesthetics and amenities and infrastructure are associated with higher walking frequencies. Both aesthetics and amenities and land use perception were correlated with safety, directness and continuity perceptions, implying improving the perception of one category was bound to have an impact on another perception category.

The study also used mixed models to identify features in the built environment that influence the multinomial model perceptions that in turn influence walking frequency. Results from the continuity, directness, land use, aesthetics and amenities perception models are as expected. For example, neighborhoods with initial low land use perception are likely to be more sensitive to the presence of new commercial premises (e.g. small convenient store) nearby. However, directness-audit parameter serves as both a disincentive and incentive. To land use perception, increasing directness features results in uninhibited access to land uses which increases walking frequency. Conversely, increase in uninhibited access results in lower safety perception. Intuitively, enclosed communities have lower traffic flows as well as speed limits that are conducive for pedestrian activity as well as providing buffers from traffic.

Overall, results indicate the need for a transactional evaluation approach, in which pedestrian behavior is multiply influenced by environmental features, perception of the walking environment, as well as social and cultural aspects.

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Lastly, I thank my family and friends for their affection and strong support all this while. Most importantly, special thanks to my parents, siblings, niece and my late nephew for their support, encouragement, and love. This would have been a truly difficult journey without them. They have my deepest appreciation, love and respect.

DEDICATION

To my sister Ray,

for taking the first step so that l could pursue a graduate program.

To my dad, brother, niece, and nephew

for their support and understanding of my absence.

Most of all to my mom,

for her tireless support, prayers and love.

She has taught me that GOD truly does come when I call on HIM.

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CHAPTER 1

INTRODUCTION

1.1. Motivation

Walking has sound health benefits and tends to be a pleasurable experience requiring no fuel, fare, license, nor registration. According to the National Household Travel Survey (NHTS) completed in 2009, approximately 10.4% out of 392 billion annual person trips in the US were walking trips. The report also indicated that about 46% of the walking trips were for recreational, health and exercise purposes, while 43% were for school, work, personal errands, and social visits.

A lot of focus has been directed towards physical activity through the President's Physical Fitness Challenge which encourages 30 to 60 minutes a day of physical activity in adults and children respectively ("Let's Move," n.d.). For recreational purposes, the Centers for Disease Control and Prevention (CDC) recommends150 minutes of physical activity per week for health benefits (CDC, 2014). With an estimated 40 billion walking trips, facilities that are conducive for walking should be provided (Santos, McGuckin, Nakamoto, Gray, & Liss, 2011). Burden (2007) reported limited research into determining the right combination of infrastructure that would create walkable, bike-friendly, transit-oriented neighborhoods eliminating unnecessary motorized trips. He further cited criticism of roadway standards set for major roads, but inappropriately implemented in local neighborhood streets. As such, roads tend to be noisy, have high traffic volumes and speeding drivers which discourage walking. Studies have also shown that high volumes, wide streets and inappropriate driving behavior by motorist are associated with high crash frequencies (Gårder, 2004; Schneider, Ryznar, & Khattak, 2003; Zegeer, Esse, Huang, Stewart, & Lagerwey, 2004). In addition the average national pedestrian fatality rate is at 1.51 per 100,000 populations (NCSA, 2012). There have been many cases of motorists leaving the road and hitting pedestrians on sidewalks or transit shelters (Velotta, 2015). One of the more recent court cases is State vs. Ruesga, Leonardo (2015), in Las Vegas where two pedestrians were killed waiting for a bus. Much as pedestrians are encouraged to use sidewalks, the facilities seem to be just as hazardous if not more than being on the roadway. Whilst walking is recommended as part of physical activity, it is necessary to provide a conducive and safe walking environment.

1.2. Background

Many research studies have evaluated the suitability of walking facilities. The studies are varied in their foci, methodology and the variables evaluated. Basically two methods of estimating the suitability of walking facilities have emerged namely; subjective and objective studies.

Subjective studies typically based on the pedestrian's walking experience are a "convenient way to sketch actual walkability conditions" (Livi & Clifton, 2004). The survey questionnaires are presented to respondents via mail, phone, or walking interviews to collect perceptions of features in their walking environment. One of the seminal works introducing non-functional attributes into the evaluation of walking facilities was by Jane Jacobs (Ewing, 1999). Together with subjectively evaluated built environment elements, aspects such as aesthetics, comfort, sense of security and community were factored into walking environment evaluation.

Subjective studies which are prevalent in health sciences, explore the relationship between the walking experience and built environment characteristics. Self-reported perceptions of the walking environment are correlated with walking reports, to estimate the suitability of walking facilities. Though useful, low reliability has been associated with subjective measures when predicting walking behavior. Inconsistencies have been reported such as unsafe areas having higher pedestrian activity (Brown, Werner, Amburgey, & Szalay, 2007; Cho, Rodríguez, & Khattak, 2009; Clifton, Smith, & Rodriguez, 2006; Schneider et al., 2003).

Objective studies measure features in the built environment at both macro and micro-scale levels which can be replicated. The measurements are then used to assess suitability of the walking environment. Earlier walkability studies employed the Level of Service (LOS) concept originally used in transportation studies to evaluate the performance of auto-transportation facilities such as highways, arterials, major and minor roadways (Park, 2008). Burden (2007) reported that left solely to traffic engineering, neighborhood street design often reflects the interests of cars rather than pedestrian needs. The LOS method evaluates elements such as pedestrian speed, flow of pedestrian movement and density of pedestrians. Objectively measured data on infrastructure such as roadway geometry and land uses in the built walking environment can be obtained from the field, GIS, Census and local agency databases among other sources. The items measured include retail floor area ratio, land use mix and proximity of the land uses to residences, urban sprawl index, intersection and residential densities among others (Lin & Vernez, 2010).

The macro-level approach used to objectively measure items in the walking environment overlooks some functional attributes of streets such as presence, completeness and condition of sidewalks. However the micro-level approach of objective studies collects data on street attributes that are not included in macro-level studies. There are many tools and instruments developed to evaluate functional features in the walking environment such as Pedestrian Environmental Factor (PEF), Pedestrian Environment Data Scan (PEDS), Microscale Audit of

Pedestrian Streetscapes (MAPS), Minnesota-Irvine tool, and Neighborhood environment walkability scale- Abbreviated (NEWS-A). Only a few of these tools "quantify the walking environment" or "provide guidance on estimating the influence of subjectively or objectively measured features on walking"(Lin & Vernez, 2010; Moudon et al., 2006; Park, 2008). Objective studies also tend to neglect non-functional aspects of the walking environment such as sense of security and comfort (Ewing, 1999). While it is important to evaluate the impacts of functional attributes on walking, objective measures may not accurately reflect pedestrian perceptions.

Though different studies vary in their foci, the goal of walkability studies is to determine features in the walking environment that encourage walking for utilitarian and recreational purposes. Some of the basic elements associated with a walkable facility include; safety, directness-minimizing travel time, continuity - completeness of the pedestrian network and comfort - visual interests and amenities. In summary, while much work has been done in advancing evaluations of the walking environment, there still exist some limitations discussed below:

1. In an effort to identify factors that would create more walkable environments, various factors have been evaluated such as commercial, residential, and intersection densities, safety related infrastructure among others. However, none of the reviewed studies considered crash risk in walkability evaluations. Safety related infrastructure does not completely illustrate potential crash risk in the walking environment. In their study Cho et al. (2009) found that actual and perceived crash locations do not necessarily coincide. Schneider et al. (2003) reported that even safety experts have a hard time distinguishing between crash and non-crash sites. Locations of high reported, but low perceived risk indicate physical problems that pedestrians are unaware of.

2. Each study method has merits but on their own, subjective and objective studies are limited in evaluating the walking environment in its entirety. The walking decision is motivated by pedestrian perception of the walking environment. Brown et al. (2007) recommended using a transactional evaluation approach in which the pedestrian behavior is multiply influenced by environmental features, perception of the features as well as social and cultural aspects.
3. Some studies performed comparative analyses between objectively measured features and subjective evaluations (Adams et al., 2009; Brown et al., 2007; Frank et al., 2010; Hajna, Dasgupta, Halparin, & Ross, 2013; Lin & Vernez, 2010). However, there is limited guidance on estimating the influence of measured features on walking for recreational or utilitarian purposes. There are a few studies that quantify walkability but with limited generalization of procedures (Ackerson, 2005; Frank et al., 2010; Park, 2008).

1.3. Research Objectives

The objective of this study was to quantify walkability by developing a comprehensive walkability index while addressing the limitations discussed above. The comprehensive index was designed to measure the walking environment in its entirety, reflecting the condition of the walking environment as well as residents' perception of it. Developing the walkability index included three sub-objectives as follows:

1. Incorporate crash risk in the development of walkability indices which has not been done in previous walkability studies. An overall safety index was designed to estimate safety in the built environment in a more complete form.
2. Analyze the impact of features in the built walking environment on walking for recreational or utilitarian purposes. The analyses also determined whether sampled

residents' perception of their walking facilities is comparable to the objective audit observations in various categories.

3. Identify features in the built environment that influence resident perception of their walking environment. This involved analyzing patterns and relationships between features in the walking environment and resident perceptions. Results would relate resident perceptions and walking environment features using calibrated statistical models.

1.4. Study Contribution

The findings of this study are expected to enhance evaluation of walking environments. Fuzzy logic was used to analyze perceptions - which are intuitively approximate - expressed in the natural language using a linguistic framework to obtain a survey perception quality index. For consistency and comparability, it was also used to estimate the comprehensive walkability index by combining perception quality, audit quality and crash indices. Therefore, the contributions of my study are:

1. Integrating crash data with resident perceptions, and objective measured audit data to quantify walkability.
2. Using fuzzy logic linguistic approach to estimate resident perception of the walking environments.

The safety index incorporating crash risk and objectively measured safety infrastructure in fuzzy logic provides a more representative indicator of safety levels within the walking environment. With improved walkability estimation, decision makers are better equipped during planning to select appropriate strategies that encourage walking in a safe environment for recreational and utilitarian purposes.

1.5. Definitions of Key Terms

Several terms relevant to the study are defined in this section.

Walkability

There are various definitions for the term walkability as discussed in Chapter 2. For this study it is defined as the extent a facility provides safe, direct connectivity to destinations while minimizing travel time and effort as well as offering a comfortable and pleasant visual environment(Southworth, 2005).

Infrastructure

Infrastructure in this context refers to the features that are found within the built environment. The features provide means of getting from one place to another with least effort and time while providing a pleasant experience. The infrastructure features are grouped under directness, continuity, amenities and aesthetics categories described below.

Directness

Directness describes express access between an origin and destination. The elements evaluated in the category demonstrate potential for or absence of circuitous routes which increase or reduce travel time.

Continuity

Continuity refers to the uninterrupted characteristic of walking, in the provided walking environment. Elements evaluated in the continuity category demonstrate potential for an unobstructed or obstructed trip.

Amenities and aesthetics

Amenities refer to facilities or services provided to facilitate comfortable and convenient walking. Aesthetics refer to visual interests that induce appreciation of the walking environment such as articulated buildings, pleasant landscape, cleanliness, as well as presence of physical and social disorders.

Land use

Land use in this study refers to the variety of land uses found within a neighborhood's study limits.

Category scores

Category score are the aggregated global values obtained for neighborhoods in the various groups of walking environment features; such as safety score, amenities and aesthetics, directness, continuity and land use scores.

Quality index

The quality index refers to the value obtained from combining category scores. For example, from combining directness, continuity, amenities and aesthetics categories, an index representing infrastructure within a neighborhood was obtained.

Quality grade

The quality grade refers to the label assigned to the quality index to infer the quality of the walking environment in natural language

1.6. Report Organization

Chapter 1 of this document introduces the reader to background information from which the motivation and objectives of the research are borne. The report is further organized into twelve chapters, with supplemental materials in the Appendices. Chapter 2 provides a literature review of methods of measuring walkability and a summary of current practices in developing walkability indices. It also includes the a description of the overall study methodology. Chapters 3, 4 and 5 discuss the procedures followed in conducting the neighborhood survey, neighborhood audit and pedestrian safety analysis. Chapter 6 describes the methodology implemented in quantifying and evaluating walkability. Descriptive summary statistics for the survey and audit data are provided in Chapters 7 and 8. Results and discussion of pedestrian safety and walkability analyses are presented in Chapters 9 and 10. Chapter 11 presents results and discussion of the multinomial logit and perception mixed models. Finally the report ends with the Conclusions and Recommendations for future research in this area, in Chapter 12.

CHAPTER 2

LITERATURE REVIEW OVERALL STUDY METHODOLOGY

2.1. Introduction

The purpose of this chapter is to review existing methods that have been used to estimate the suitability of walking environments. Various elements that are measured in the estimating walkability are also discussed. A summary of limitations and gaps identified from the literature is provided.

2.2. Defining "Walkability"

For the purposes of this study, walkability is defined as the extent the walking environment provides safe, direct connectivity to destinations while minimizing travel time and effort, as well as offering a comfortable and pleasant visual environment (Southworth, 2005). There are various other definitions for the term walkability that sometimes evolves depending on the scope of measurement and estimation variables such as; accessibility, walking rates, residential density, network connectivity, and mixed land use. Mayne et al. (2012) defined it as the ability of the built environment to facilitate walking for various purposes. Lwin & Murayama (2011) referred to walkability as a concept which conveys how conducive the built environment is to walking. Park (2008) in his dissertation defined it as the "quality of the walking environment as perceived by the walkers and as measured by micro-level urban design attributes".

2.3. Methods of Evaluating Walkability

Measuring walkability has generally taken two approaches namely subjective and objective studies; i.e. depending on type of and how the data is collected. Subjective studies focus primarily on the pedestrian experience. Respondents' opinions on their walking environment are obtained from surveys - and used to estimate walkability. Objective studies utilize objectively measured data from the field or databases, on infrastructure such as roadway geometry and land uses in the built walking environment. The data is then used to assess walkability.

2.3.1. Subjective Studies

Subjective studies are typically based on the pedestrian's walking experience. Features in the built environment are measured subjectively by collecting respondents' perceptions of infrastructure such as street connectivity, access to and proximity of adjacent destinations, aesthetics/amenities and safety risks from traffic and crime. Capturing pedestrian perceptions is typically achieved using surveys. Questions are phrased to elicit respondent opinions on different features in their walking environment. Livi & Clifton (2004) stated that using "perception questions is a convenient way to sketch actual walkability conditions". The surveys are implemented by either mailing questionnaires to respondents, making phones calls, or interviewing pedestrian in their walking environment. Below are studies that have used subjective methods to evaluate walkability.

Kelly, Tight, Hodgson, & Page (2011) conducted three surveys in Leeds UK, designed to increase understanding of factors that influence levels of walking and pedestrian route choice. The surveys were used to assess the pedestrian environment from a pedestrian’s perspective. The first survey was a stated preference survey which was used to determine the relative influence of environmental factors identified from reviews of walkability studies. In this survey, respondents were requested to select preferred routes based on various pedestrian attributes and associated levels of Council Tax rebates. Relative weights were assigned to the attributes and aggregated to obtain a score (utility). Higher scores indicated a more suitable pedestrian walking environment. The second survey was a route-based on-street survey designed to investigate values and attitudes towards different attributes of the walking environment. Interviewers waiting at the end of a route asked respondents to rate 21 pedestrian factors on a five point scale ranging from very good (5) to very bad (1). The last survey was a walking interview designed to capture actual pedestrian experiences while respondents were walking. The interview was digitally recorded which allowed detailed discussion with real illustrations along the walking environment as well as future analyses of human-environmental interactions and body language. Results of the stated preference survey indicated pavements disorders and heavy traffic as restrictive factors for walking. The on-street survey and walking interviews suggested need for improvements in traffic safety.

Shriver (2003) used the Walkable Places Survey (WPS) to evaluate a 10-block length of Baltimore Avenue in West Philadelphia, PA. The study area comprised of some of the earliest developments in West Philadelphia, as far back as the 1850s. Survey participants representing a cross-section of professional backgrounds and community interests were divided into four groups to evaluate four study sites. After orientation, survey participants evaluated 30 WPS environmental design characteristics associated with walkable places on assigned areas while walking. Participants generated numerical evaluations on a likert scale as well as a post-occupancy analysis of their walking experience. Quantitative results were averaged across a 3 likert scale (poor, fair, good) for each of the evaluation areas. Survey participants assigned higher than average scores to buildings that were situated close to wide sidewalks along narrow streets which fostered a sense of enclosure. Some segment earned higher scores due to ongoing activities such as eating, biking which enhances street livability. Conversely, survey participants poorly rated cracked and dirty sidewalks, vacant lots, abandoned buildings, chaotic signage which detracted from visual interest, noise from cars and trolleys, inadequate public seating and marked crosswalks.

In their study, Pikora et al, (2003) identified potential environmental influences on pedestrian activity from published evidence, policy literature and interviews with Delphi experts. The authors calculated inter-quartile ranges (IQR) for items scores assigned by Delphi experts to determine agreement levels. The Delphi experts' scores were assigned based on "personal or professional convictions or guesswork in the absence of empirical walkability research". High agreement of what was important for walking was indicated by an IQR of <10. Their final model determined four categories of environmental factors that could potentially influence walking as illustrated in Figure 2-1.

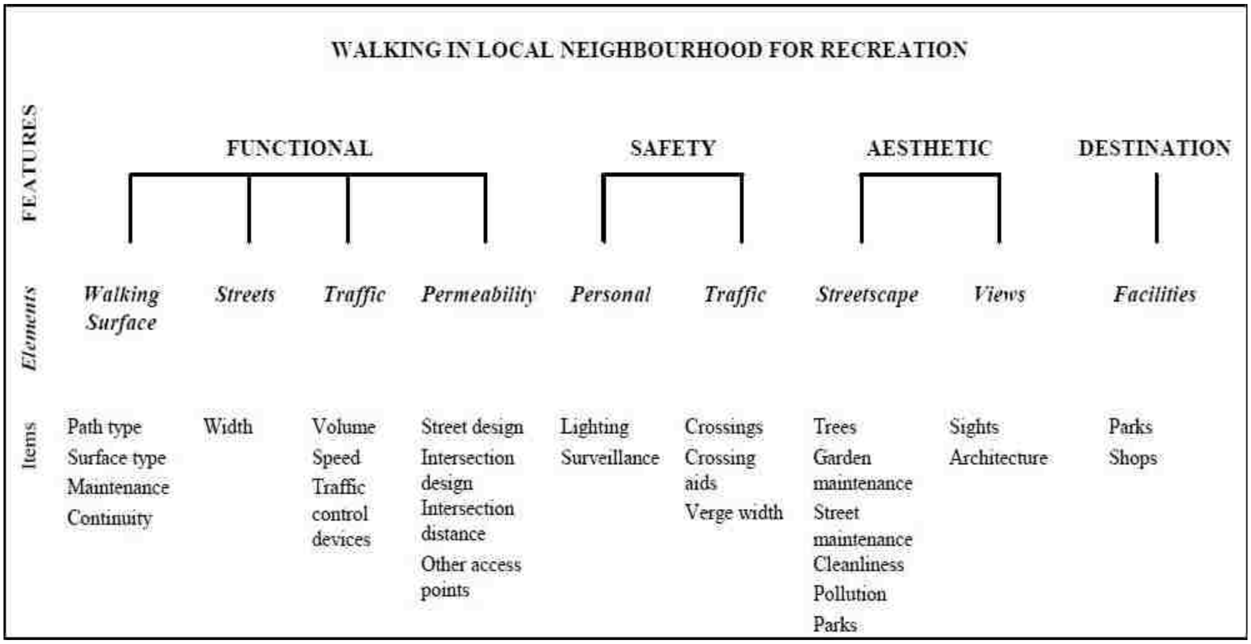


FIGURE 2-1 Final model of the physical environmental factors that may influence walking for recreation in the local neighborhood.

Functional category features comprised of elements such as path surface, maintenance, continuity, traffic operation and control devices, roadway geometry and midblock access points. The second category was comprised of traffic and personal safety features. Items in this category included lighting, surveillance, crossing aids and buffers. The third category related to aesthetics and presence of physical disorders such as maintenance and cleanliness, while the last category was land uses. Interview results highlighted issues that were important to walking in the order of personal safety, attractiveness and presence of destinations.

Limitations of subjective studies

Subjective studies have low reliability when predicting walking behavior (Brown et al., 2007; Clifton et al., 2006; Lin & Vernez, 2010; Sallis, Johnson, Calfas, Caparosa, & Nichols, 1997). In studies correlating pedestrian activity with perceptions of the walking environment, there were instances of confounding results. For example, several authors showed resident perception of safety risk conflicted with locations of actual risks (Cho et al., 2009; Schneider et al., 2003). Brown et al. (2007) cited cases of increased walking despite walking barriers such as heavy traffic and limited mixed land use.

Though surveys tend to be more convenient, methods of administration can be challenging. For example, though recent reports indicate mail surveys have higher responses rates compared to phone interviews; mail surveys are limited in having respondents recall walking conditions of sometimes large areas (Prairie Research Associates, n.d.). This can introduce inaccuracies to collected data. Interviews of pedestrians in their walking have the advantage of exposing respondents to the same walking environment in the same way (Brown et al., 2007).

As seen from the reviewed studies, there various approaches to developing walkability indices. Shriver (2003) averaged likert scores to obtain their walkability index while Pikora et al. (2003) calculated inter-quartile ranges. The process of developing of walkability indices, where various factors (weighted or un-weighted) are aggregated tends to be subjective. In addition, there are limitations in replicating perceptions from one area to another which can presents challenges in comparison across studies.

2.3.2. Objective Studies

Objective studies are conducted at both micro and macro-level scales. At macro-level scale, variables in the built environment are aggregated over large areas such as census tracts, assessor parcels and traffic analysis zones (TAZ). The impacts of aggregated built environment elements on walking for recreational or utilitarian purposes are then evaluated. Built environmental variables are often obtained from field audits, Geographic Information System (GIS) databases or in combination to examine the built environment. For example, land use types, retail floor area, and assessor acreage can be gotten from local planning agency GIS databases. Social demographic information such as household income, total population is obtained from the Topologically Integrated Geographic Encoding and Referencing (TIGER) files in the Census Bureau database. In addition, roadway geometry, pedestrian and traffic volumes used to calculate pedestrian Level of Service (LOS) can be measured from the field or obtained from agency databases.

The level of detail of information stored in agency databases influences how macro-scale objective studies quantify walkability. In most cases, street level attributes such as street furniture presenting obstructions to pedestrians, driveways and sidewalk conditions are not included. Several researchers have developed audit tools or instruments for evaluating street-level attributes of walking environments at micro-level scale. These frameworks seek to determine features in the built environment that influence pedestrians' decision to walk. Micro-level studies employ audit tools to objectively catalogue in detail, attributes of the walking environment that are not included in macro-level studies. Example of audit tools include Pedestrian Environmental Data Scan (PEDS), the abbreviated Neighborhood Environment Walkability Scale (NEWS-A) and Microscale Audit of Pedestrian Streetscapes (MAPS). Variations of these tools were used in this study are discussed further below.

The PEDS instrument was originally developed as the Systematic Pedestrian and Cycling Environmental Scan (SPACES) instrument remotely collecting data using GIS (Pikora et al. 2002). Later, the SPACES tool was adapted of to the U.S. environment, assessing street-level features in the pedestrian environment using integrated handheld technology and referred to as PEDS (Clifton et al., 2006). The instrument is designed to objectively and subjectively assess the overall quality of the cycling and walking built and natural environment by evaluating features related to pedestrian activity. These include road geometry; walking and cycling facilities as well as macro-scale factors like land use. Several studies including this study have used PEDS or variants to conduct neighborhood audits (Ackerson, 2005; Hajna et al., 2013).

More current audit instruments include NEWS-A, the abbreviated version of NEWS and the Microscale Audit of Pedestrian Streetscapes (MAPS). NEWS-A examines resident perceptions of neighborhood design features related to physical activity such as; residential density mix, accessibility and proximity of land uses, street connectivity, walking/cycling facilities, neighborhood aesthetics, traffic and crime safety, and neighborhood satisfaction (Saelens, Sallis, Black, & Chen, 2003).

MAPS tool measures built environment features such as street crossing amenities, sidewalk qualities, transit stops, street design, social features and aesthetics (Cain et al., 2014). Millstein et al. (2014) used to MAPS to examine the relationship of physical activity patterns across age groups in different locations with street-level attributes of the walking environment. Using the available MAPS scoring system, overall summary scores for routes, intersections, segments, and cul-de-sacs were obtained. The authors conducted regression analyses to analyze the impact of obtained MAPS scores on physical activity. Results indicated strong relationships between utilitarian walking/biking and land uses, streetscape, segment and intersection variables. Physical activity for recreational purposes was related to aesthetic variables. The overall summary score was related to total moderate and vigorous physical activity (MVPA) in children and older adults.

Other audit tools include the Pedestrian Environmental Factor (PEF) "a composite measure of pedestrian friendliness". The PEF developed in 1993 by planners in Oregon aggregates ease of street crossings, sidewalk continuity, street geometry, and topography. Used in the LUTRAQ project analysis, households in neighborhoods with high PEF values showed less vehicle-related travel compared to households with low PEF ("*Making the connections -A summary of the LUTRAQ project,"* 1997). Much later the Irvine Minnesota Inventory evaluating pedestrian facilities under categories of accessibility, pleasurability, perceived safety from crime and traffic risks was developed (Day, Boarnet, Alfonzo, & Forsyth, 2006). Brown et al. (2007) used a variation of the Irvine Minnesota Inventory to collect objective ratings of the environment which were combined with subjective ratings obtained from surveying pedestrians in their walking environment. Inter rater reliability tests values were used to rank route walkability as low, mixed, or high in various categories. Using the tool, trained raters verified that more walkable segments were safer, more aesthetically pleasant, had more diverse land use and pedestrian amenities. A variety of other tools and instruments for assessing the environment as well as perceptions of the environment can be found on the active living research webpage ("*Active Living Research"*, 2015).The following section highlights studies that have used various objective methods to evaluate walkability.

Peiravan, Derrible, and Ijaz (2014) developed a Pedestrian Environment Index (PEI). The PEI is zone based, mostly suited for MPOs and defined as a product of four sub-indices that capture characteristics relevant to walking. These sub-indices are land use diversity (based on the entropy concept) population density, commercial density and intersection density. The land use diversity index indicated homogeneity or heterogeneity of various land uses defined as follows.

$$LDI_i = \frac{\frac{E_i}{A_i}}{Max\,(\frac{E_j}{A_j})}, 0 \leq \ LDI_i \leq 1$$

Equation (2-1)

Where

LDI is the land-use diversity index,

j is from *1* to *n* representing areas being studied and

E_i is the entropy defined as:

$$E_i = \begin{cases} -\dfrac{\sum_{j=1}^{k}(p_j \ln(p_j))}{\ln(k_j)} & \text{for } k_j > 1 \\ 0 & \text{for } k_j = 1 \end{cases}$$

Equation (2-2)

Where

p_j is the ratio of the surface area of land-use type *j* over the total area of the study zone *i*,

k_i is the total number of different land-use types within the study zone *i*.

The population density index (PDI), illustrating a measure of community environment was defined as:

$$PDI_i = \frac{\frac{Pop_i}{A_i}}{max(\frac{Pop_j}{A_j})}, \qquad 0 \leq PDI_i \leq 1$$

Equation (2-3)

Where

Pop_i is the total population in the study zone *i*,

A_i is the area of the study zone *I*,

j is from *1* to *n* representing areas being studied.

The Commercial density index (CDI) represented destinations such as work, shopping and other trips, was defined as:

$$CDI_i = \frac{\frac{GFA_i}{A_i}}{max(\frac{GFA_j}{A_j})}, 0 \leq PDI_i \leq 1$$

Equation (2-4)

Where

GFA_i is the total Gross Floor Area of commercial establishments in the study zone i,

A_i is the area of the study zone I,

j is from 1 to n representing areas being studied.

The Intersection Density Index (IDI) indicating crossing opportunities was seen as a proxy to block size was defined as:

$$IDI_i = \frac{\sum_z \frac{N_{iz}}{A_i}}{max\left(\sum_z \frac{N_{jz}}{A_j}\right)}, 0 \leq IDI_i \leq 1$$

Equation (2-5)

Where

N_{iz} is the intersection equivalency factor for intersection z in zone i; i.e. number of links meeting at node z,

A_i is the area of zone i,

j is from 1 to n representing areas being studied.

The PEI combining the above indices was defined as:

$$PEI_i = \frac{1}{16}\ (1+LDI_i) * (1+PDI_i) * (1+CDI_i) * (1+IDI_i)\ ,$$

Equation (2-6)

Where LDI_i , PDI_i, CDI_i, and IDI_i for zone i are as earlier defined above.

The index is a product rather than the typical sum, based on the rationale that factors affecting the pedestrian walking environment "have cause-and-effect or non-linear feedback impacts on each other – i.e., a change in one factor can result in changes in the other factors"(Peiravian, Derrible, & Ijaz, 2014).

Allan, (2001) developed walking permeability indices as a principal form of analysis to evaluate how utilitarian walking was catered for in the City of Adelaide and others in Australia. Walking Permeability Distance Index (WPDI) index that determined the level of walking facilitated in urban areas. WPDI was developed on the rationale that pedestrians do not have the time or endurance to walk unnecessarily, and expressed as:

$$WPDI = \frac{AD}{DD} \qquad \text{Equation (2-7)}$$

Where

AD = Actual Distance by most practical route

DD = Direct Distance between origin and destination

In locations without a dedicated pedestrian network, where pedestrians share the road network with other transport modes, the Walking Permeability Time Index (WPTI) was used to determine how accessible destination are for pedestrians. In restricted pedestrian networks, distance maybe insignificant if there are inadequate crossing opportunities as well as long delays at pedestrian crossings locations. The Walking Permeability Time Index is expressed as:

$$WPTI = \frac{ADT}{DDT}$$ Equation (2-8)

Where

ADT = Actual distance in time

DDT = Direct Distance in time

A WPDI value of 1 indicated sufficient permeability and 1.5 set as the limit of accessibility. A WPTI index of 2 was set as the practical limit of pedestrian accessibility. Study results showed mixed land uses provided opportunities for walking as a mode of transport. Large numbers of intersections as well as circuitous routes resulted in higher WPDI and WPDI values.

Kuzmyak, et al. (2006) with the Baltimore Metropolitan Council (BMC) undertook an effort to advance incorporation of land use considerations in the regional transportation planning process. In the study, walking opportunities were explored given the influence of local and regional accessibility on rates of vehicle ownership and vehicle miles traveled (VMT). The data used for analyses included parcel land use data, 2000 Census data as well as 1-day travel diaries, employer data and the BMC's traffic analysis zones (TAZs). Using the disaggregate travel survey data, walkability for individual households was estimated as a function of intersections per acre using a GIS and calculated as:

$$Walkability = \sum_{i=1}^{n} I_i$$ Equation (2-9)

Where

I_i is ½ for three-way intersections, ½ for four-way intersections involving a principal roadway (major arterial or freeway), and 1 for four-way intersections without a principal roadway,

n is the number of intersections within a 0.25-mi radius of the household.

Though not originally planned, determination of origins and destination for walking trips was incorporated into the study which resulted into the walking opportunities index. Using GIS, the distance of walking opportunities within the 0.25-mi buffer was calculated reducing each walking opportunity by the calculated distance as follows:

$$\text{Walk opportunity} = \sum_{O_i}^{O_n} \frac{W_i * S_i}{D_i}$$

Equation (2-10)

Where

O_i = opportunity within 0.25-mi of a household;

W_i = importance weight for opportunity;

S_i = size factor, where small = 1, medium = 2, large = 3;

D_i = distance from household to opportunity

Travel behavior represented as VMT was estimated as function of socioeconomic characteristics, regional accessibility, and local accessibility. Study results indicated more walking at households adjacent to a more varied land use mix and better accessibility. Results also indicated that greater regional accessibility and high land use mix afforded more walking opportunities resulting from reduced vehicle ownership. In addition, results suggested that mixing commercial and residential parcels as well as good regional transit connections would serve to manage VMT growth and reduce demand for new capacity.

In urban studies, Frank et al., 2010 developed a walkability index as a function of residential density, intersection density, retail Floor Area Ratio (FAR) and land use or entropy score. The net residential density indicated how compressed origins and destinations were which resulted into more non-auto trips. Higher densities are also synonymous with more interesting street life and security for pedestrians (Cervero & Kockelman, 1997). A higher intersection density was indicative of a variety of route options. The entropy score or Shanon index represented the diversity of land uses within a particular area. Retail floor area ratio was included as an important predictor of walking and pedestrian oriented design. Using GIS, the variables were obtained from parcel-based land use data and street centerline shape files. The walkability index was obtained by summing the variables that were standardized using a z-score. Summing was done on the basis that "combining the variables represented walkability as well as explaining travel behavior" as expressed below (Frank et al., 2010).

$$\text{Walkability} = 2(z\text{-intersection density}) + (z\text{-residential density}) + (z\text{-retail FAR}) + (z\text{-land use})$$

Equation (2-11)

Walkability indices ranged between values of -2.7 and 9.2 indicating poor and good walking environments respectively. Several other studies have used GIS as well as the same procedure to quantify walkability in various regions (Coughenour, Pharr, & Gerstenberger, 2014; Dobesova & Krivka, 2012; Lemon, 2012; Stevens, 2005).

Limitations of objective studies

Aggregated features measured in objective studies overlooks non-functional attributes of the walking environment such as sense of security and community. Further, the input of pedestrians who use the walking environment being measured is not included. In summary, while it is important to evaluate the impacts of urban features on walking, objectively measured features may not accurately reflect some characteristics that impact pedestrian perceptions of their walking environment.

2.3.3. Combined Studies

Due to the limitation of individual objective and subjective methods for quantifying walkability, several studies combine perception surveys with objectively measured data of features in the walking environment to obtain a comprehensive walkability index. A common approach in studies combining objective and subjective measures is performing comparisons between the objective and subjective results.

Adams et al. (2009) in an effort to validate their Neighborhood Environment Walkability Scale (NEWS) survey tool compared it to GIS objectively measured items within a 1-mile street network buffer around survey participants' residences. Survey questions posed to respondents were categorized into accessibility to various land uses, diversity of the land uses, aesthetics, and safety from traffic and crime variables. Survey participants rated the questions on a four point likert scale ranging strongly agree to strongly disagree which were averaged in each category to obtain an index. Corresponding survey items available in GIS were estimated as counts and proportions. Correlation tests were performed between NEWS survey items and corresponding

GIS variables. On most items, significant weak to moderate concordance was obtained indicating agreement of subjectively measured items with objectively measured items.

In a similar study, Hajna et al. (2013) used GIS to obtain land-use mix, street connectivity, and residential density data. The threes GIS-derived variables were summed to obtain a walkability index. The audit walkability index ranged between 0.3 and 0.71; higher index scores indicating better walkability. The researchers also conducted neighborhood audits using a modified PEDS instrument as well surveys collection pedestrian perceptions using a self-administered questionnaire. The survey walkability score was between 0.15 and 1.00. A Pearson correlation of 0.97 value indicated high inter-rater agreement in the audit-based assessments. Relationships between calculated audit, GIS, and survey indices were analyzed using Spearman correlation coefficients. Their findings determined no correlation between pedestrian perceptions and objectively measured audit and GIS indices. Conversely, there was correlation between audit and GIS-derived walkability indices implying it was reasonable to use GIS-derived measures in place of more labor-intensive audits. Maghelal & Capp (2011) reviewed various walkability studies and developed indices and provided parallel measures in GIS that can be used in place of audit objectively measured variables.

Ackerson (2005) conducted a survey of middle school students together with a micro- as well as macro-scale analysis of neighborhood walkability and pedestrian safety. The micro-scale analysis was an audit performed using the PEDS walkability audit instrument collecting 78 measures of street walkability. The data was categorized using Pikora et al.'s (2003) Delphi study's model to identify audit items that were related to safety for further analysis. Using Lee and Moudon's (2003) Behavioral Model of Environments (BME), the identified items were further evaluated to ensure the human interaction with spatiophysical, spatiobehavioral, and spatiopsychosocial characteristics of the built environment was met. The walking locations were then rated using identified audit items which enabled survey of walking routes to school. The survey responses were used for comparisons between potential pedestrian routes with actual routes taken. Using GIS software, shortest and most walkable routes from home to school were compared. GIS was also used to evaluate the spatial distribution of land-use types, street and intersection densities and characteristics. Five parameters including comparisons of intersection characteristics and densities, road classifications, land-uses, walkability safety ratings, and student routes were used as indicators of walkability in the study (Ackerson, 2005).

Park (2008) conducted two surveys as well as developing an audit instrument with which he used to audit street segments near his study sites (transit stations). Walkability indicators from the audit were aggregated and summarized into path walkability indicators. In the station user survey, mail-back self-administered questionnaires were distributed to transit users at the station gates, collecting access mode choices, trip origins, and socio-economic data. The on-board perception survey requested transit users to score their walking routes. Using factor analysis and multiple regression models, a composite walkability index was obtained by correlating survey participants' perceptions with objectively measured street attributes of reported routes to the station. Reported importance of walkability items was proportionately used to weigh the given walkability items in the overall model as shown in Table 2-1 below. Model testing revealed heavy clustering of composite walkability scores between 5 and 10. The model was mathematically rescaled using the formula: (X-4)*10/6, where X is the unscaled composite walkability score.

TABLE 2-1 Final Formulas for Composite Path Walkability Index (Park, 2008)

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))]

Limitations of studies combining objective and subjective measures

Review of past studies that combined objective and subjective methods showed generalization limitations. In Ackerson’s (2005) study, the streets were rated amongst themselves “in absence of established rating standard for this type of analysis”. Park (2008) reported limited generalizability as one of the drawbacks to conducting a single-station survey in his study.

2.4. Summary

Lin & Vernez (2010) reported that objective measures of the built environment were more strongly associated with walking compared to subjective measures. However, as evidenced in the literature, each method on its own is limited in quantifying walkability in its entirety. The walking decision is motivated by pedestrian perception of the walking environment. Pikora et al. (2003) recommended adopting "a social ecological model" while Brown et al. (2007) recommended a "transactional approach" where pedestrian behavior is multiply influenced by the physical environment and psychological experiences". When both subjective and objective approaches are combined, there's a higher likelihood of accurately estimating the suitability of the walking environment.

Some of the typical elements measured in walking environment evaluations include population density, land use diversity, permeability, and safety infrastructure. There was no study that included crash risk in walkability evaluation. The few studies found relating actual and perceived crash risk to the walking environment reported that locations with police-reported crashes were not perceived as dangerous by pedestrians or drivers. Conversely, there were locations which were perceived as dangerous though no pedestrian crashes had occurred (Schneider et al., 2003). In their results Cho et al. (2009) determined that locations with more crashes were associated with increased perceived crash risk, which is intuitive. However higher perceived crash risk was negatively associated to actual crash rates. The authors contemplated that pedestrians modified their behaviors to avoid exposures to high-perceived risk areas, or exercised increased caution and alertness when in these areas. Locations of high reported but low perceived risk indicates physical problems that pedestrians are unaware of (Schneider et al., 2003).

Apart from a lack of consensus on variables to be measured, the handfuls of studies that do quantify walkability employ different methods to calculate walkability indices. The PEI walkability index developed by Periavian et al. (2014) was a product of four variables. Frank et al. (2010) weighted and added standardized scores of their four variables to estimate walkability. In several audit instruments such as PEDS and MAPS, weighed and unweighted factors are combined with the inter-rater reliability scores and used in estimating walkability (Cain et al., 2014; Clifton et al., 2006). Park (2008) used factor and regression analyses as well as weighting to obtain his comprehensive walkability index. With so many varied approaches to quantifying walkability, comparison across studies can be a challenge.

2.5. Overall Study Methodology

This Section describes the overall study procedure as illustrated in Figure 2-2 below. The methodology included conducting a survey and an audit, performing pedestrian safety analysis followed by calculation of survey and infrastructure quality indices, audit safety index, overall audit and perception walkability indices as well as the comprehensive walkability index.

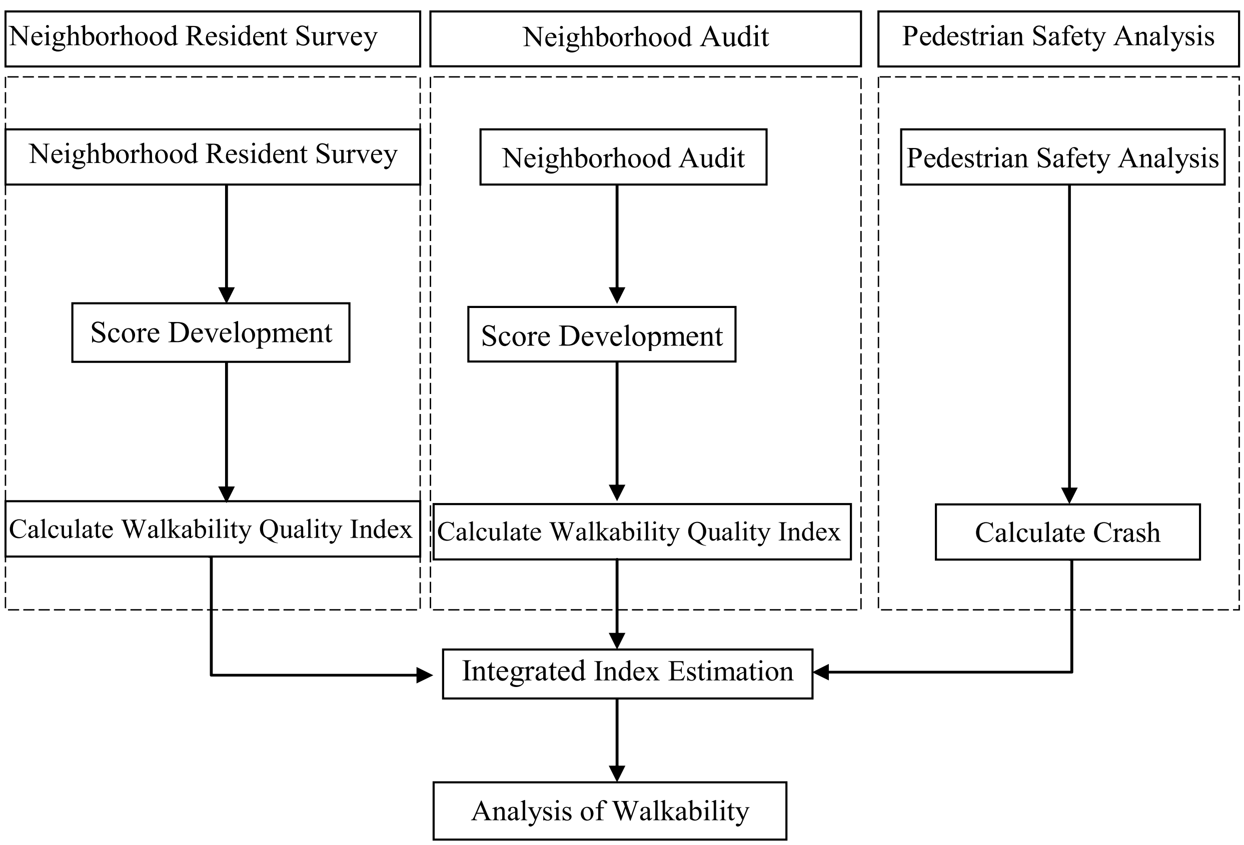


FIGURE 2-2 Overall study methodology.

The objective of the resident survey was to explore resident perceptions and concerns on different aspects of their walking environments including safety, access, land use and convenience. Written questionnaires are presented online, by mail, or dropped off to a randomly selected sample of community residents in different neighborhoods. Survey responses were then used to determine the suitability of the walking environment in the score development step. Walkability indices from the perception data were developed and used to estimate the integrated index as well as further analyses.

The audit was performed using selected walkability audit instruments to estimate walkability as functions of land use characteristics, infrastructure, street design and traffic operational parameters. The audit is performed in the same neighborhoods selected in the survey. The same procedure used to calculate indices in the survey was used to obtain indices for safety, land use, directness, continuity, amenities and aesthetics.

A crash index was developed in the same selected neighborhoods as the survey/audit using crash data, assessor parcel area data and US Census Bureau population data. The pedestrian safety analysis evaluated impacts of various elements of roadway geometry, traffic controls and operations on pedestrian safety. Patterns and relationships are identified between different roadway elements and the obtained index.

The indices from the survey, audit, and pedestrian safety analyses were integrated in the index estimation step. Walkability analyses were performed using the developed scores and the indices. Statistical models were calibrated to identify relationships between perceptions and audit observations. Further, the relative influence of audit elements on resident perception was estimated.

CHAPTER 3

RESIDENT SURVEY METHODOLOGY

3.1. Introduction

In this section the procedures followed to conduct the survey are described. The methodology includes designing the survey instrument, sampling procedure, implementation of the survey, data compilation, and score development. Figure 3-1 below illustrates the procedure followed.

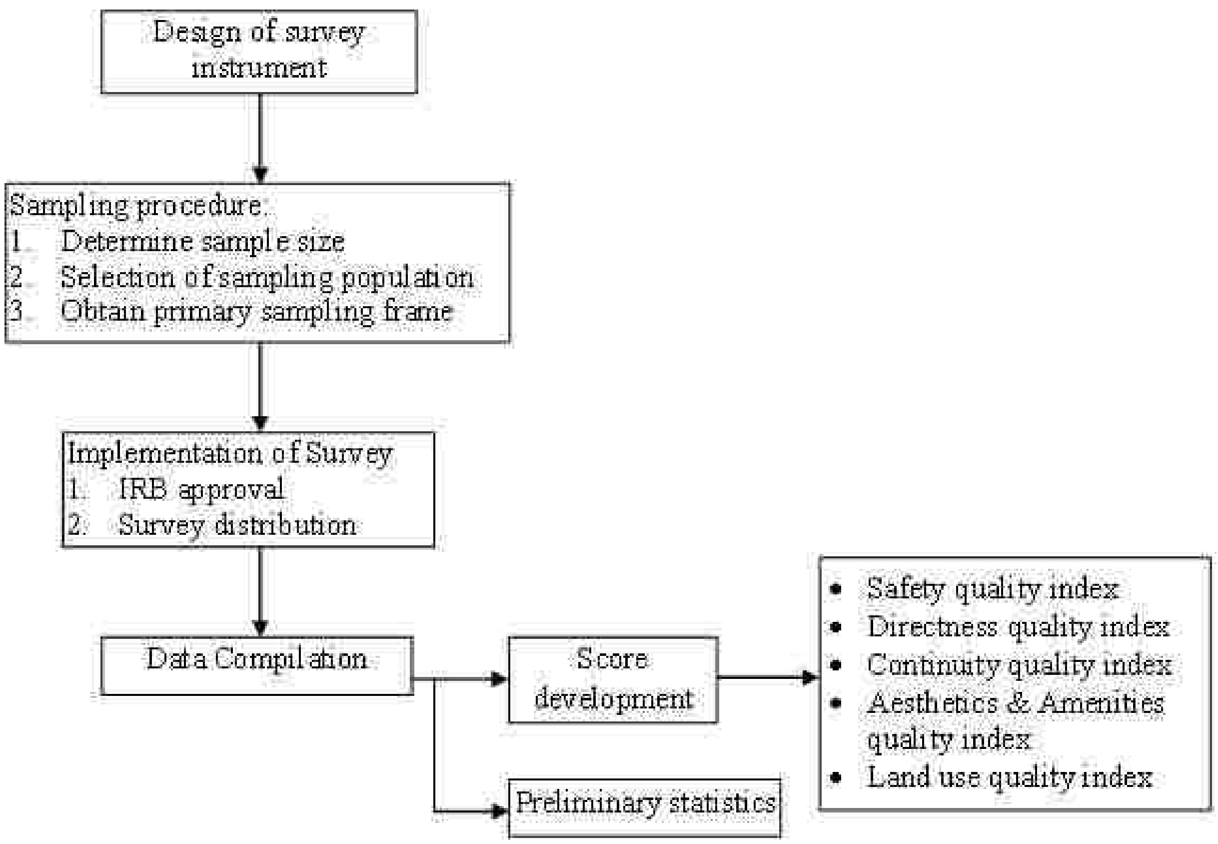


FIGURE 3-1 Resident survey methodology.

The objective of the survey was to explore resident perceptions and concerns on different aspects of their walking environments such as safety, access and convenience. Including pedestrian perceptions, recommendations that would prompt increased pedestrian activity for both utilitarian and recreational purposes were collected.

3.2. Survey Design

The survey data was organized into seven sections namely;

1. Reasons For Walking,
2. Land uses Within 15-Minute Walk Of Residences,
3. Directness,
4. Continuity,
5. Aesthetics/Amenities,
6. Safety
7. Socio Demographic Information.

Questions used to design the survey tool were based off the Microscale Audit of Pedestrian Streetscapes (MAPS) and Neighborhood environment walkability scale- Abbreviated (NEWS-A) instruments (Cain et al., 2014; Sallis, 2014). A complete survey is attached in Appendix I.

Likert responses with a four category scale were used to determine resident accord with given survey statements. The four response scale indicated level of agreement from strongly agree, somewhat agree, somewhat disagree and strongly disagree. A neutral or midpoint category was not offered. Studies have shown that a neutral option can introduce unreliability when respondents are trying to be overly helpful or otherwise (Garland, 1991). In addition, presenting a neutral category provided opportunities for respondents not answer questions. In his study, Ducharme (2014) noted that neutral options added no value to the respondent when assessing individual preferences or attitudes. Further, he showed that a likert forced choice was warranted if it was reasonable to assume that respondents should have an opinion and be familiar with the topic. This being where respondents resided, it was safe to assume that residents were familiar with and had an opinion on their neighborhoods regardless of whether they walked or not. This approach reduced the possibility of introducing bias towards the neutral category. Moreover, the somewhat agree and somewhat disagree categories accommodated respondents who were unsure of their experiences and therefore wouldn't fit either responses.

3.3. Survey Sampling

Initially, a sample size of 2000 households was to be surveyed, based on budget limitations. However 287 surveys were mailed out due to limited access to some neighborhoods, while 1740 surveys were delivered to residences resulting in total sample of 2027.

The sampling population was limited to the Las Vegas valley from which a representative cross section was selected. The primary sampling frame was derived from the United States Census Bureau TIGER/Line data comprising of Community Survey (ACS) 5-Year estimates and 2010 Census shape files (U.S. Census Bureau, 2015). The shape files consisted of demographic and economic data aggregated over census tracts and block groups for confidentiality purposes. Census tracts and block groups are units of analysis designed by the census bureau consisting of between 1,500-8,000 and 600-3000 people respectively (Iceland & Steinmetz, 2003). These tracts represent neighborhoods which are relatively homogeneous with respect to population characteristics, economic status, and living conditions.

There were 501 census tracts sorted into Henderson, Clark County, City of Las Vegas and City of North Las Vegas jurisdictions within the Las Vegas valley. Income data obtained from the Census Bureau was used to stratify the census tracts into 5 income groups according to the Census bureau estimates as shown below (Elwell, 2014; Francis, 2012):

Poverty → ≤ $20,592

Working class → $20,593 ≤ X ≤ $39,735

Lower-middle class → $39,736 ≤ X ≤ $64,553

Upper-middle-class → $64,554≤ X ≤ $104,086

Upper class→ ≥ $191,150

Due to cost and time limitation, 11 census tracts, 2 tracts representing a strata (income group) were selected randomly from the 4 jurisdictions with 200 sample size each. Statistically, larger sample sizes result in smaller sampling errors. Similarly, homogenous clusters generate smaller sampling errors compared to heterogeneous populations (Babbie, 1973). A stratified sampling design was adopted.

3.4. Survey Implementation

The survey fell under social behavioral research involving human research subjects and therefore required prior approval from the Institutional Review Board (IRB) with the Office of Research Integrity – Human subjects. After designing the survey instrument the UNLV-IRB reviewed the instrument to ensure compliance with federal regulations.

Various survey methods are associated with better responses or deemed more successful than others. For example, Brown et al. (2007) reported that walking interviews had advantage of collecting respondents' perceptions in an identical walking space and time frame. For this study, the survey was self-administered both manually and online - hosted by QUALTRICS (Qualtrics, Provo, UT, 2015). The survey questionnaires, in English and Spanish contained links through which respondents could fill out the survey electronically. The survey package consisted of self-addressed stamped envelope and the survey which was delivered to residents' doors-and mailed back to the Civil engineering department office. For two of selected high income neighborhoods, survey packages were mailed due to limited resident access. Compiled addresses for the two locations represented a secondary sampling frame. For respondents who filled out the survey online, responses were saved on the QUALTRICS website. Figure 3-2 below illustrates the selected neighborhoods, to which the survey was distributed.

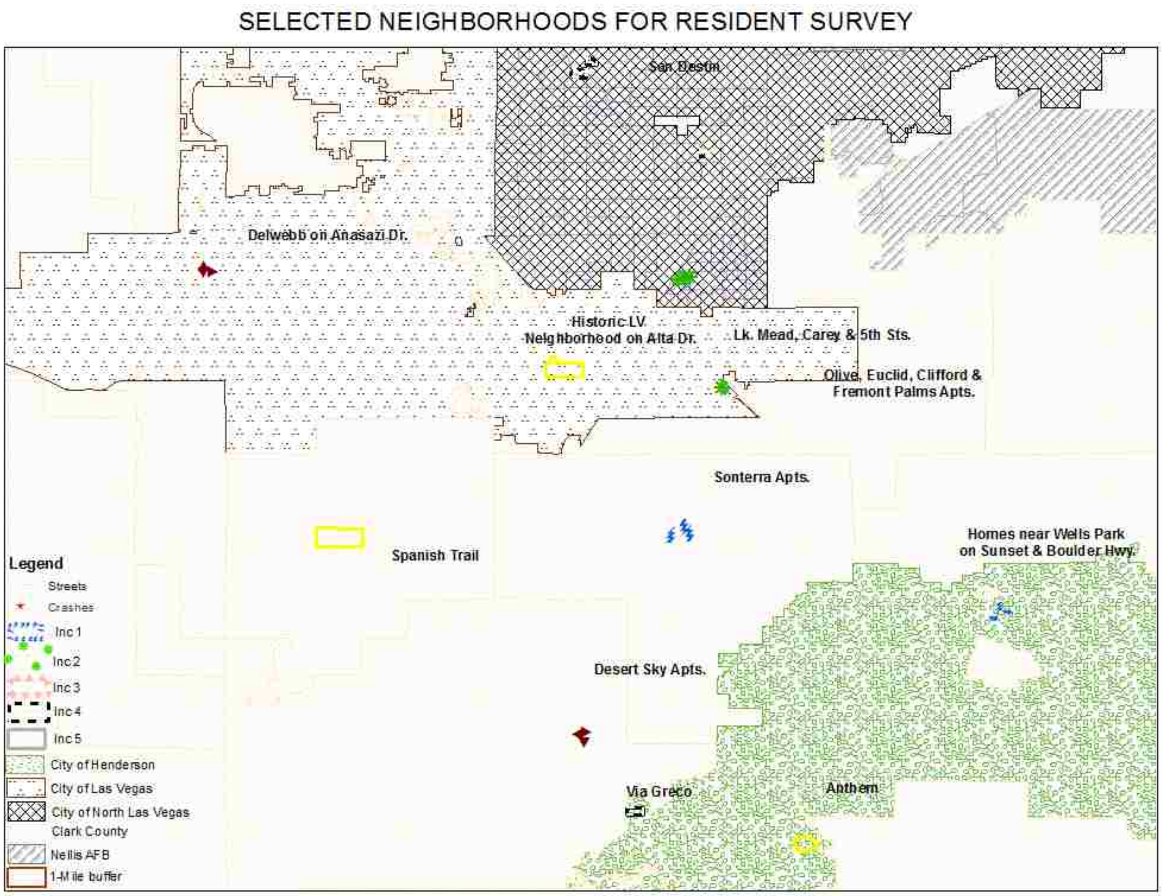


FIGURE 3-2 Neighborhoods in selected census tracts for resident survey.

3.5. Data Compilation and Score Development

Mailed back responses were manually coded onto a spreadsheet. Online responses were downloaded on a spreadsheet and combined with mailed back responses. The data was collapsed from four likert responses to three responses for ease of analysis. The "somewhat agree" and "somewhat disagree" categories containing elements of agreement and disagreement, were combined into a new category called “a bit of both”.

The three categories; strongly agree, a bit of agree and disagree, and strongly disagree were assigned weights 3, 2, and 1, in order of declining agreement respectively. The perception for each category was taken as the average of residents' agreement for each neighborhood. Upper and lower thresholds threshold scales were developed from the best and worst case scenarios; within which a category score was measured against. The best case was obtained when respondents strongly agreed to having all favorable elements in a category that promoted walking. Conversely, the worst case was where residents reported presence of elements in a category that detracted from walking. The category scores and scales obtained from the best and worst cases were standardized between zero and one as illustrated below, Figure 3- 3 and used for further analyses.

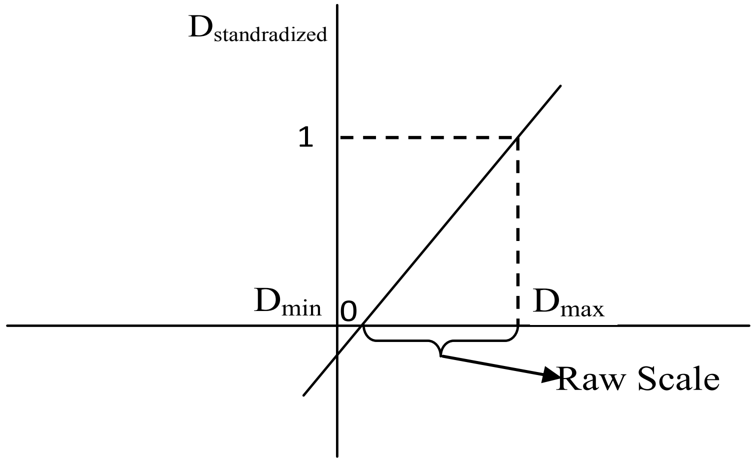


FIGURE 3-3 Unit standardization of perception scores.

The category scores were assigned quality grades using labels on a four point scale to determine the suitability of the walking environment in each neighborhood as described below.

Quality grade A - Very good walking facilities.

Quality grade B - Walking facilities are pretty good.

Quality grade C - Walking facilities are fine, but needs work.

Quality grade D - Walking facilities need immediate attention

CHAPTER 4

AUDIT METHODOLOGY

4.1. Introduction

In this section the procedure followed to design and conduct the audit is outlined. The methodology involved design of audit instruments, implementation of the audit, data compilation and reduction and score development. The audit was performed in the neighborhoods that were selected in the survey. Figure 4- 1 below illustrates the procedure followed.

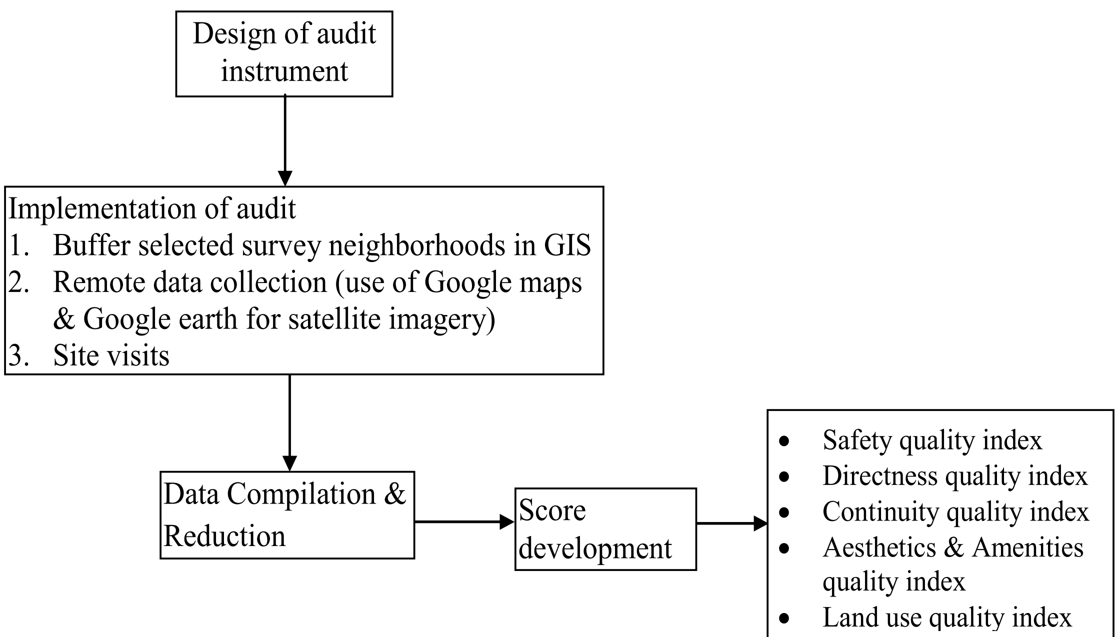


FIGURE 4- 1 Audit methodology.

4.2. Design of Audit Instrument

The objective of the audit was to collect data on features in the built environment that influence walking that could be objectively measured. Similar to the survey, the audit instrument was designed based of questions from the MAPS and the Pedestrian Environment Data Scan (PEDS) (Cain et al., 2014; Clifton, Livi Smith, & Rodriguez, 2007; Sallis, 2014). The features are grouped into five categories closely resembling survey categories to enable comparable analyses. The built environment features measured, are discussed as follows:

1. Land uses
2. Directness
3. Continuity
4. Safety
5. Aesthetics/amenities

4.3. Audit Sampling

The audit was performed in the same randomly selected neighborhoods as the survey, see section 3.3. In the survey, respondents were asked to highlight different land uses within a 15minute walk of their residences. Studies have shown that pedestrians are typically willing to walk 10 to15-minutes to access transit (APTA, 2010). A 15-minute buffer translated to a 0.682 mile buffer in radius using a walking speed of 4 feet per second as shown in Equation (4-1) (USDOT, 2003).

$$(15\ min)*(60\ secs/min)*(4\ ft./sec)*(1/5280\ miles/ft.) = 0.682\ miles$$

Equation (4-1)

The 4 feet per second walking speed accommodates the lower percentage of populations with walking difficulties, though some findings support elderly pedestrian walking speeds of 2.5 to 3.25 feet/sec (Knoblauch, Pietrucha, and Nitzburg, 1997). A 1-mile buffer around each neighborhood was used to determine the limits for the audit. Buffer areas that intersect freeways were reduced by eliminating areas that crossed freeways, parallel to discouraging pedestrians from crossing freeways. Figure 4-2 below illustrates the buffered selected neighborhoods for the audit.

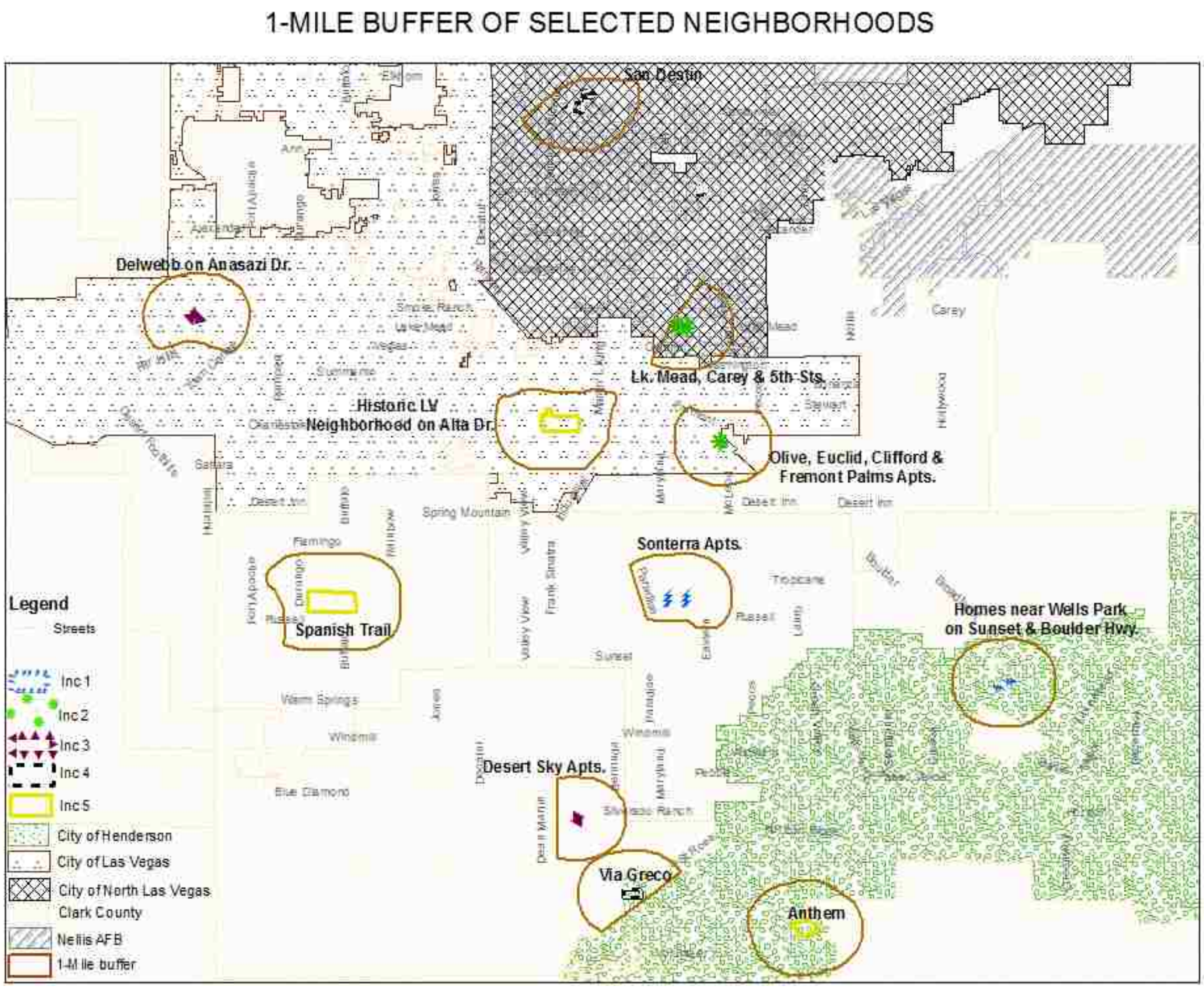


FIGURE 4-2 Buffered neighborhoods for audit.

4.4. Audit Implementation

The audit was conducted remotely using satellite imagery tools such as Google earth and Google maps street view. This was due to limited access to two of the high income neighborhoods whose surveys were mailed out (Anthem, Spanish Trail). As such, all neighborhoods were audited in a comparable manner. Site visits for confirmation of audit parameters were performed where possible. The audit data was collected by roadway segments varying between 0.1 miles to 0.75miles. Segment data was catalogued under the following categories described below. A spreadsheet of the audit instrument is attached in Appendix II.

4.4.1. Land Uses

Land use mix was estimated as a proportion of land uses found within a neighborhood out of a selected group of typical land uses that attract walking trips. For comparability, survey land uses were used as the ideal balance of land uses attracting walking trips. Among others, these included stores, recreational facilities, office buildings, bus stops, clinics, and banks. Clark County Assessor's parcel area data was used to determine land uses that were within a 0.75 mile buffer of selected neighborhoods. A smaller buffer of 0.75miles, instead of 1 mile was used to account for time taken at pedestrian and traffic signal stops.

4.4.2. Directness

Under directness, the information collected was used to evaluate convenience of getting around within the neighborhood. Information catalogued on each segment included presence of gated or walled communities, street gradients and Floor Area Ratio (FAR). To catalogue neighborhood enclosure, the number of gated or walled communities on each audited segment was counted. This indicated how far residents travel to get to their destinations; implying longer distances if there were many enclosed properties on a segment. Steepness of the sidewalk was coded as zero, one and two; for flat sidewalks, slightly hilly sidewalks and hilly sidewalks respectively. A sidewalk was considered flat if there is no noticeable gradient. Clifton et al. (2007) described flat sidewalks as those where a stroller wouldn't roll downhill if left unlocked on it. A slightly hilly segment had a discernible gentle slope but pedestrians could still walk with ease. Hilly segments had steep gradients which made walking difficult.

Distance travelled between origin and destination on commercial parcels was estimated in terms of FAR. Commercial parcels data from the Clark County Assessor parcel database was used to determine the distance between parcel limits and actual building footprint. A bigger ratio between parcel area and actual building square footage indicated a shorter distance traveled to access premises. A smaller ratio implied large parking lots on the premises hindering quick access to the buildings.

4.4.3. Continuity

Elements evaluated in the continuity category demonstrated potential for an unobstructed or obstructed trip. Intersection density indicating distance walked to cross streets was catalogued by counting the number of intersections within a one mile buffer of a neighborhood. Obstructions indicate the ease or lack thereof, of facility access for all pedestrians. Types and quantity of obstructions were counted on each segment. The presence of sidewalks was coded as 0 and 1 for segments with and without sidewalks respectively, on both sides of the street. The average sidewalk width was coded as 1 and 2, for sidewalks that were at least five feet wide and those wider than five feet respectively. The completeness of the sidewalks was also evaluated and coded as 0 or 1 for segments with incomplete sidewalks or sidewalk breaks on both sides of a segment. Segments that had dead-ends were coded as 1 and those without were coded as zero. The number of driveways on a segment was counted and catalogued as well.

4.4.4. Safety

In the safety category, infrastructure that facilitates safe interaction between pedestrians and traffic in the walking environment was catalogued. Intersection geometry was catalogued on each segment which included associated left and right turn operations and curb ramps. Right turning lanes that are channelized were also counted as exclusive right turn lanes. The presence of pedestrian signs, signals, crosswalks, chokers, traffic circles, stop signs and curb ramps was catalogued by indicating how many were found on each segment.

Segments with traffic calming measures such as bike lanes, street parking, school and emergency zones, were catalogued by coding 0 and 1 for segments with and without the mentioned elements respectively. In Las Vegas, bike lanes can share right-of-way with vehicles with three feet separation as well as have a dedicated lane as part of the right-of-way. Bike lanes and street parking tend to lower speed limit by reducing street capacity as well as providing separation between traffic and pedestrians.

Segments with raised medians or median alerts as well as buffers were coded as 0, and 1 for those lacking raised medians and buffers. Medians are strips of land in the middle of the road separating opposing traffic movements while buffers are areas that separates pedestrians on sidewalks and traffic on the road. The medians can be reserved lanes serving as two-way left-turn lanes, or raised medians with inset trees which can serve as refuge islands allowing pedestrians to cross one direction of traffic at a time. The posted speed limit and number of lanes on a segment were catalogued as identified on a segment. The residential streets speed limit whether posted or not is set at 25mph (ClarkCounty, 2012). Direction of traffic movement was coded as one and two for one-way and two-way traffic respectively. Though there are merits to both one and two-way streets, pedestrians' exposure to traffic in both directions are higher compared to one-way streets. Higher speeds are considered unfavorable for pedestrian activity. Lastly, under safety features, segments with street lighting were coded as one while those without were coded as zero.

4.4.5. Amenities and Aesthetics

Aesthetics includes attractiveness of the streetscape, diverse and articulate views which tend to be rather subjective. Segments evaluated for aesthetics and amenities were catalogued by coding 1 for segments having indicated amenities and 0 if none were present. The segments were also coded 1 if there was evidence of indicated physical and social disorders and 0 if none were present. Segments considered to have at least 25% to 75% of the street shaded either by trees or building abutments are coded as 1, 2 for 75% of segment shaded and 0 if less than 25% of the segment was shaded. The sidewalk condition was graded between 1 and 3 representing poor, fair and good sidewalk condition respectively.

4.5. Data Compilation and Reduction and Score Development

The collected data was summarized by estimating proportions within each neighborhood for each feature such that it is more useful and informative. Multiple aggregation and subjective weighting which is classified into several tiers was performed on the data in an adhoc framework developed for this study. The weights had positive or negative valences depending on the influence of the item to pedestrian walkability. The resulting category score was obtained as expressed below, Equation (4-2).

$D_i = \Sigma W_j X_j$ Equation (4-2)

Where

W_j is a subjectively assigned weight controlling the influence of each element with respect to how the data is collected and aggregated.

X_j is an element in a category and D_i represents a resulting summed and weighted category score.

Table 4-1 provides an illustration of the procedure used to develop category scores for three segments in a neighborhood. The upper and lower thresholds for the scales were developed from the best and worst case scenarios within which a category score was evaluated against, similar to the perception data. The best case was obtained when a neighborhood had all category features that promote walking in excellent condition. Conversely, the worst case was where elements in a category that detract from walking were prevalent. Audit category scores and scales were standardized as illustrated in Figure 3-3. Audit quality grades were assigned on a four point scale to determine the suitability of the walking environment in each neighborhood as described in Section 3.5. The audit data was used for index estimation and statistical modeling as described in the following Chapters.

TABLE 4-1 Illustration of Compilation and Score Development for Safety Category

Category	Item	Segment Name			Proportion	Weights	Score
		Seg 1	Seg 2	Seg 3			
Safety	Segment Length	0.48	0.39	0.43	1.3		
	Total Segments				3		
	No. of Traffic Controls						
	Traffic Signal	3	2	2	5.4	2	
	Dedicated turning arrow (protected lefts)	6	4	4	10.8	1	
	Exclusive right turn		1		0.8	-1	
	Exclusive right turn(Channelized lanes added)	0	1	1	1.5	-1	
	Pedestrian signals/crosswalk	1		1	1.5	1.2	
	Pedestrian signs	4	1	5	7.7	1.2	
	Curb Ramps	15	5	12	24.6	0.5	
	Yield, 2-Way stop sign	1			0.8	0.25	
	4-Way Stop sign		2		1.5	0.25	
	Traffic Circle				0.0	0.5	
	Speed bumps/dips	2	2		3.1	1	
	Chicanes or chokers (present=1, absent=0)				0	1.5	
	Raised median, median alert (present=1, absent=0)	1		1	0.7	1.5	
	School zones (present=1, absent=0)	1			0.3	1.5	
	Bike lanes, share the road signs (present=1, absent=0)			1	0.3	1.5	
	Emergency zones (present=1, absent=0)				0	1.5	
	Traffic subscale					**0.4**	48.3
	Buffers (present=1, absent=0)						
	Trees	1		1	0.67	2	
	Fence(temporary/flexible)				0	1	
	Hedges				0	1	
	Landscape(desert)	1		1	0.67	2	
	Grass				0	1	
	Buffer subscale					**0.25**	2.67
	Other traffic elements						
	No. of lanes	1	5	2	2.67	-1.5	
	Traffic Direction (1-way street=1, 2way-street=2)	2	2	2	1	-1.5	
	Speed limit	25	35	25	0.33	-2	
	Street parking (present=1, absent=0)	1	1	1	1	2	
	Lighting (present=1, absent=0)	1	1	1	1	2	
	Other Safety subscale					**0.35**	-2.17
	Overall Safety Subscore						**19.2**

TABLE 4-2 Illustration of Compilation and Score Development for Land Use, Continuity, Directness, Aesthetics & Amenities Categories

Category	Item	Segment Name			Proportion	Weights	Score
		Seg 1	Seg 2	Seg 3			
	Segment Length	0.48	0.39	0.43	1.3		
	Total Segments				3		
Land uses	No. of Landuses in neighborhood (GIS derived)			10	1	1	
	Land use sub-score					1	**1.00**
Directness	Gated or walled community (present=1, absent=0)	1	1	1	1.00	-0.02	
	Hilly streets(flat=0, slight hill=1, steep hill=2)	1		1	0.67	-0.01	
	Floor Area Ratio (GIS derived)				0.13	2.25	
	Overall directness sub-score						**0.27**
Continuity	Int Density (GIS derived)				57.34	0.05	
	No. of Obstructions						
	Temporary signs				0.00	-0.05	
	Permanent signs		3	1	1.33	-0.8	
	Trees				0.00	-0.05	
	Utility Poles/hydrants		3	3	2.00	-0.5	
	Magazine racks/cabinets				0.00	-0.05	
	Transit shelters/benches				0.00	-0.5	
	Parked cars				0.00	-0.05	
	Sidewalk (present=1, absent=0)	1	1	1	1.00	2.5	
	Sidewalk width (<5'=1,>5=2)	1	2	2	1.67	1	
	Sidewalk breaks e.g incomplete sidewalks etc(present=1, absent=0)	0	1	0	0.33	-3.5	
	No. of driveways	7	48	12	51.54	-0.09	
	Deadends (present=1, absent=0)				0.00	-2.25	
	Overall continuity sub-score						**-0.84**
Aesthetic/ Amenities	*Amenities (present=1, absent=0)*						
	Garbage cans	1		1	0.67	3	
	Benches		1	1	0.67	1	
	Working Water Fountain				0.00	1	
	Bicycle racks				0.00	1	
	Street vendors/vending machines				0.00	1	
	Covered transit shelters	1			0.33	2	
	Timetable	1			0.33	2	
	Proportion of street having shade (overhead coverage, <.25, .26-.75,>.75 = 0,1,2)	1	2		0.67	2	
	Amenities subscale					**0.3**	**5.33**
	Cleanliness/presence of physical disorders (present=1, absent=0)						
	Abandoned cars				0.00	-1	
	Buildings with broken/boarded windows				0.00	-1	
	Broken glass		1		0.33	-1	
	Beer/liquor bottles/cans	1			0.33	-3	
	Litter	1	1		0.67	-3	
	Neighborhood watch signs			1	0.33	-1	
	Umaintained compounds/ empt lots/bldgs				0.00	-3	
	Graffiti		1	1	0.67	-3	
	Physical disorder subscale					**0.3**	**-5.67**
	Sidewalk condition/maintenance (poor, fair, good=0, 1,2,3)	2	2	3	5.38	2.35	
	Other Amenities/Aesthetics subscale					**0.4**	**12.7**
	OverallAmenities/Aesthetics subscore						**4.96**

CHAPTER 5

PEDESTRIAN SAFETY ANALYSIS

5.1. Introduction

One of the contributions of this study was to integrate crash data with audit data such that the overall safety audit index reflects geometrical safety elements in place, as well as safety risks in terms of crashes. Further, the impacts of roadway geometry, traffic controls and operations on pedestrian safety were evaluated to identify relationships between safety and road infrastructure. In this section, the methodology followed to evaluate pedestrian safety using crash and audit data is outlined, Figure 5-1. The methodology involved data collection and estimating the crash index.

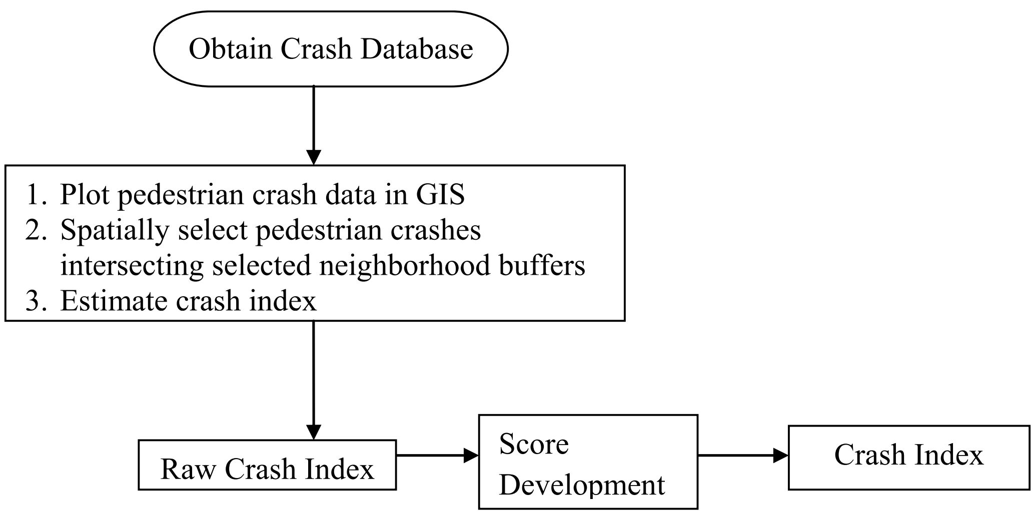


FIGURE 5-1 Pedestrian safety analysis methodology.

5.2. Sampling

The one mile buffers used for audit purposes were the same ones used for pedestrian safety analysis. Figure 5-2 Illustrates selected crashes within neighborhood buffers used for analysis.

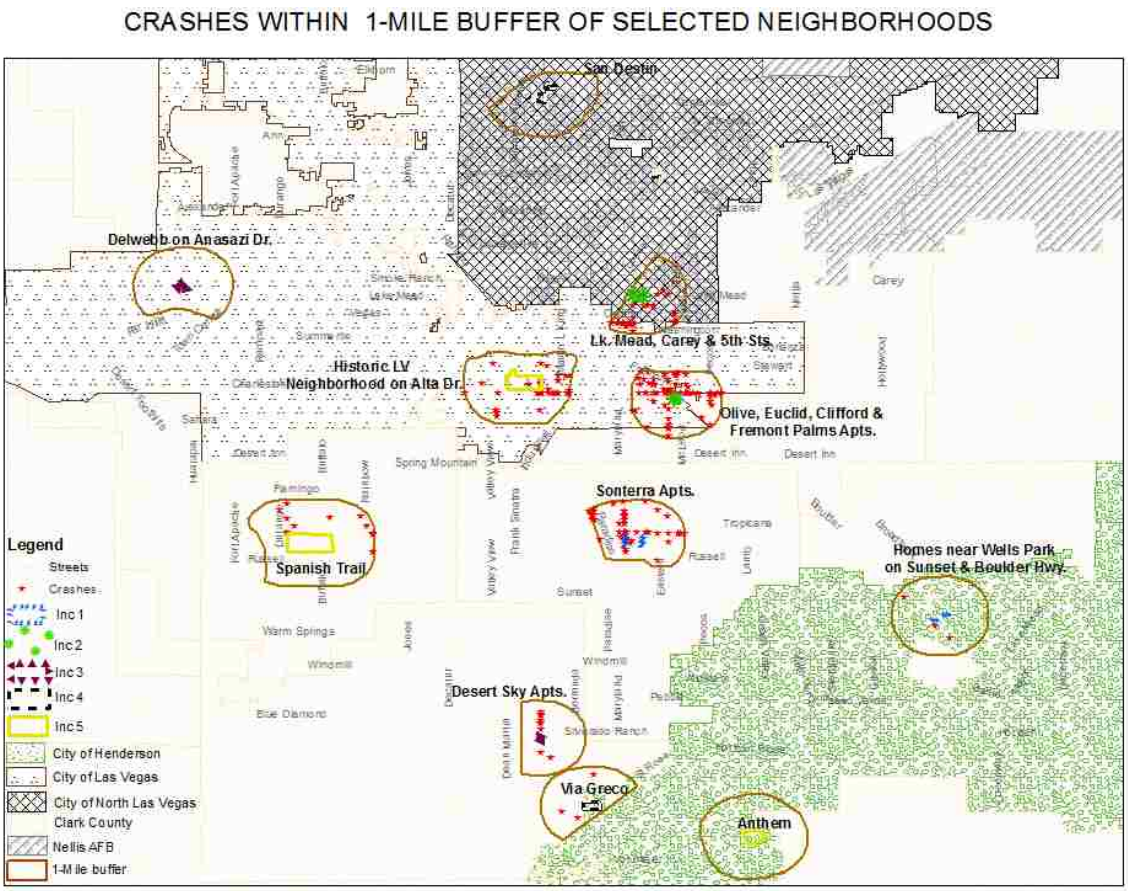


FIGURE 5-2 Crashes within one-mile buffer of selected neighborhoods.

5.3. Crash Data Collection

Audit data used for pedestrian safety analysis was collected as described in Chapter 4. The crash index is estimated as described in the following section. Pedestrian Crash Data was obtained from Nevada Department of Transportation (NDOT). The five year crash data was from 2007 to 2012. The crashes were overlaid onto the Las Vegas arterial network (street centerline database) in GIS. Crashes falling within and intersecting the study neighborhood buffers were spatially selected.

Ideally, pedestrian and traffic volumes are typically used to estimate crash rates. However, pedestrian were not readily available to estimate crash rates. Community Survey (ACS) 5-year population estimates from the US Census Bureau TIGER/Line data, and Clark County Assessor parcel data were used to estimate the crash index. The pedestrian crash index was estimates as a function of the total population and commercial footprint area with a modification factor *x*, as illustrated in Equation (5-1) below.

$$CI = \frac{CF_i}{Pop_i}(1 - x_i) + \frac{CF_i}{CA_i} * x_i \; ; \qquad x_i = \frac{CA_i}{BA_i}$$

Equation (5-1)

Where

x_i is the ratio of commercial building parcel area and the building footprint within buffer *i*

CI is the Crash Index

CF_i is crash frequency within buffer *i*

Pop_i is the total population within buffer *i*

CA_i is this the footprint area of a commercial building *i*

BA is the total area of buffer *i*

It is reasonable to assume that if a buffer has no commercial land use the crash index will be estimated as a function of buffer population alone. Conversely, if a buffer is zoned for commercial land use, the crash index is estimated as a function of commercial land use. Safety grades between A-D were assigned to the crash index as discussed in Section 3.5, "A" being a low crash index and "D" indicating a high crash index. The crash index was also standardized between zero and one as illustrated in Figure 3-3. The developed crash index was used to obtain other category indices as well as the pedestrian safety analysis described in the following Chapters.

CHAPTER 6

WALKABILITY INDEX CALCULATION

6.1. Introduction

One of the objectives of this study was to develop a comprehensive walkability index that was comprised of resident perceptions and objectively audited walking environment features. Perceptions heavily influence human recognition, decision and execution processes (Zadeh, 2001). To estimate walking frequency, perceptions of the walking environment that influence the walking decision were combined and analyzed. For example, the quality indices for directness, continuity aesthetics and amenities categories were combined in fuzzy logic to obtain one overall quality index for walking environment infrastructure. Several studies that have quantified walkability typically present numerical scores. Zadeh (2008) expressed that "most real-world probabilities are based on perceptions rather than on measurements, though the use of mathematically precise values was more prevalent".

6.2. What is Fuzzy Logic

Founded by Zadeh in 1965, fuzzy logic can be described as "precise logic of imprecision and approximate reasoning" (Zadeh, 2008). Since its inception, fuzzy theory has been applied in many fields such as industrial engineering, clinical diagnosis, education, information processing and marketing, among others. One of the most significant concepts of fuzzy theory is the linguistic approach which enables computing in the natural language. Human representation of knowledge is expressed using natural language that describes perceptions. Zadeh (2008) described perceptions of physical or mental objects -such as speed, force, comfort etc. - as " intrinsically imprecise, reflecting the bounded abilities of human sensory organs, and ultimately the brain, to resolve detail and store information". Manipulation of perceptions plays a key role in human recognition, decision and execution processes (Zadeh, 2001).

6.2.1. Fuzzy Logic Rationale

Computing in the natural language is mainly used in two general instances. One is when available data is too imprecise to justify the use of numbers. The second reason as well as the reason for application in this study is when analyses tolerate imprecision which can be exploited to achieve robustness, low solution costs and a more consistent relationship with perceptions (Zadeh, 2001). The neighborhood survey collected resident perception of various features in the walking environment using linguistic labels. Fuzzy logic was used to combine the perceptions in an approximate framework (similar to the human ability to manipulate and reason with perceptions) as described below.

The linguistic approach was applied to interpret the perceptions that were aggregated by categories into a fuzzy linguistic variable "quality grade". The quality grade cardinality was characterized using labels A-D representing excellent, good, fair and poor walking environment conditions respectively. In other words, if attributes of the walking environment can be contained in an interval [*i, j*] then the interval is a granular value of the linguistic variable, "quality grade". Granular values are similar to natural language characterization using linguistic terms such as "*excellent*", "*good*", "*fair*", and "*poo*r".

As earlier noted, perceptions typically have unsharp or imprecise boundaries. In fuzzy logic, the perceptions characterized as granular values were represented using overlapping triangular fuzzy membership functions. The granular values representing perceptions were combined in the fuzzy inference process described in Chapter six to obtain global indices and grades for combined categories. The impreciseness associated with discriminating between good, and fair was exhibited in the overlapping fuzzy sets. For example, a quality grade that fell within the overlapping zone of *fair* and *good* fuzzy sets would have some degree of membership or truthfulness in each fuzzy set. This indicates an uncertainty on whether the quality grade should be considered fair or good. On the other hand, a quality grade that fell in the middle of the *"good"* fuzzy set had membership only in the "*good"* fuzzy set with a truthfulness value of one, indicating with certainty that the quality index described was good.

6.2.2. Applications of Fuzzy Logic

Fuzzy logic has been used to solve problems in various fields. For example, Degani and Bortolan (1988) proposed a "linguistic approach to decide upon various diagnostic abnormalities suggested by the analysis of the electrocardiographic (ECG) signal" in clinical decision making. Fuzzy logic has been applied in other areas such as strategy selection, engineering economics, project scheduling, manufacturing and forecasting (Kahraman, 2006).

Herrera et al. (2006) proposed a linguistic quality evaluation model to evaluate the services offered by the web sites using fuzzy logic. Their linguistic approach was based on the rationale that it "provided adequate representation when faced with imprecision thereby eliminating the burden of qualifying a qualitative concept". The authors developed a linguistic evaluation model in which users provided their opinions in a linguistic term set according to their knowledge. Based on their perceptions, users evaluated website services such as entertainment, convenience, information reliability, site design, security and assurance, virtual environment, and product offer on various criterion using any of the provided term sets. For example a user could use a term set B_T represented using triangular membership functions as shown in Figure 6-1 to describe a website criteria or dimension, where;

$B_T = \{b0=none, b1=low, b2=medium, b3=high, b4=perfect\}$

Equation (6-1)

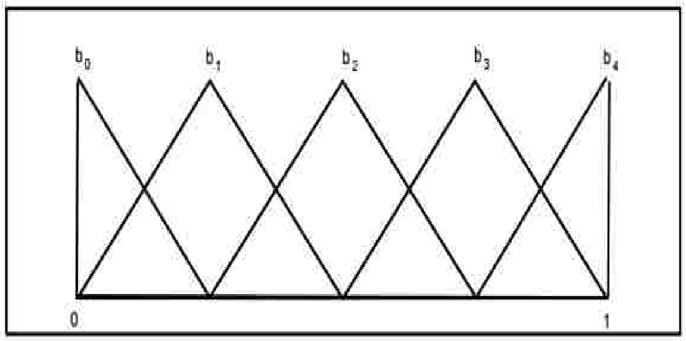


FIGURE 6-1 Fuzzy triangular membership functions for a linguistic variable 'B'.

User opinions were evaluated to obtain the quality value of each criteria and dimension expressed in a linguistic 2-tuple. The 2 tuple fuzzy linguistic model typically comprising of a linguistic label '*s*' and precise value '*α*', is widely to transform between linguistic and numerical values. The 2-tuple values for each criterion were averaged for all users to compute collective values for each criterion. These were further averaged to obtain collective values for each dimension. Different weights were assigned depending on the website being evaluated. A 2-tuple linguistic weighting average operator was applied to obtain a global linguistic evaluation for the quality of a web site.

Law (1996) applied a fuzzy logic to model an educational grading system that would assist teachers in aggregating different test scores to obtain a single student's grade. The system would also help determine the need for revisions on instructional procedures. Linguistic values (grades A-F) were represented using membership functions determined from an ideal population of test takers. In his illustration, Law determined the ideal proportions of students receiving grades A, B, C, D, F were P_A = 15%, P_B = 35%, P_c = 20%, P_D = 20%, P_F = 10%. For each question, a student's true score was obtained as a function of the observed score, maximum possible question score that was standardized between 0 and 1.

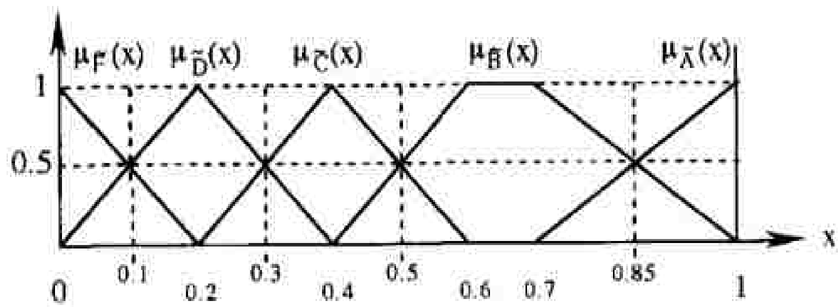


FIGURE 6-2 Membership functions for grades.

Where

$\mu_{\tilde{i}}(x)$ indicates the mean proportion of students receiving a particular grade, ĩ={ A, B, C, D, E,F}

For each question, a student's true score was obtained as a function of the observed score, maximum possible question score that was standardized between 0 and 1.The final score for each question was then assessed for degree of membership to each grade Figure 6-2. Students' overall scores were derived by aggregating the degrees of memberships and defuzzified using the centroid method. Weights were then assigned to the overall score depending on the interval the overall score fell in. The highest and lowest degrees of membership are 0.8878 and 0.0781 for grades A and F respectively. Law reported several advantages of assigning grades by means of membership degree such as better means of predetermining failure and pass rates, defensibility - eliminating favoritism defects and a more equitable method of grade assignment.

In the marketing field, Yager, Goldstein and Mendels (1994) used fuzzy logic operations to determine consumer willingness to purchase based on survey participant perceptions on economic conditions. The authors reported that surveyed consumer perceptions had a cause and effect relationship with intentions and purchasing behavior. In addition, there was evidence indicating consumer sentiments towards current or future business conditions influenced expenditures on discretionary products and services. In the survey, respondents were asked to rate economic condition indicators using linguistic terms. A respondent's economic attitude U(I) took values in the space G = {good, normal, bad} and corresponding purchase behavior took values in the space V (I) = {yes, no}. Fuzzy operators MAX, MIN, and NEG rooted in fuzzy set theory and an ordered weighted averages vector W^k were used to obtain a composite value U(I) as expressed below, Figure 6-3.

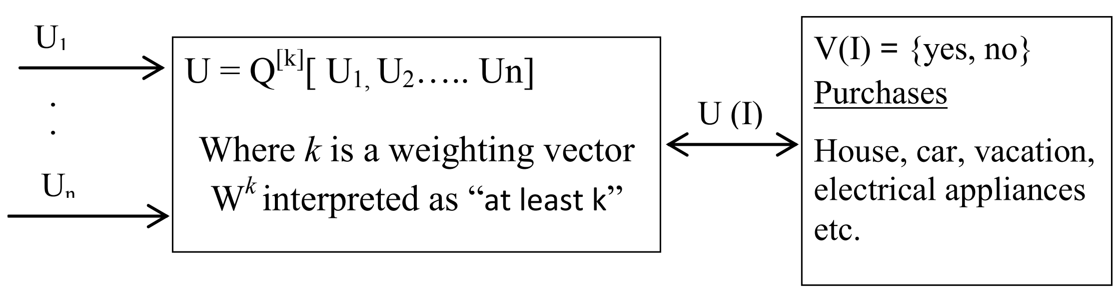


FIGURE 6-3 Fuzzy Market Research system (FUZMAR).

A respondent's economic attitude U(I) attained a good score if at least *k* of the components had good scores. Survey data was used to identify a value of *k* that resulted in best prediction of purchase behavior. Probabilities of a participant describing the economic indicators as good, normal or bad were estimated based on entropy. With the probabilities and associated purchases, entropies for the five economic conditions were computed ranging from 0.5086 to 0.5207. The minimal entropy principal indicating less degree of uncertainty was used to select the preferred model. The model where participants rated economic indicators highest provided the best predictor of purchase.

6.3. Fuzzy Logic for Walkability

The overall process to develop the comprehensive walkability index and quality grades using fuzzy logic is illustrated in Figure 6- 4. Value precise audit data was also combined into other categories such as infrastructure and audit safety, using fuzzy logic for consistency and comparison with the perception data. Combination of categories as well as the audit and perception data to estimate the overall comprehensive walkability index was completed in the fuzzy inference process. The fuzzy inference process is illustrated using survey directness, aesthetics and amenities, and continuity perception categories in the following sections of this Chapter.

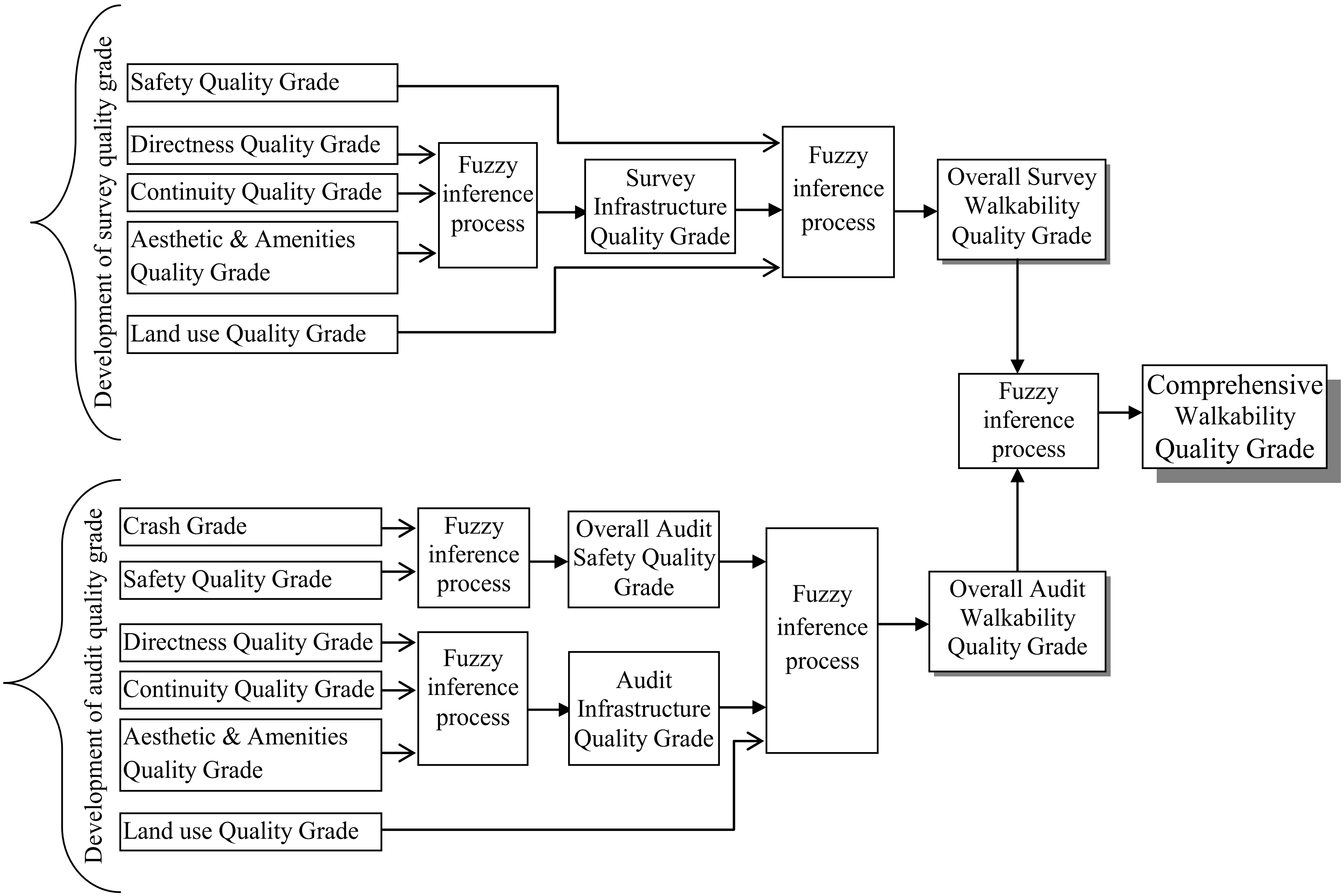


FIGURE 6-4 Overall-study fuzzy logic process.

6.4. Fuzzy Logic Process

Fuzzy logic maps inputs -which sometimes are comprised of varying degrees of membership - onto an output space in a process referred to as inference process, illustrated in Figure 6-4. The fuzzy inference process, based on Lotfi Zadeh's work on fuzzy algorithms for complex systems and decision processes is comprised of five steps (Mathworks, 2015; Zadeh, 2008).

(1) Fuzzification of the input variables

Fuzzification transforms crisp input values into degrees of membership within fuzzy sets as expressed below in. Fuzzy sets are analogous to human characterization of the parameters in linguistic terms such as excellent, good, fair and poor:

$$C = \{x, \mu_c(x) | x \in X\} \qquad \text{Equation (6-2)}$$

Where

X is the linguistic variable or the universe of discourse and its elements denoted by *x*.

$\mu_c(x)$ is the membership function that assumes values between 0 and 1.

Membership functions (MFs) represent fuzzy sets. Membership functions come in various shapes such as triangular, trapezoidal, Gaussian, sigmoidal, quadratic among others. Triangular MFs were used in the study based on their simplicity.

(2) Application of the fuzzy operator

After fuzzification, a fuzzy operator is used to operate on the degree of membership for each input to obtain one truth value that will represent all used fuzzified inputs. The Boolean Logic operators AND, OR and PROBOR built into fuzzy logic are used ad fuzzy operator as expressed in Equations (6-2) to (6-4). The AND operator was used in this study.

AND represents the intersection or minimum between two fuzzy sets C and D, expressed as:

$$\mu_{C \cap D} = min\ [\mu_C(x),\ \mu_D(x)]$$

Equation (6-3)

OR represents the union or maximum between the two fuzzy sets C and D, expressed as:

$$\mu_{C \cup D} = max\ [\mu_C(x),\ \mu_D(x)]$$

Equation (6-4)

PROBOR (probabilistic OR) represents the algebraic sum between the two fuzzy sets C and D, expressed as:

$$Probor\ (C, D) = C + D - CD$$

Equation (6-5)

(3) Implication from the antecedent to the consequent.

Fuzzy inference rules were defined by the relationship between the antecedent observation and the resulting action in the form of:

if<PREMISE>, then <CONSEQUENCE>

All the rules activate in parallel to some degree and the consequent output is a union of fuzzy results from each rule based on the max min operator expressed as:

$$\delta^{\alpha} = max\ min_{x \in X} = [\mu_{c}^{\alpha}\ (x), \mu_{D}^{\alpha}\ (x)]$$

Equation (6-6)

Where δ^{α} is the output of the aggregated subset of activated rules of fuzzy sets C and D, in the universes of discourse represented by X.

(4) Aggregation of consequents across the rules

The output is based on activating all the rules represented in the fuzzy sets and combining the result to determine an action. Fuzzy toolbox in MATLAB offers three built methods of aggregation.

i. Maximum method disregards the shape of the output function and only considers the highest degrees the membership functions. Outputs are generally biased towards overestimation.
ii. Probabilistic OR method sums then subtracts the products of the fuzzy outputs from the implication step.

iii. The sum method aggregates the fuzzy outputs from the implication step. The sum method was adopted for this study.

(5) Defuzzification

The final step in the inference process is deffuzification, where a precise non-fuzzy number is given as the output. There are various algorithms used in deffuzification such as maximum membership (height method), Mean max membership, weighted average, centroid and center of sums (Mathworks, 2015; Zadeh, 2008). The centroid method was selected for the study given that it would be most representative of aggregated resident perception of infrastructure within their neighborhood. This method is recommended for quantitative decisions and computes the centroid of the composite area expressed as:

6.5. Fuzzy Inference

As earlier indicated, Fuzzy logic was primarily used to estimate perception indices in an approximate framework that is similar to respondents making decisions using perceptions. With this approach, indices estimated have a more cohesive relationship with initially obtained responses. In addition, combining both survey perceptions and audit observations practitioners are better equipped to implement strategies that can enhance the walking environment based on objective information and resident concerns.

The quality index for infrastructure was determined in the inference process based on the fuzzy if-then rules, Table 6-1. For example, if the continuity, and directness perceptions were good and the aesthetics and amenities perception was fair, the infrastructure quality index was fair as highlighted in Table 6-1 and described below.

$$if\ \{Continuity\ is\ good\};\{directness\ is\ good\}and\ \{Aesthetics\ are\ fair\}$$

$$then\ \{Infrastructure\ is\ fair\}$$

The degree of truthfulness of infrastructure to a quality index is equal to:

$$\mu(Infrastructure) = \min(\ \mu(Directness), \mu(Continuity), \mu(Aesthetics\ \&\ Amenities)\ )$$

Equation (6-7)

The inference process employs cointension which is "a measure of the degree to which a mathematically-based measure fits a perception based measure". Quality indices were described by triangular fuzzy membership sets Figure 6-5 which are analogous to human characterization of attributes expressed as "excellent, good, fair and poor" in linguistic terms. Mamdani's fuzzy inference method based on Lotfi Zadeh's work on fuzzy algorithms for complex systems and decision processes was used in the study (Mathworks, 2015).

Fuzzy inference was also used to develop other indices such as infrastructure indices for both audit and surveys combining directness, continuity, amenities and aesthetics categories. The overall walkability indices for audit as well as survey were comprised of safety, infrastructure and land use categories. Finally the comprehensive walkability index was obtained by combining overall audit and survey walkability indices as illustrated in Figure 6-4.

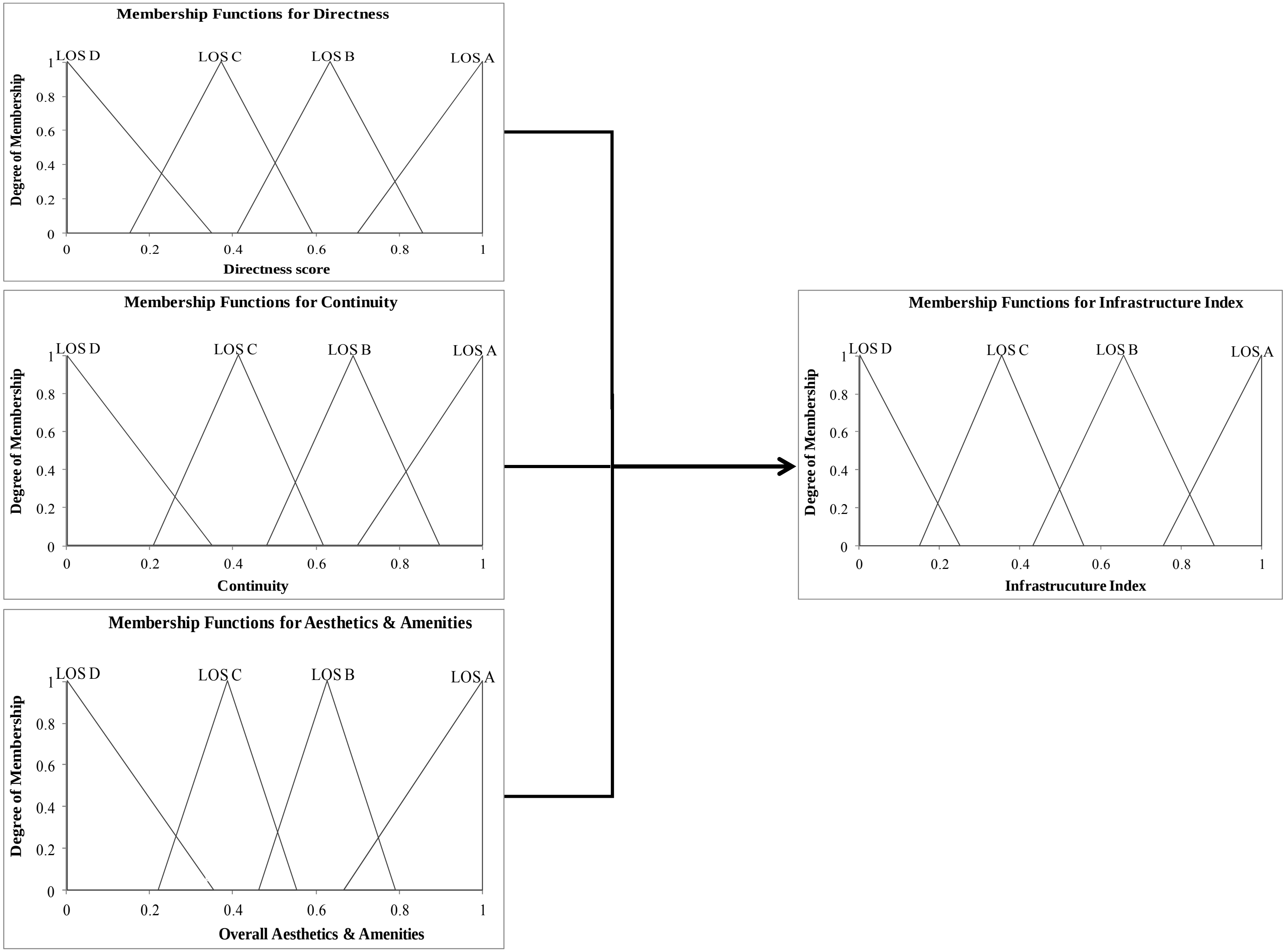


FIGURE 6-5 Membership functions for estimating infrastructure index.

TABLE 6-1 Fuzzy Rules for Infrastructure Index

Weights			Survey Infrastructure Index															
0.2	Directness	A (Excellent)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2		B (Good)																
0.2		C (Fair)																
0.2		D (Poor)																
0.5	Continuity	A (Excellent)	1	1	1	1												
0.5		B (Good)					1	1	1	1								
0.5		C (Fair)									1	1	1	1				
0.5		D (Poor)													1	1	1	1
0.3	Amenities	A (Excellent)	1				1				1				1			
0.3		B (Good)		1				1				1				1		
0.3		C (Fair)			1				1				1				1	
0.3		D (Poor)				1				1				1				1
			0.8	0.7	0.7	0.5	0.7	0.7	0.6	0.5	0.7	0.6	0.6	0.4	0.4	0.3	0.3	0.2
			A	B	B	C	B	B	B	C	B	C	C	D	D	D	D	D

Weights																		
0.2	Directness	A (Excellent)																
0.2		B (Good)	1	1	1	1	1	1	**1**	1	1	1	1	1	1	1	1	1
0.2		C (Fair)																
0.2		D (Poor)																
0.5	Continuity	A (Excellent)	1	1	1	1												
0.5		B (Good)					1	1	**1**	1								
0.5		C (Fair)									1	1	1	1				
0.5		D (Poor)													1	1	1	1
0.3	Amenities	A (Excellent)	1				1				1				1			
0.3		B (Good)		1				1				1				1		
0.3		C (Fair)			1				**1**				1				1	
0.3		D (Poor)				1				1				1				1
			0.7	0.7	0.6	0.5	0.7	0.6	**0.6**	0.4	0.6	0.5	0.5	0.4	0.4	0.3	0.2	0.1
			B	B	B	C	B	B	**C**	D	B	C	C	D	D	D	D	D

Weights																		
0.2	Directness	A (Excellent)																
0.2		B (Good)																
0.2		C (Fair)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2		D (Poor)																
0.5	Continuity	A (Excellent)	1	1	1	1												
0.5		B (Good)					1	1	1	1								
0.5		C (Fair)									1	1	1	1				
0.5		D (Poor)													1	1	1	1
0.3	Amenities	A (Excellent)	1				1				1				1			
0.3		B (Good)		1				1				1				1		
0.3		C (Fair)			1				1				1				1	
0.3		D (Poor)				1				1				1				1
			0.7	0.6	0.6	0.5	0.6	0.6	0.5	0.4	0.6	0.5	0.5	0.3	0.3	0.2	0.2	0.1
			B	B	C	C	B	C	C	D	C	C	C	D	D	D	D	D

Weights																		
0.2	Directness	A (Excellent)																
0.2		B (Good)																
0.2		C (Fair)																
0.2		D (Poor)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.5	Continuity	A (Excellent)	1	1	1	1												
0.5		B (Good)					1	1	1	1								
0.5		C (Fair)									1	1	1	1				
0.5		D (Poor)													1	1	1	1
0.3	Amenities	A (Excellent)	1				1				1				1			
0.3		B (Good)		1				1				1				1		
0.3		C (Fair)			1				1				1				1	
0.3		D (Poor)				1				1				1				1
			0.6	0.5	0.5	0.4	0.6	0.5	0.4	0.3	0.5	0.4	0.4	0.3	0.2	0.2	0.1	0.0
			B	C	C	D	C	C	D	D	C	D	D	D	D	D	D	D

CHAPTER 7

DESCRIPTIVE SUMMARY RESULTS AND STATISTICS OF NEIGHBORHOOD SURVEYS

7.1. Introduction

This chapter presents descriptive summary statistics of the survey data. Box plots were used to identify trends and patterns as well as features in the walking environment that influence resident perceptions. In addition, Kendall's Tau, a measure of association was used to evaluate the relationship between identified walking environment features and reasons for walking. Trends were tested for significance (α=0.05) using a one-tailed test. Features with significant relationships (α=0.05, 0.1) to walking frequency were identified.

7.2. Summary of Survey Data

There were 154 survey responses in total received, 145 mailed back and 9 online responses. Out of 2027 survey packages distributed, the response rate was approximately 7.6%. Table 7-1 provides a summary breakdown of the survey respondents. Majority of the survey participants reported walking frequently - everyday or a few times a week. This implied mainly walking for recreational purposes since only 13% of respondents reported using transit and only 5% seldom had a vehicle available.

TABLE 7-1 Summary of Survey Data

Category	Group	Count
Walking Frequency	Frequent	105
	Moderate	28
	Seldom/ Never	19
Transit	Users	20
	Non-users	117
Car availability	Always	126
	Sometimes	19
	Seldom/ Never	8
Age-groups	18-30	8
	31-40	16
	41-55	31
	56-65	43
	65+	53
Gender	Male	48
	Female	86

Survey responses were assigned indices and aggregated per category and neighborhood to obtain category and overall perception of the walking environment as discussed in Section 3.5. The scores were then standardized between zero and one and assigned quality indices. Table 7- 2 presents a summary of the perception data from the survey.

TABLE 7-2 Raw and Standardized Survey Data

Neighborhood	Landuse Raw score	Landuse Standardized score	Landuse Quality Grade	Directness Raw score	Directness Standardized score	Directness Quality Grade	Continuity Raw score	Continuity Standardized score	Continuity Quality Grade	Amenities Raw score	Amenities Standardized score	Amenities Quality Grade	Safety Raw score	Safety Standardized score	Safety Quality Grade
5th & Carey	2.30	0.65	B	1.79	0.39	D	2.18	0.59	C	1.78	0.39	D	1.93	0.46	C
Euclid	2.17	0.58	B	2.07	0.54	C	2.07	0.54	D	1.88	0.44	C	2.08	0.54	C
Sonterra-Apts	1.97	0.48	C	2.19	0.60	C	2.11	0.56	C	1.88	0.44	C	2.23	0.61	C
Sunset & Boulder	1.76	0.38	C	2.12	0.56	C	2.04	0.52	D	1.78	0.39	D	2.03	0.51	C
DelWebb	1.46	0.23	D	2.02	0.51	C	2.26	0.63	C	2.21	0.61	B	2.31	0.66	B
DesertSky-Apts	2.60	0.80	A	2.21	0.61	B	2.34	0.67	B	2.24	0.62	B	2.27	0.63	B
San Destin	2.39	0.69	B	2.32	0.66	B	2.27	0.64	C	2.51	0.76	B	2.40	0.70	B
ViaGreco	1.51	0.26	D	2.16	0.58	C	2.15	0.57	C	2.13	0.57	C	2.06	0.53	C
Anthem	1.56	0.28	D	2.13	0.57	C	2.36	0.68	B	2.38	0.69	B	2.43	0.72	B
Historic Alta	2.39	0.69	B	2.18	0.59	C	1.96	0.48	D	2.06	0.53	C	2.09	0.55	C
SpanishTrail	1.38	0.19	D	2.13	0.57	C	1.97	0.48	D	2.28	0.64	B	2.10	0.55	C

7.3. Survey Analysis

Perception data was analyzed for trends and patterns in the overall perception, land use, directness, continuity, safety and aesthetics and amenities. . The following box-plots illustrate the influence of various variables on resident perception of their walking environment. Adjacent groupings of in a variable were tested for significant trends using paired sample t-tests for small samples. Some of the variable groupings had small sample sizes. Appendix III presents tables illustrating how significant trends in plotted using boxplots were identified.

7.3.1. Overall Resident Perception of Walkability

Trends in overall resident perception of the walking environment were evaluated by various parameters. Trend plots for walking frequency, gender, and car-availability are presented.

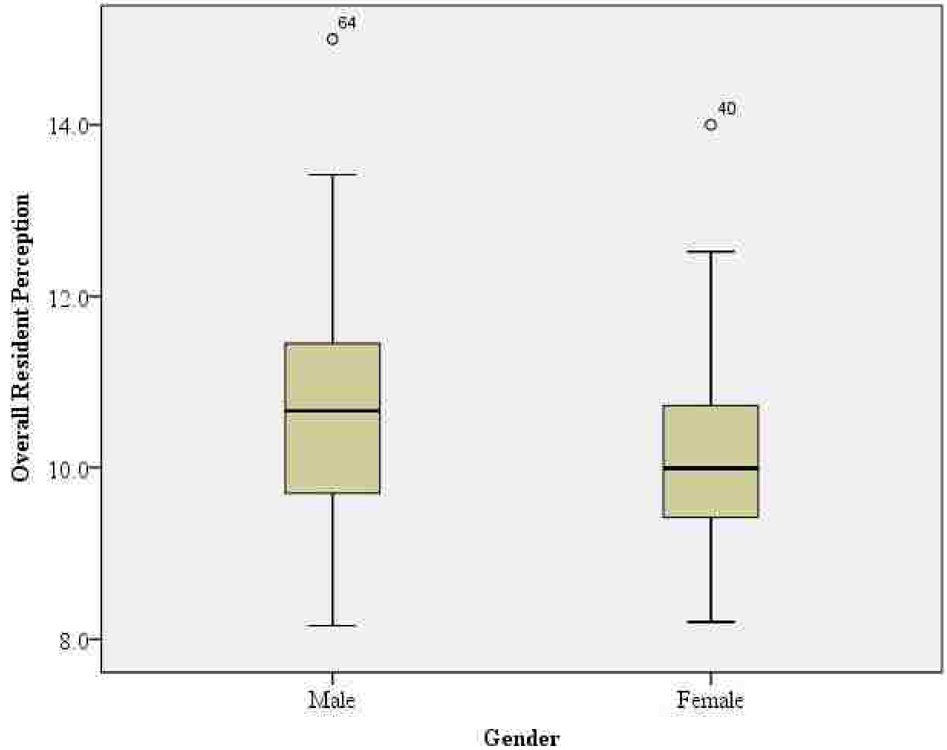


FIGURE 7-1 Box-plot of overall resident perception by gender.

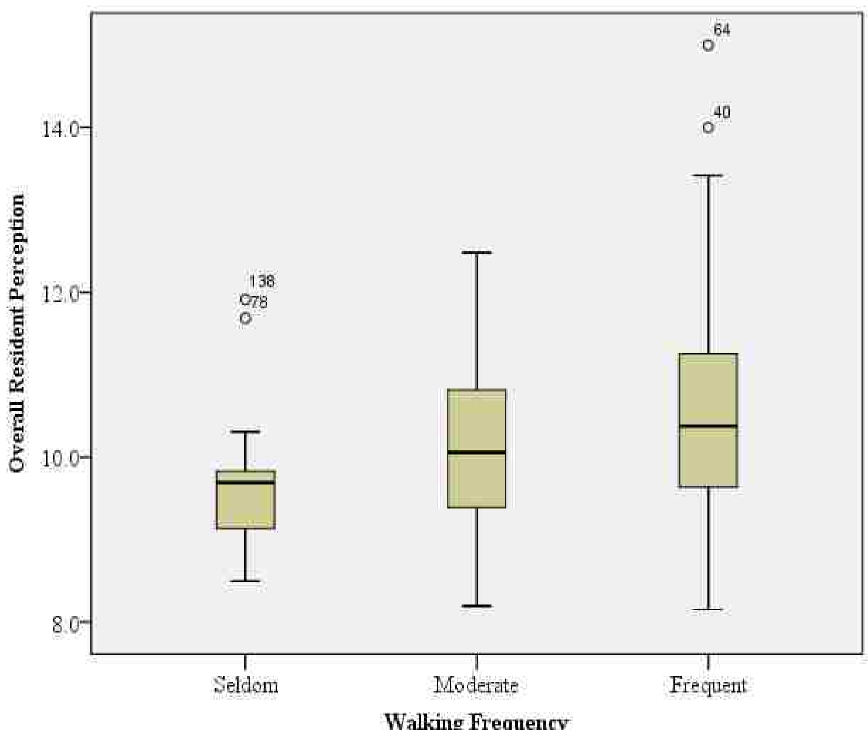


FIGURE 7-2 Box-plot of overall resident perception by walking frequency.

The overall resident perception by gender was above average as seen in Figure 7-1. The overall male perception of the walking environment was higher than for women. An upward trend is evident in the overall resident perception and walking frequency, Figure 7-2. Residents who walked more frequently have a more positive perception of the walking environment. The difference in perception between seldom and moderate walkers is not statistically significant. However the overall perception difference between moderate and frequent walkers is statistically significant. This would imply that an overall higher perception of the walking environment is associated with more walking since there's no difference between the higher walking frequency categories.

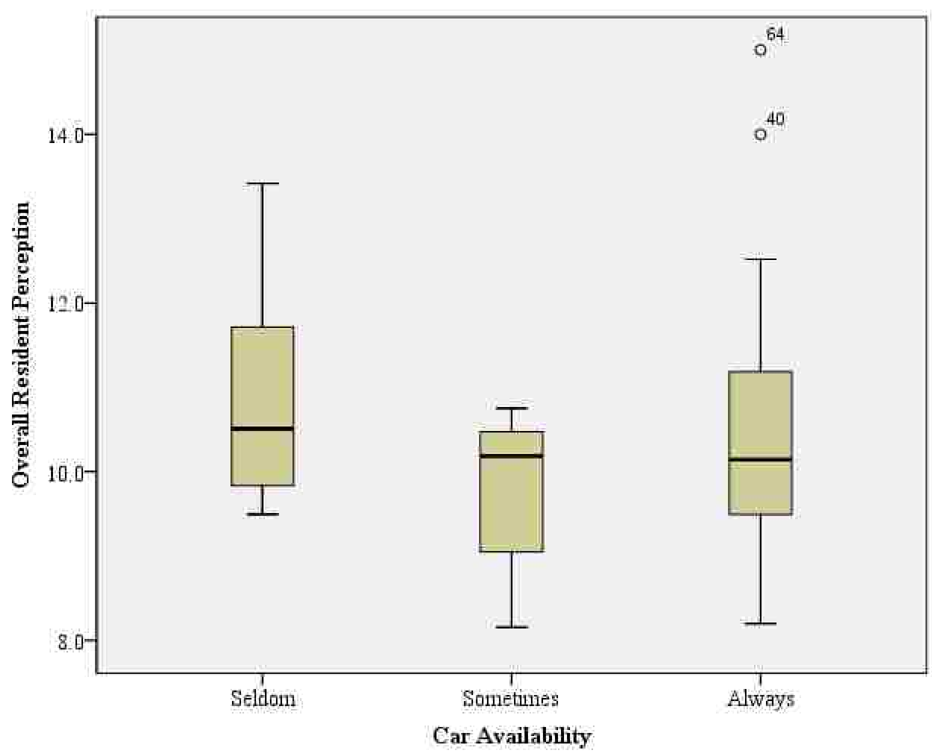


FIGURE 7-3 Box-plot of overall resident perception by car availability.

Respondents who seldom had vehicles available had a more positive perception of their walking environment compared to those who drove often, Figure 7-3. The overall resident perception difference between the two mentioned groups was statistically significant. Intuitively, higher walking frequency provides more interaction with the walking environment resulting in more familiarity of the walking environment. However low perception of the walking environment could also be attributed to use of vehicles rather than walking.

7.3.2. Land Use Perception Box-plots

Land use perception refers to opinions of availability of nearby varied land uses within the neighborhood. Variables that exhibited significant trends when plotted against land use perception are presented.

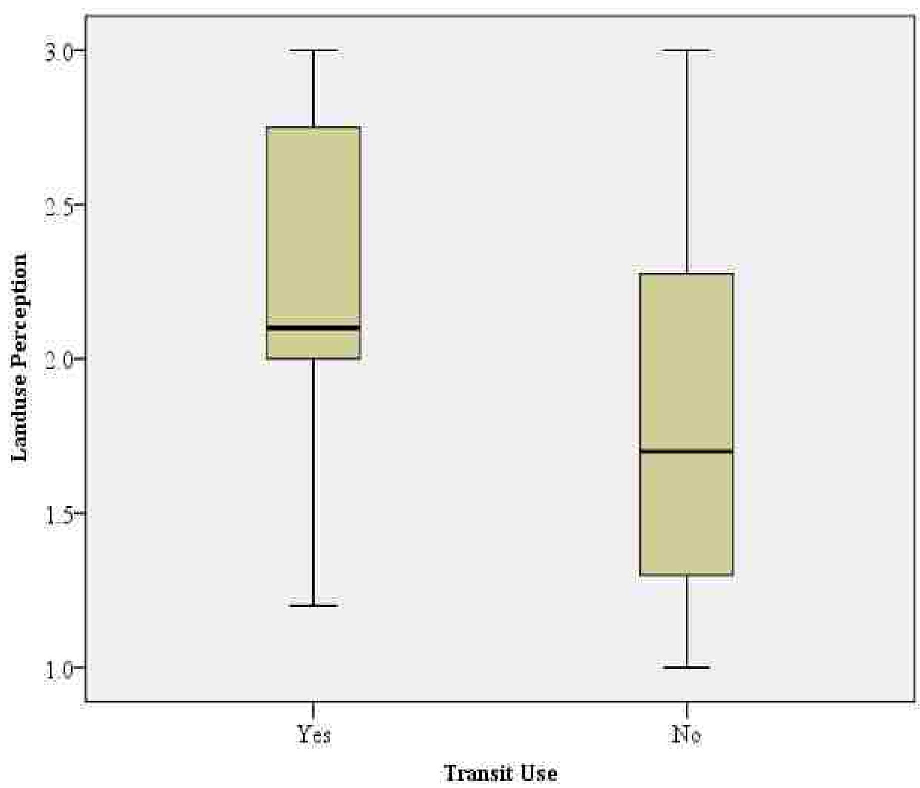


FIGURE 7-4 Box-plot of land use perception by transit use.

Figure 7-4 above indicates that respondents who reported using transit had a higher perception of the land uses within their neighborhood. Of the surveyed neighborhoods, DelWebb in income group three, San Destin in income group four and Anthem in income group five had no transit stops. Intuitively, transit users who walk frequently are more likely to notice more land uses within their vicinity compared to those who seldom walked. In addition, Cervero and Kockelman (1997) reported that presence of convenient stores between transit stops and residential neighborhoods held potential for increased utilitarian trips as well as trip chaining.

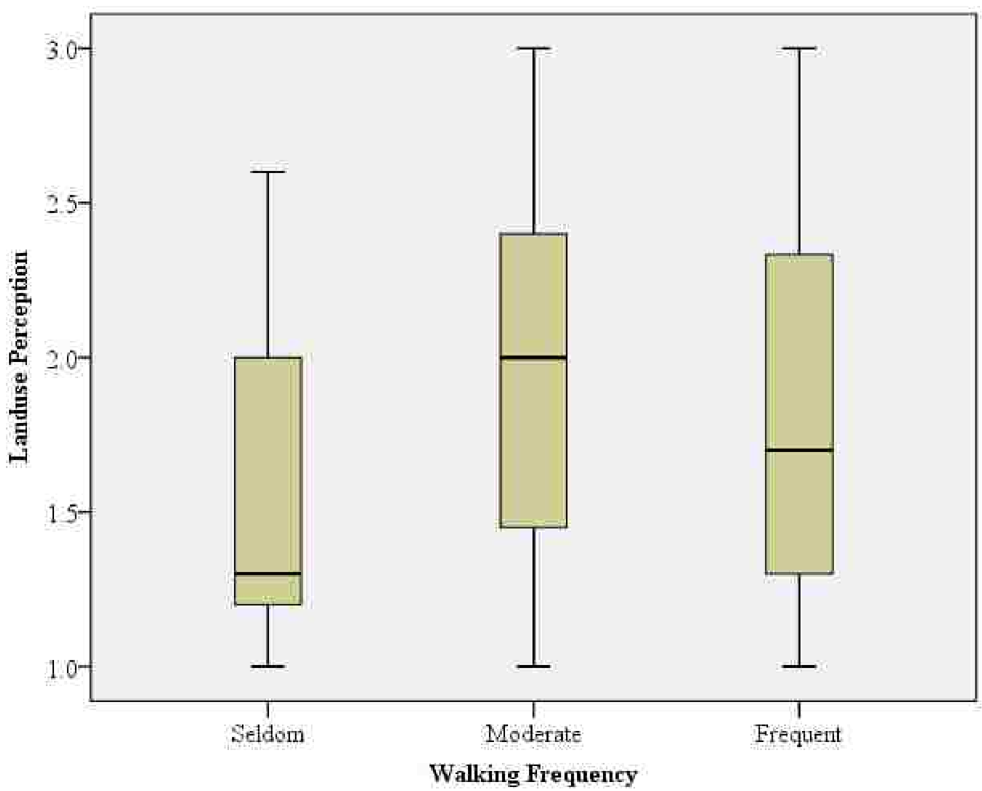


FIGURE 7-5 Box-plot of land use perception by walking frequency.

Intuitively, residents who have limited exposure to their walking environment are likely to be less familiar with the variety of land uses within their neighborhood. Figure 7-5 confirms this, indicating that respondents who seldom walk having a low land use perception. On the other hand, limited availability of high land use mix could lead to increased vehicle use while searching for services that are not close by. Cervero and Kockelman (1997) in their literature review reported lower vehicle use in areas with mixed land use areas. In addition, the size of land use influences pedestrian perception. Larger scale commercial premises are bound to be more noticeable compared to those with smaller footprints.

7.3.3. Directness Perception Box-plots

Directness evaluated quick and easy access to various destinations. Of all the socio-demographic variables tested, only age showed a slight significant trend.

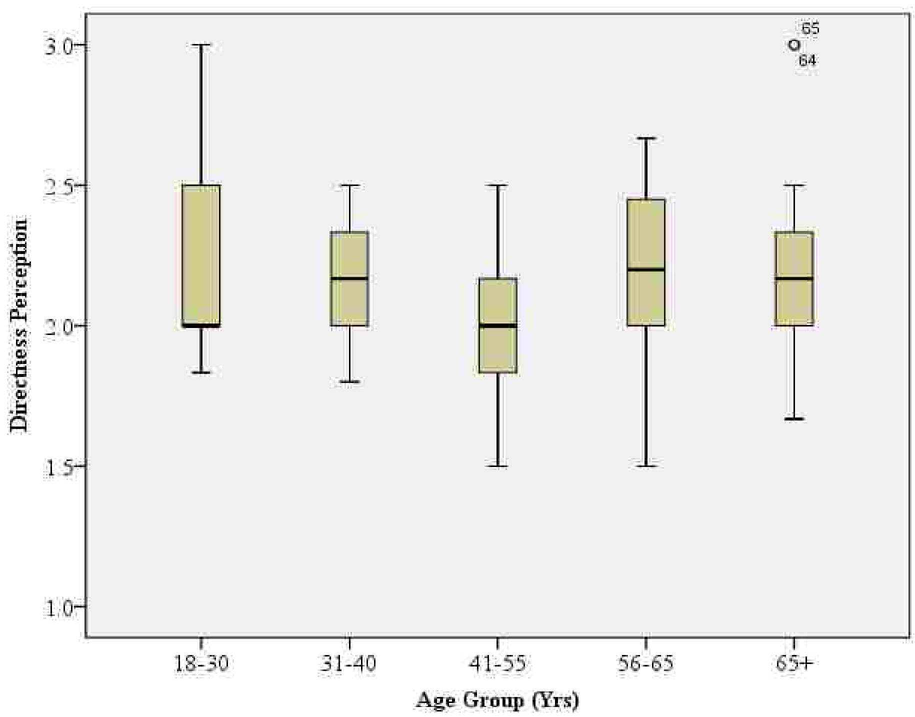


FIGURE 7-6 Box-plot of directness perception by age.

There was no significant difference between, the younger age groups less than 40 years of age. However, there was a significant difference in directness perception between age groups three and age group four, Figure 7-6. Majority of the respondents in the data were over 40 years of age. In addition, DelWebb, an enclosed retirement community had hilly streets and few land uses, inhibiting directness. This neighborhood also had the highest response rate, therefore their age and neighborhood directness quality is intensely reflected.

7.3.4. Continuity Perception Box-plots

Variables that exhibited a trend as well as significant differences in continuity perception between groups were age and length of residency. With respect to age, continuity of facilities is important to facilitate safe walking for pedestrians using walking aids, especially in Las Vegas which has a large population of retirees. As Figure 7-7 shows, there difference in continuity perception is statistically significant between the two youngest age groups. A slight increasing trend between age groups 31-40, 41-55, and 56-65 is evident but the continuity perception differences are not significant. Street furniture that obstructs pedestrian paths presents safety risks as pedestrians try to maneuver around them, especially for those in wheelchairs.

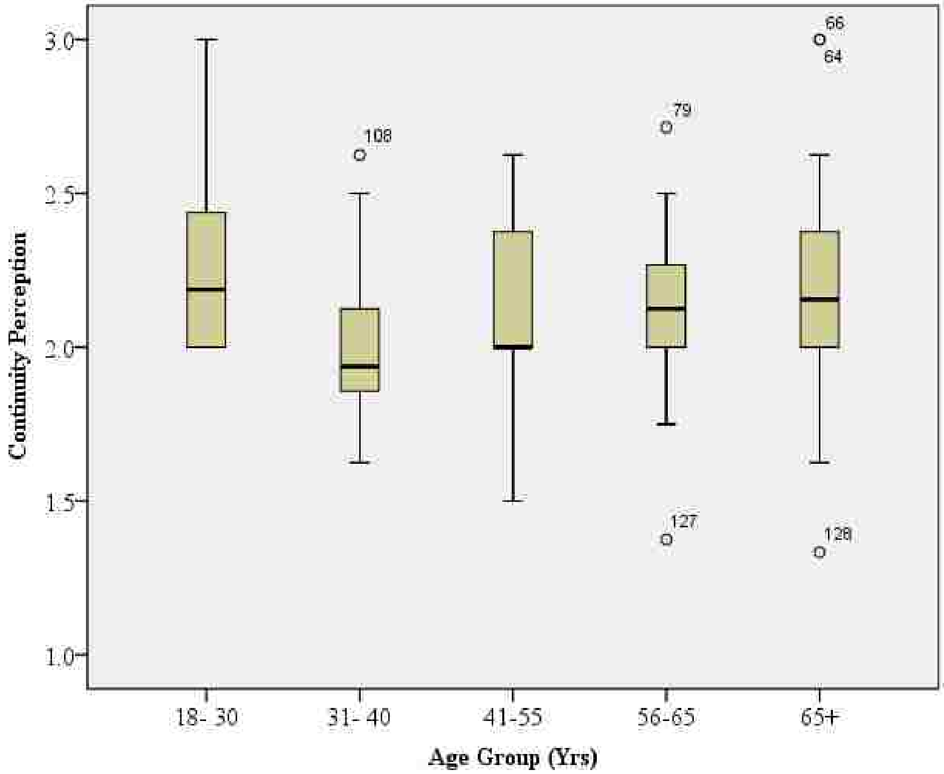


FIGURE 7-7 Box-plot of continuity perception by age.

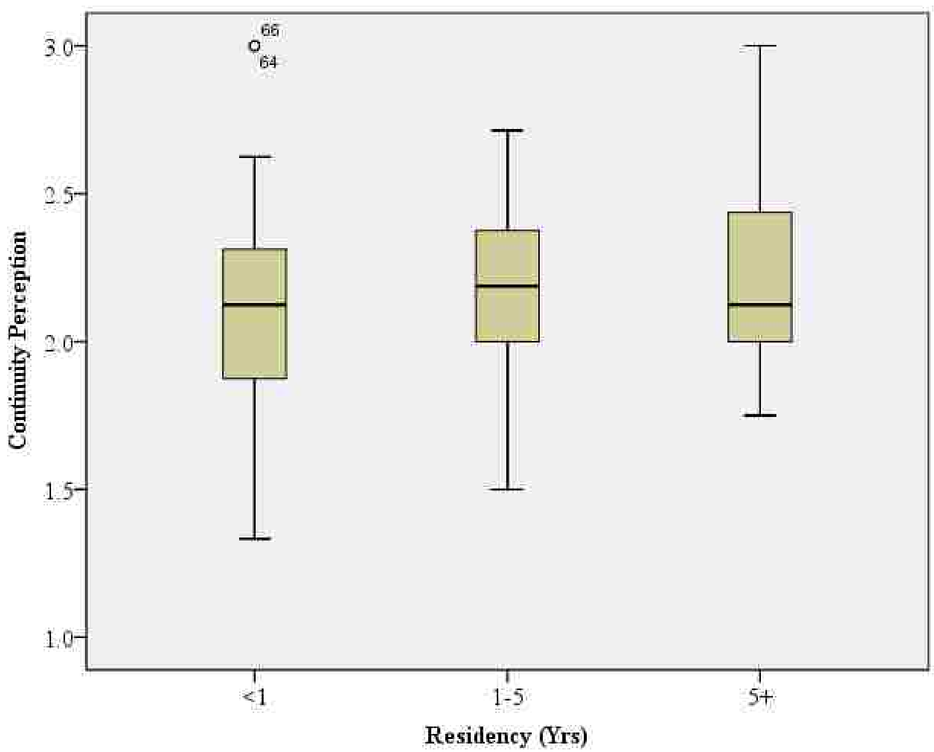


FIGURE 7-8 Box-plot of continuity perception by residency.

From Figure 7-8 above, there's an upward trend between residency and continuity perception, implying respondents who've lived in their neighborhoods longer have a more positive continuity perception. Intuitively, it is reasonable to expect that newer residents are not as familiar with the neighborhood as older residents. The relationship levels off after five years, implying after one year, there's no difference between what three year residents perceive in terms of continuity features and ten year residents. This could imply that there are no new discoveries in terms of continuity features after a short while of residency.

7.3.5. Amenities & Aesthetics Perception Box-plots

The following box-plots in Figure 7-9 and Figure 7-10 illustrate the influence of socio-demographic variables on residents' perception of amenities and aesthetics.

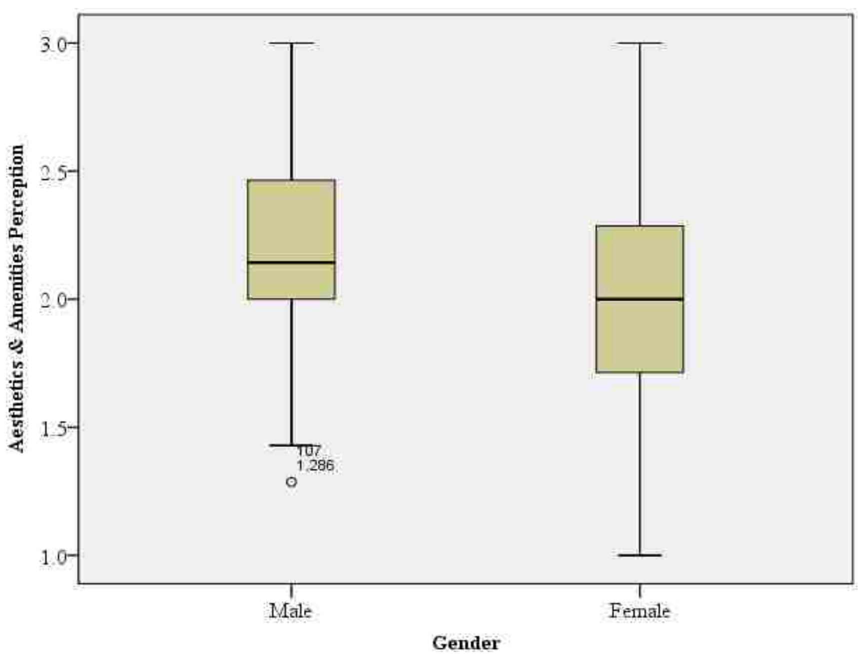


FIGURE 7-9 Box-plot of aesthetics and amenities perception by gender.

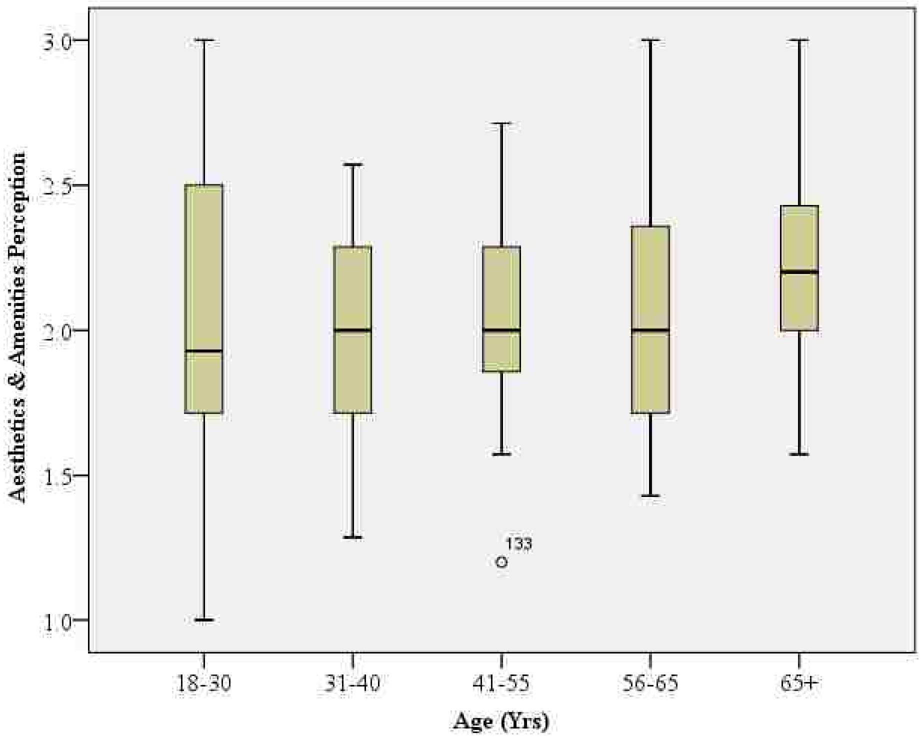


FIGURE 7-10 Box-plot of aesthetics and amenities perception by age group.

From Figure 7-9 above, men had a more positive average aesthetics and amenities perception compared to women which was statistically significant. Of respondents who reported their gender and walking frequency, there were an equal proportion of both men and women (68%) who reported walking frequently. Overall, there were more female respondents compared to men Table 7-1, which would imply that men walked more frequently than women.

There was a slight increasing trend in aesthetics and amenities perception with increase in age. However, the perception difference was only statistically significant between the two oldest groups, Figure 7-10. It would appear with age advancement, there's more appreciation of surroundings. Alternatively, it could also be interpreted that neighborhoods where older respondents lived had better aesthetics and amenities. In DelWebb neighborhood a retirement community, though it lacked transit use, it had appealing aesthetics that were verified during site visits.

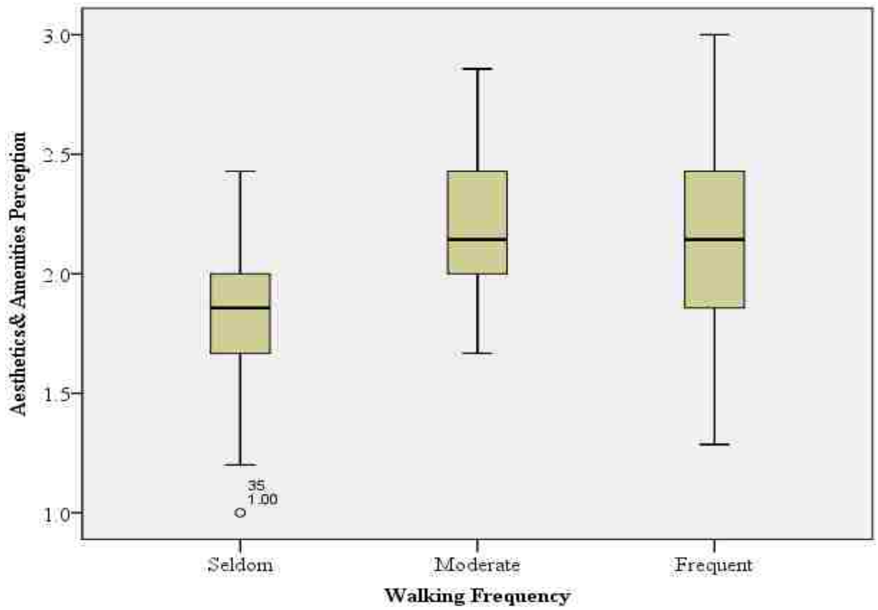


FIGURE 7-11 Box-plot of aesthetics and amenities perception by walking frequency.

Similarly, an increasing trend in aesthetics and amenities perception was evident with increase in walking frequency, Figure 7-11. The aesthetic and amenities perception difference was only statistically significant between respondents who seldom and moderately walked. Intuitively for recreational purposes appealing aesthetics and amenities have a higher likelihood of increasing recreational walking. Studies have reported an association between recreational physical and aesthetics (Millstein et al., 2014; Pikora et al., 2003). Both groups of higher walking frequency have a higher average perception of aesthetics and amenities compared to the seldom walking frequency group. The difference in aesthetics and amenities perception between respondents who seldom and moderately walk was statistically significant. However the perception between moderate and frequent walkers is not. This can be interpreted as, respondents whose neighborhoods have limited amenities and aesthetics seldom walk. Alternatively, respondents who seldom walk, report limited amenities and aesthetics hence the low walking frequency.

7.3.6. Safety Perception Box-plots

The box-plots in Figure 7-12 and Figure 7-13 illustrate the influence gender and age on safety perception. In Figure 7-12 below, men have a more positive safety perception of their neighborhood walking environment compared to women. As earlier indicated, men had higher walking frequency given a higher aesthetics and amenities perception compared to women. In Pikora's (2003) study, safety followed by aesthetics was the most important issues that influenced walking. It is therefore reasonable to expect more walking from men given that they had higher safety and aesthetics and amenities perception compared to women.

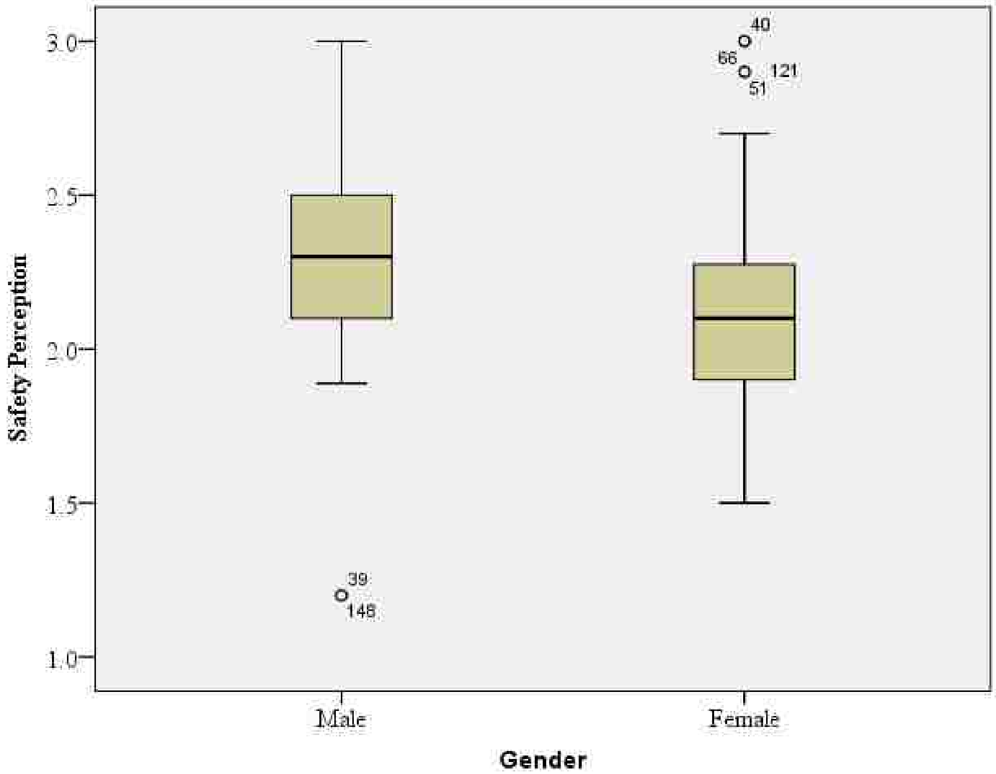


FIGURE 7-12 Box-plot of safety perception by gender.

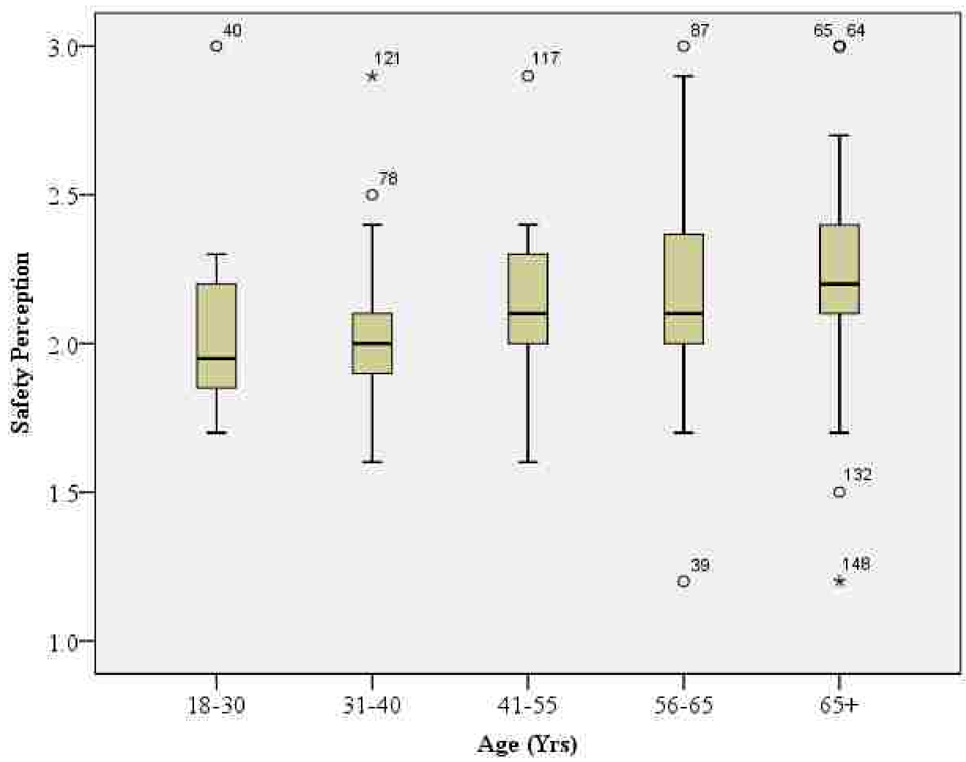


FIGURE 7-13 Box-plot of safety perception by age.

Figure 7-13 illustrates an increasing trend of safety perception with increase in age. However, the difference in safety perception was only significant between the second and third age groups. This would imply that neighborhoods that had more elderly residents were safer compared to other neighborhoods.

7.4. Analysis of Walking Environment Features using Statistical Measures of Association

The second objective of the study was to analyze the features in the built walking environment on walking for recreational or utilitarian purposes. This process was conducted using contingency tables (also referred to as cross-tabulation), Chi-square (χ^2) statistics and Kendall's tau. Contingency tables and χ^2 statistic were used in parallel to identify walking environment features that had significant influence on walking reasons. Kendall's Tau, a directional measure was used to estimate the direction and strength of the impact or relationship between identified features and reasons for walking. Kendall's Tau b and c were used for square and rectangular cross tables respectively, estimated as:

$$\tau = \frac{n_c - n_d}{\frac{1}{2} n(n-1)}$$

Equation (7-1)

Where:

n_c and n_d are the number of concordant pairs and discordant pairs respectively.

Kendall's cutoff measures used for this study were:

TABLE 7- 3 Kendall Tau-b Cutoff Values

Very weak	<	± 0.1
Weak	=	± 0.1 - 0.19
Moderate	=	± 0.2 - 0.29
Strong	>	± 0.3

Consistent with the study organization, perception of walking environment features were grouped into the 5 categories (land use, directness, continuity, aesthetics and amenities and safety) previously used. Walking reasons used in the survey and for analysis included:

1. Walking to access transit,
2. Walking to specific places like store, banks, pharmacy etc.,
3. Walking for exercise,
4. Walking to enjoy the outdoors,
5. Walking to visit neighbors
6. Walking to get out with friends & family
7. Walking pets

7.4.1. Walking Frequency

This section presents features in the walking environment that are associated with walking frequency and reasons for walking. Features in the waking environment and reasons for walking were tested for independence using Chi-square tests. Observed and expected frequencies were used to estimate the Chi-Square (χ^2). If the observed and expected frequencies confirmed a given hypothesis, a trend was identified and presented if there was a less than 5% likelihood of observing the relationship or association by chance. Kendall's Tau was used to identify the strength of the association as well as the direction of, i.e. positive or negative relationship. The tables summarize the walking environment features by category in the first column, as well as providing the χ^2 statistic, degrees of freedom (df), Kendall's Tau (τ) value, its standard error, and significance values for both χ^2 and τ.

TABLE 7-4 Association Measures for Walking Frequency

Category	Walking Environment Features	Chi-Square (χ^2)			Kendall's Tau (τ)		
		χ^2	df	p-value	τ	Std. Error	p-value
Directness	Parking lots	15.684	4	0.00	-0.17	0.07	0.02
Land use	Recreation facilities(in/outdoors)	7.795	4	0.01	0.18	0.08	0.02
Other	Presence of other pedestrians	15.933	4	0.00	0.29	0.06	0.00

Walking frequency is associated with presence of large parking lots in the directness category and availability of recreational facilities in the land use category as well as the presence of other pedestrians, Table 7-4. The following contingency tables summarize observed frequencies - in the first row, expected frequencies - in the second row and the difference between observed and expected frequencies - in the third row for each walking frequency group as illustrated in Table 7-5.

TABLE 7-5 Contingency Table of Large Parking Lots

			Large parking lots at retail stores			Total
			Agree	A bit of both	Disagree	
Walking Frequency	Frequent	Observed (Obs)	11	37	51	**99**
		Expected (Expd)	8.37	47.41	43.23	
		Difference = Obs - Expd	*2.63*	*-10.41*	*7.77*	
	moderate	Observed (Obs)	0	19	8	**27**
		Expected (Expd)	2.28	12.93	11.79	
		Difference = Obs - Expd	*-2.28*	*6.07*	*-3.79*	
	non-walker	Observed (Obs)	1	12	3	**16**
		Expected (Expd)	1.35	7.66	6.99	
		Difference = Obs - Expd	*-0.35*	*4.34*	*-3.99*	
Total			**12**	**68**	**62**	**142**

From Table 7-5, more observed that expected respondents who walked reported large parking lots in front of commercial premises. However there were more frequent walking respondents who disagreed compared to those who agreed. In the non- walking category, less than expected non-frequent walkers reported large parking lots while more than expected frequent walkers reported large parking lots. Typically, patrons tend to park closer to a store to reduce the walking distance and the resulting exposure. Kendall's Tau in Table 7-4 indicates a weak negative association between presence of large parking lots and walking frequency.

TABLE 7-6 Contingency Tables for Presence of Recreational Land Uses & Other Pedestrians

		Recreational facility			Total
		Agree	A bit of both	Disagree	
Walking Frequency	Frequent	56	24	16	**96**
		50.74	25.37	19.89	
		5.26	*-1.37*	*-3.89*	
	moderate	13	5	7	**25**
		13.21	6.61	5.18	
		-0.21	*-1.61*	*1.82*	
	non-walker	5	8	6	**19**
		10.04	5.02	3.94	
		-5.04	*2.98*	*2.06*	
Total		**74**	**37**	**29**	**140**

		Presence of other peds'			Total
		Agree	A bit of both	Disagree	
Walking Frequency	Frequent	42	52	2	**96**
		32.91	61.03	2.06	
		9.09	*-9.03*	*-0.06*	
	moderate	6	20	0	**26**
		8.91	16.53	0.56	
		-2.91	*3.47*	*-0.56*	
	non-walker	0	17	1	**18**
		6.17	11.44	0.39	
		-6.17	*5.56*	*0.61*	
	Total	**48**	**89**	**3**	**140**

More frequent walkers reported recreational facilities within a 15 minute walking distance than expected, Table 7-6. Though weak, the positive association implies nearby recreational facilities will encourage frequent pedestrian activity, Table 7-4. Areas that have high pedestrian activity should be maintained to attract more walkers. The presence of other pedestrians had strong positive significant association with walking frequency indicated by Kendall's Tau-b. More observed frequent walkers than expected felt the presence of other pedestrian made walking a more pleasant experience, Table 7-4. Shriver (2003) reported higher rating for segments with activities which enhances street livability. In Park (2008) regression model, street transparency coefficient had one of the higher values.

7.4.2. Walking to Access Transit

Safety features that influence walking to access transit

Walking to access transit was associated with resident perceptions of speed limits, presence of crossing aids, midblock crosswalks and high traffic volumes, Table 7-7. Majority of the respondents did not use transit, but of the few who did, fewer than expected transit users, felt the speed limits were safe. The almost moderate negative association (Tau-b = -0.189) implies an increase in posted speed limits, reduces the likelihood of walking to access transit.

TABLE 7-7 Association Measures for Walking to Access Transit

Category	Measure	Chi-square (χ^2)			Kendall's Tau-b (τ)		
		χ^2	df	p-value	τ	Std. Error	p-value
Safety	High posted speed limits	10.70	2	0.00	-0.19	0.07	0.01
	Crossing aids(e.g. flashers)	8.65	2	0.01	0.19	0.07	0.01
	Midblock crosswalks	5.96	2	0.05	0.12	0.07	0.10
	High traffic volumes	5.46	2	0.07	-0.14	0.06	0.02
Directness	Cul-de-sacs	4.58	2	0.10	-0.13	0.06	0.03
Aesthetics & Amenities	Presence of trees	7.05	2	0.03	-0.16	0.06	0.01
	Landscaping	6.81	2	0.03	-0.16	0.07	0.02
Land uses	Retail shopping	12.97	2	0.00	0.25	0.07	0.00
	Restaurants	6.70	2	0.04	0.15	0.07	0.00
	Post office	9.89	2	0.01	0.17	0.07	0.00
	Grocery store	7.89	2	0.02	0.12	0.07	0.00
	Bus station	13.22	2	0.00	0.25	0.07	0.00

TABLE 7-8 Contingency Tables for High Traffic Volumes & Posted Speed Limits

		High posted speed limits			**Total**
		Agree	A bit of both	Disagree	
Walking to transit	Transit-u	4	11	4	**19**
		1.31	8.56	9.14	
		2.69	*2.44*	*-5.14*	
	Non-tran	5	48	59	**112**
		7.69	50.44	53.86	
		-2.69	*-2.44*	*5.14*	
Total		**9**	**59**	**63**	**131**

		High traffic volumes			**Total**
		Agree	A bit of both	Disagree	
Walking to transit	Transit-user	2	14	3	**19**
		1.16	10.59	7.25	
		0.84	*3.41*	*-4.25*	
	Non-transit user	6	59	47	**112**
		6.84	62.41	42.75	
		-0.84	*-3.41*	*4.25*	
Total		**8**	**73**	**50**	**131**

More observed transit users than expected reported high traffic volumes. Intuitively, high traffic volumes can convey safety risk perceptions, reducing the likelihood of walking to access transit implied by the negative though weak association, Table 7-8. However it would seem neighborhoods with transit stops do not have high posted speed-limits or high traffic volumes.

TABLE 7-9 Contingency Tables for Availability of Crosswalks and Crossing-aids

		Crossing-aids available			
		Agree	A bit of both	Disagree	**Total**
Walking to transit	Transit-user	8	7	3	**18**
		3.95	6	8.05	
		4.05	*1.00*	*-5.05*	
	Non-transit user	21	37	56	**114**
		25.05	38	50.95	
		-4.05	*-1.00*	*5.05*	
Total		**29**	**44**	**59**	**132**

		Midblock-crosswalks available			
		Agree	A bit of both	Disagree	**Total**
Walking to transit	Transit-user	7	6	6	**19**
		3.29	7.43	8.29	
		3.71	*-1.43*	*-2.29*	
	Non-transit user	16	46	52	**114**
		19.71	44.57	49.71	
		-3.71	*1.43*	*2.29*	
Total		**23**	**52**	**58**	**133**

Availability of crosswalks and crossing aids are positively associated with walking to access transit, Table 7-9. More observed transit users than expected reported pedestrian crossing aids like flashers and signs as well as crosswalks. Few observed than expected non-transit users reported presence of crossings aids and crosswalks indicated in Table 7-9. The positive association between transit use and crossing aids illustrated in Table 7-7 implies higher likelihood of transit use with increased presence of crossing aids and crosswalks which would probably make transit users feel safer.

Directness features that influence walking to access transit

Cul-de-sacs in the directness category indicated a relationship with transit access walking. Of transit users, more than expected reported few cul-de-sacs in their neighborhoods, Table 7-10. This would imply fewer cul-de-sacs associated with enclosed communities in neighborhoods whose respondents used transit.

TABLE 7-10 Contingency Table of Presence of Many Cul-de-sacs

		Presence of many cul-de-sacs			**Total**
		Agree	A bit of both	Disagree	
Walking to transit	Transit-user	0	9	10	**19**
		2.74	9.12	7.14	
		-2.74	*-0.12*	*2.86*	
	Non-transit user	18	51	37	**106**
		15.26	50.88	39.86	
		2.74	*0.12*	*-2.86*	
Total		**18**	**60**	**47**	**125**

More than expected non-transit users reported presence of many cul-de-sacs in their neighborhoods. Intuitively, cul-de-sacs inhibit directness and continuity of routes. The negative association shown in Table 7-7 implies reduced likelihood of walking to access transit with increase of cul-de-sacs though the relationship is weak.

Aesthetics and amenities features that influence walking to access transit

In the aesthetics category, there was a significant relationship between perception of presence of trees, landscaping and with transit access walking.

TABLE 7-11 Contingency Tables for Presence of Trees and Attractive Landscaping for Transit Walking

		Presence of trees			**Total**
		Agree	A bit of both	Disagree	
Walking to transit	Transit-user	5	12	3	**20**
		10.45	7.46	2.09	
		-5.45	*4.54*	*0.91*	
	Non-transit user	65	38	11	**114**
		59.55	42.54	11.91	
		5.45	*-4.54*	*-0.91*	
Total		**70**	**50**	**14**	**134**

		Presence of attractive landscaping			
		Agree	A bit of both	Disagree	**Total**
Walking to transit	Transit-user	4	9	6	**19**
		8.22	7.94	2.84	
		-4.22	*1.06*	*3.16*	
	Non-transit user	54	47	14	**115**
		49.78	48.06	17.16	
		4.22	*-1.06*	*-3.16*	
Total		**58**	**56**	**20**	**134**

Fewer observed transit users than expected reported having trees in their neighborhoods. The weak and negative association indicates neighborhoods inhabited by transit users have fewer trees compared to other neighborhoods, Table 7-11. Fewer observed transit users than expected reported attractive landscaping in their neighborhoods. In addition, fewer than expected transit users reported trees along pedestrian routes. The weak and negative association in Table 7-7 indicates neighborhoods inhabited by transit users have less attractive landscaping as well as trees for shading compared to other neighborhoods.

Land uses that influence walking to access transit

Land uses that had an influence of walking frequency included retail stores, grocery stores, post office, restaurants. The positive association is moderately strong for retail/grocery stores and bus station and weak for restaurants and post office as shown in Table 7-7.

TABLE 7-12 Contingency Tables for Land Uses such as Grocery Stores and Bus Station

		Grocery store			**Total**			Bustop			**Total**
		Agree	A bit of both	Disagree				Agree	A bit of both	Disagree	
Walking to transit	Transit-user	13	3	3		Walking to transit	Transit-user	16	2	2	
		7.72	3.4	7.88				8.69	3.77	7.54	
		5.28	*-0.40*	*-4.88*	**19**			*7.31*	*-1.77*	*-5.54*	**20**
	Non-transit user	37	19	48			Non-transit user	37	21	44	
		42.28	18.6	43.12				44.31	19.23	38.46	
		-5.28	*0.40*	*4.88*	**104**			*-7.31*	*1.77*	*5.54*	**102**
Total		**50**	**22**	**51**	**123**	**Total**		**53**	**23**	**46**	**122**

More transit users reported services such as retail stores, grocery stores, post office, restaurants within a 15min walking distance from their residences than expected, Table 7-12. For respondents who used transit, more access to services would positively impact walking to transit.

7.4.3. Walking to Specific Places

Walking to specific places included trips for utilitarian purposes such as going to work, going to grocery stores, going to eat among others. These were influenced by various walking environment features under safety, directness, continuity, aesthetic and amenities, and land use categories, Table 7-13.

TABLE 7-13 Association Measures for Walking to Specific Places

Category	Measure	Chisq (χ^2)			Kendall's Tau-b (τ)		
		χ^2	df	p-value	τ	Std. Error	p-value
Safety	High posted speed limits	12.10	4	0.02	-0.19	0.09	0.03
	Drivers exceed speed limits	8.30	4	0.08	-0.20	0.09	0.02
	Availability of street parking	7.71	4	0.10	-0.20	0.09	0.02
	Availability of crosswalks & pedestrian signs	8.51	4	0.08	0.21	0.08	0.01
Directness	Cul-de-sacs	16.58	4	0.00	-0.29	0.08	0.00
Aesthetics & Amenities	Presence of trees	8.29	4	0.08	-0.20	0.08	0.01
	Landscaping	9.76	4	0.05	-0.25	0.08	0.00
Land uses	Worship places	7.58	4	0.11	0.23	0.08	0.01
	One's work place	14.36	4	0.01	0.28	0.08	0.00
	Retail-shopping	17.88	4	0.00	0.34	0.08	0.00
	Restaurants	9.84	4	0.04	0.22	0.08	0.01
	Post office	12.73	4	0.01	0.29	0.08	0.00
	Office-building	10.24	4	0.04	0.25	0.08	0.00
	Grocery store	13.07	4	0.01	0.29	0.08	0.00
	Bus station	21.87	4	0.00	0.37	0.07	0.00
	Banks	14.11	4	0.01	0.30	0.08	0.00

Safety features that influence walking to specific places

Features measured under the safety category that significantly influenced walking to specific places included speed limits and drivers exceeding them, streets parking, availability of crosswalks and pedestrian signs, Table 7-13.

TABLE 7-14 Contingency Tables for High Posted Speed Limits and Drivers Exceeding Speed Limits

		High posted speed limits			Total
		Agree	Abit of both	Disagree	
Walking to specific place	Walkers	4	14	14	**32**
		2.19	14.50	15.32	
		1.81	*-0.50*	*-1.32*	
	Moderate walkers	1	19	7	**27**
		1.85	12.23	12.92	
		-0.85	*6.77*	*-5.92*	
	Non-walkers	3	20	35	**58**
		3.97	26.27	27.76	
		-0.97	*-6.27*	*7.24*	
Total		**8**	**53**	**56**	**117**

		Drivers exceeding speed limits			
		Agree	Abit of both	Disagree	**Total**
Walking to specific place	Walkers	17	11	4	**32**
		11.31	16.55	4.14	
		5.69	*-5.55*	*-0.14*	
	Moderate walkers	10	16	2	**28**
		9.90	14.48	3.62	
		0.10	*1.52*	*-1.62*	
	Non-walkers	14	33	9	**56**
		19.79	28.97	7.24	
		-5.79	*4.03*	*1.76*	
Total		**41**	**60**	**15**	**116**

Of frequent walkers, fewer observed than expected perceived posted speed limits being high. Conversely, of respondents who didn't walk to specific places, more observed than expected reported dissatisfaction with posted speed limits, which could explain why they didn't walk to specific places. The negative, almost moderately strong association implies higher posted speed limits have a negative impact on likelihood of walking to specific places, Table 7-13.

More pedestrians than expected walking to specific places reported drivers exceeding speed limits, Table 7-14. Also of respondents who felt drivers exceeded speed limits, fewer than expected walked to specific places. The moderate negative association implies reduced likelihood of pedestrians walking to specific places when drivers exceeded speed limits due to perceived safety risks.

TABLE 7-15 Contingency Tables for Crosswalks & Pedestrian Signs, & Street Parking Availability for Walking to Specific Places

		Street parking available			
		Agree	Abit of both	Disagree	**Total**
Walking to specific place	Walkers	13	13	6	**32**
		18.48	9.66	3.86	
		-5.48	*3.34*	*2.14*	
	Moderate walkers	15	10	2	**27**
		15.59	8.15	3.26	
		-0.59	*1.85*	*-1.26*	
	Non-walkers	39	12	6	**57**
		32.92	17.20	6.88	
		6.08	*-5.20*	*-0.88*	
Total		**67**	**35**	**14**	**116**

		Crosswalk &ped-signs available			
		Agree	Abit of both	Disagree	**Total**
Walking to specific place	Walkers	16	14	3	**33**
		10.54	14.70	7.76	
		5.46	*-0.70*	*-4.76*	
	Moderate walkers	7	14	7	**28**
		8.94	12.47	6.59	
		-1.94	*1.53*	*0.41*	
	Non-walkers	15	25	18	**58**
		18.52	25.83	13.65	
		-3.52	*-0.83*	*4.35*	
Total		**38**	**53**	**28**	**119**

More respondents than expected who do not walk to specific places reported available street parking, Table 7-15. Fewer than expected pedestrians walking to specific places reported no street parking available. The moderate negative association indicates limited street parking in neighborhoods where residents walked to specific places. Street parking helps in calming traffic as well as providing an additional barrier between traffic and pedestrians on sidewalks.

A moderately strong positive association, implying more pedestrian signs & crosswalks increased the likelihood of waking to specific places is indicated in Table 7-15 above. More observed than expected respondents who do not walk to specific places felt there were inadequate pedestrian signs & crosswalks.

Directness features that influence walking to specific places

Cul-de-sacs hinder direct access when walking to specific places indicated in Table 7-13 above. Fewer observed than expected respondents walking to specific places reported many cul-de-sacs in their neighborhoods. However, more observed non-walkers agreed their neighborhoods had many cul-de-sacs, Table 7-16.

TABLE 7-16 Contingency Tables for Availability of Connected Sidewalks and Presence of Many Cul-de-sacs

		Presence of many cul-de-sacs			
		Agree	Abit of both	Disagree	**Total**
Walking to specific place	Walkers	2	11	18	**31**
		4.89	14.96	11.15	
		-2.89	*-3.96*	*6.85*	
	Moderate walkers	1	17	8	**26**
		4.11	12.54	9.35	
		-3.11	*4.46*	*-1.35*	
	Non-walkers	15	27	15	**57**
		9.00	27.50	20.50	
		6.00	*-0.50*	*-5.50*	
Total		**18**	**55**	**41**	**114**

		Connected sidewalks			
		Agree	Abit of both	Disagree	**Total**
Walking to specific place	Walkers	5	11	8	**24**
		1.56	12.49	9.95	
		3.44	*-1.49*	*-1.95*	
	Moderate walkers	0	9	5	**14**
		0.91	7.28	5.80	
		-0.91	*1.72*	*-0.80*	
	Non-walkers	3	44	38	**85**
		5.53	44.23	35.24	
		-2.53	*0.23*	*2.76*	
Total		**8**	**64**	**51**	**123**

Similarly, fewer observed than expected respondents who walked to specific places reported disconnected sidewalks. Of respondents who did not walk to specific places, more observed than expected reported disconnected sidewalks which could explain why they did not walk. The negative almost strong association indicated presence of cul-de-sacs and incomplete sidewalks in neighborhoods where respondents did not walk to specific places. Intuitively, restricted or incomplete routes are synonymous with circuitous routes. While developing a walking permeability index, Allan, (2001) rationalized that pedestrians preferred more direct access between their origin and destinations.

Aesthetics and Amenities features that influence walking to specific places

Similar to the relationship found in walking to access transit, presence of shading by trees and attractive landscaping was also associated with walking to specific places.

TABLE 7-17 Contingency Tables for Presence of Trees and Attractive Landscaping for Walking to Specific Places

		Presence trees			Total
		Agree	Abit of both	Disagree	
Walking to specific place	Walkers	10	18	5	**33**
		16.64	12.13	4.23	
		-6.64	*5.87*	*0.77*	
	Moderate walkers	15	9	4	**28**
		14.12	10.29	3.59	
		0.88	*-1.29*	*0.41*	
	Non-walkers	34	16	6	**56**
		28.24	20.58	7.18	
		5.76	*-4.58*	*-1.18*	
Total		**59**	**43**	**15**	**117**

		Attractive landscaping			Total
		Agree	A bit of both	Disagree	
Walking to specific place	Walkers	8	15	9	**32**
		13.13	13.95	4.92	
		-5.13	*1.05*	*4.08*	
	Moderate walkers	10	14	4	**28**
		11.49	12.21	4.31	
		-1.49	*1.79*	*-0.31*	
	Non-walkers	30	22	5	**57**
		23.38	24.85	8.77	
		6.62	*-2.85*	*-3.77*	
Total		**48**	**51**	**18**	**117**

Fewer observed than expected respondents walking to specific places reported amenities compared to those who didn’t walk to specific places Table 7-17. The negative moderate association indicates neighborhoods where respondents walked to specific places as well as accessing transit had few or no aesthetics or amenities observed. It could be that majority of respondents walking to specific places come from neighborhoods with few trees and or landscaping, hence the negative moderate to strong association implying presence of trees & landscaping reduced the likelihood of walking to specific places.

Land uses features that influence walking to specific places

As expected, a varied land use mix is associated with higher walking frequency as earlier illustrated in Table 7-13. The moderate to very strong association implies having various land uses encourages walking to specific places, especially bus stations and retail stores. Associated contingency tables foe land uses and walking to specific places are attached in Appendix III.

7.4.4. Walking for Exercise

Safety features that influence walking for exercise

Perceptions of elements in the built environment that have a statistically significant relationship with walking for exercise are illustrated in Table 7-18 below. Street parking in the safety category indicates a positive, almost moderately strong relationship with walking for exercise.

TABLE 7-18 Association Measures for Exercise Walking

Category	Measure	Chisq χ^2			Kendall's Tau-b (τ)		
		χ^2	df	p-value	(τ)	Std. Error	p-value
Safety	Street parking	8.15	4	0.09	0.17	0.08	0.04
Aesthetics & Amenities	Presence of trashcans	9.57	4	0.05	0.22	0.07	0.00
	Landscaping	9.71	4	0.05	0.20	0.08	0.01
Land uses	One's work place	10.21	4	0.04	-0.23	0.10	0.03
	Recreation facilities(in/outdoors)	13.33	4	0.01	0.25	0.08	0.01
	Grocery store	7.95	4	0.09	-0.19	0.08	0.02
Other	Presence of other pedestrians	11.12	4	0.03	0.26	0.07	0.00

TABLE 7-19 Contingency Tables for Availability of Street Parking & Presence of Other Pedestrians

		Street parking available			**Total**
		Agree	A bit of both	Disagree	
Walking for excercise	Walkers	66	23	12	**101**
		60.45	27.28	13.27	
		5.55	*-4.28*	*-1.27*	
	Moderate walkers	14	13	4	**31**
		18.55	8.37	4.07	
		-4.55	*4.63*	*-0.07*	
	Non-walkers	2	1	2	**5**
		2.99	1.35	0.66	
		-0.99	*-0.35*	*1.34*	
Total		**82**	**37**	**18**	**137**

		Presence of other peds'			**Total**
		Agree	A bit of both	Disagree	
Walking for excercise	Walkers	43	56	2	**101**
		35.16	63.59	2.24	
		7.84	*-7.59*	*-0.24*	
	Moderate walkers	3	26	1	**30**
		10.44	18.89	0.67	
		-7.44	*7.11*	*0.33*	
	Non-walkers	1	3	0	**4**
		1.39	2.52	0.09	
		-0.39	*0.48*	*-0.09*	
Total		**47**	**85**	**3**	**135**

More observed than expected respondents walking for exercise reported street parking, Table 7-19. Street parking has a positive impact on walking for exercise though the association is not as strong. Street parking provides an additional buffer between pedestrians and traffic as well as calming traffic down due to narrow lanes. Though not worded as safety element, the presence of other pedestrians in the walking environment is associated with a more pleasant walking experience. The positive, moderate association indicates busier paths or routes will most likely increase walking for exercise. Ewing, (1999) reported that the presence of other pedestrians was reported to enhances a sense of safety and community.

Amenities and aesthetics features that influence walking for exercise

Elements in amenities and aesthetics such as landscaping and presence of trashcans had moderately strong association with walking for exercise.

TABLE 7-20 Contingency Tables for Availability of Trashcans & Attractive Landscaping for Exercise Walking

		Trashcans available			
		Agree	Abit of both	Disagree	**Total**
Walking for excercise	Walkers	23	30	52	**105**
		17.75	28.84	58.42	
		5.25	*1.16*	*-6.42*	
	Moderate walkers	1	7	24	**32**
		5.41	8.79	17.80	
		-4.41	*-1.79*	*6.20*	
	Non-walkers	0	2	3	**5**
		0.85	1.37	2.78	
		-0.85	*0.63*	*0.22*	
Total		**24**	**39**	**79**	**142**

		Attractive landscaping			
		Agree	Abit of both	Disagree	**Total**
Walking for excercise	Walkers	54	40	12	**106**
		47.77	42.55	15.68	
		6.23	-2.55	-3.68	
	Moderate walkers	7	16	8	**31**
		13.97	12.44	4.58	
		-6.97	3.56	3.42	
	Non-walkers	3	1	1	**5**
		2.25	2.01	0.74	
		0.75	-1.01	0.26	
Total		**64**	**57**	**21**	**142**

More than the expected respondents walking for exercise reported attractive landscaping in their neighborhoods, Table 7-20. The positive association implies that neighborhoods with attractive aesthetics and amenities are bound to attract recreational walking Table 7-18. Provision of trash cans for discarding trash instead of carrying it around or trashing sidewalks/paths offers conveniences while walking for exercise. Pedestrians can carry water and snacks during their walk and dispose of trash, thus maintaining the cleanliness of their routes. Better landscaping increases the likelihood of walking for both utilitarian and recreational purposes.

Land uses that influence walking for exercise

Respondents walking for recreational purposes reported various land uses, such their work places, grocery stores and recreational facilities. Of respondents who walked for exercise, more observed than expected reported their work places being more than 15min walk of their residences Table 7-21. On the other hand more observed respondents who did not walk for exercise reported their work places being within 15min walk of their residences. The moderate negative association implies offices being nearer to residences within 15min of residences would not encourage walking for exercise. This implies if work places were closer to residences, respondents might still not walk to work for exercise but maybe for utilitarian purposes. The relationship between walking for exercise and recreational facilities within 15 minutes of residences is moderately strong and positive.

TABLE 7-21 Contingency Tables for Workplace & Recreational Facility Land Uses

		One's workplace						Recreational facility			**Total**
		Agree	Abit of both	Disagree				Agree	Abit of both	Disagree	
Walking for excercise	Walkers	6	4	74	**84**	Walking for excercise	Walkers	63	20	17	**100**
		8.40	6.30	69.30				54.01	26.28	19.71	
		-2.40	*-2.30*	*4.70*				*8.99*	*-6.28*	*-2.71*	
	Moderate Walkers	4	4	23	**31**		Moderate Walkers	10	13	9	**32**
		3.10	2.33	25.58				17.28	8.41	6.31	
		0.90	*1.68*	*-2.58*				*-7.28*	*4.59*	*2.69*	
	Non-walkers	2	1	2	**5**		Non-walkers	1	3	1	**5**
		0.50	0.38	4.13				2.70	1.31	0.99	
		1.50	*0.63*	*-2.13*				*-1.70*	*1.69*	*0.01*	
		12	**9**	**99**	**120**	**Total**		**74**	**36**	**27**	**137**

More observed than expected respondents who had access to recreational facilities reported walking for exercise Table 7-21. There is a moderate negative relationship between walking for exercise and presence of grocery stores within 15min walk of residences. This would imply walking to grocery stores is not associated with walking for exercise but more for utilitarian purposes. Cervero and Kockelman, (1997) reported having small grocery stores within a neighborhood increased the potential for chained trips. Of respondents walking for exercise, few observed grocery stores close to their residences.

7.4.5. Social Walking

Reasons for social walking included in walking to enjoy the outdoors, visiting neighbors, getting out with friends and family as well as walking pets, Table 7-22.

TABLE 7-22 Association Measures for Social Walking

Category	Walking Reason	Measure	Chisq (χ^2) χ^2	df	p-value	Kendall's Tau (τ) τ	Std. Error	p-value
Safety	Enjoy the Outdoors	Street parking	24.69	4	0.00	0.21	0.09	0.02
Safety	Visit neighbors	Availability of crosswalks & pedestrian signs	9.55	4	0.05	0.21	0.07	0.00
Directness	Visit neighbors	Intersection distance	10.43	4	0.03	0.26	0.07	0.00
Land uses	Enjoy the Outdoors	Post office	7.77	4	0.10	-0.17	0.09	0.05
	Out with friends & family	Post office	9.61	4	0.05	0.23	0.08	0.01
	Visit neighbors	Post office	16.37	4	0.00	0.22	0.09	0.02
	Enjoy the Outdoors	Clinics/pharmacy	7.77	4	0.10	-0.16	0.08	0.05
	Visit neighbors	One's work place	16.89	4	0.00	0.28	0.09	0.01
		Banks	8.86	4	0.07	0.19	0.09	0.03
	Out with friends & family	Banks	8.65	4	0.07	0.22	0.08	0.01
		Worship places	16.37	4	0.00	0.34	0.08	0.00
		Restaurants	11.67	4	0.02	0.27	0.07	0.00
		Bus station	8.75	4	0.07	0.18	0.09	0.03

TABLE 7-23 Contingency Table of Street Parking for Social Walking

		Street parking available			
		Agree	A bit of both	Disagree	**Total**
Walk to enjoy outdoors	Walkers	61	18	10	**89**
		54.08	24.65	10.27	
		6.92	*-6.65*	*-0.27*	
	Moderate Walkers	18	18	3	**39**
		23.70	10.80	4.50	
		-5.70	*7.20*	*-1.50*	
	Non-walkers	0	0	2	**2**
		1.22	0.55	0.23	
		-1.22	*-0.55*	*1.77*	
Total		**79**	**36**	**15**	**130**

In the safety category, features that had moderate significant relationships with walking for social purposes included street parking, availability of crosswalks and pedestrian sign/signals. There were more observed than expected social walkers who walked frequently that reported presence of street parking available. Of respondents who seldom walked more observed than expected reported limited street parking as illustrated in Table 7-23. Together with the positive association between social walking and street parking Table 7-22, increasing street parking, a traffic calming technique as well as serving as a buffer between pedestrians and traffic is most likely to increase social walking.

TABLE 7-24 Contingency Tables of Intersection Distance & Availability of Crosswalks & Pedestrian Signs

		Crosswalk &ped-signs available			**Total**			Short intersection distance			**Total**
		Agree	A bit of both	Disagree				Agree	A bit of both	Disagree	
Walk to visit neighbors	Walkers	9	11	1	**21**	Walk to visit neighbors	Walkers	13	5	0	**18**
		6.88	9.41	4.71				8.20	6.91	2.89	
		2.12	*1.59*	*-3.71*				*4.80*	*-1.91*	*-2.89*	
	Moderate Walkers	24	24	15	**63**		Moderate Walkers	29	22	11	**62**
		20.64	28.24	14.12				28.23	23.80	9.96	
		3.36	*-4.24*	*0.88*				*0.77*	*-1.80*	*1.04*	
	Non-walkers	5	17	10	**32**		Non-walkers	9	16	7	**32**
		10.48	14.34	7.17				14.57	12.29	5.14	
		-5.48	*2.66*	*2.83*				*-5.57*	*3.71*	*1.86*	
Total		**38**	**52**	**26**	**116**	**Total**		**51**	**43**	**18**	**112**

From Table 7-24, more observed than expected respondents who walked to visit neighbors reported availability of crosswalks and pedestrian signs as well as short spacing between intersections in their neighborhoods. Intuitively, providing safe locations for pedestrian-vehicular interaction should reduce instances of jaywalking. However studies have shown more pedestrian injuries at intersections and marked crosswalks compared to jaywalking. This could be due to risky pedestrian and driver behavior (Dultz et al., 2013).

Intuitively, walking to the post office and clinic/pharmacy had negative significant relationship with recreational walking. Contingency tables for land use associated with social walking are attached in Appendix IV.

7.5. Summary

This chapter presented the descriptive summary statistics, analyzing the impact of features in the built walking environment and various socio-demographic variables on walking for recreational or utilitarian purposes. The summaries are as follows:

1. Overall perception was comprised of land use, directness, continuity, safety and aesthetics and amenities perceptions. Socio-demographic variables that influence overall perception included gender, walking frequency and car-availability. Male respondents, respondents who frequently walk, and respondents who seldom had vehicles available to them had a more positive overall perception of the walking environment.
2. In general, respondents who walk more frequently such as transit users and those who seldom had vehicles available to them had higher land use perception. Intuitively, more walking exposes respondents to their walking environment which would make them more familiar with land uses within their neighborhoods.
3. Directness and Continuity perceptions were mainly influenced by age. The third and fourth age groups between (41-65 years) had the lowest and highest directness perception respectively.
4. Continuity perception declined between the first two age groups then started ascending with advance in age; implying neighborhoods with older residents had better continuity

features. Continuity was also influenced by residency, which showed an increasing trend for new residents and then leveled off, implying no new discoveries with increased residency.

5. Aesthetics and Amenities perception was influenced by gender, age and walking frequency. Men had a more positive average aesthetics and amenities perception compared to women. There was a slight increasing trend in aesthetics perception with increase in age which was significant between the two oldest age-groups. This could imply that neighborhoods where older respondents live have better aesthetics and amenities. Respondents with moderate and frequent walking frequency had higher average perception of aesthetics and amenities compared to the seldom walking frequency group.

6. Safety perception was mainly influenced by gender and age. Men had a more positive safety perception of their neighborhood walking environment compared to women. There was an increasing trend of safety perception with increase in age. The difference in safety perception was significant between the second and third age groups (31-55 years). This implies that neighborhoods that have more elderly residents are safer compared to other neighborhoods.

In addition to observing trends, relationships of features in the built environment were observed for their impact on walking frequency and reasons for walking. Some of the measured elements that featured often with significant negative influence - on walking frequency and walking to access transit - included high posted speed-limits and high traffic volumes, presence of obstructions and cul-de-sacs. Features that had positive significant influence on walking - frequency, walking to access transit and social walking - include land uses, presence of attractive landscaping, street parking, connected sidewalks and availability of crosswalks and pedestrian signs. For recreational walking features that exhibit significant positive association, include street parking, presence of trash cans, presence of other pedestrians and presence of recreational land uses.

CHAPTER 8

DESCRIPTIVE SUMMARY RESULTS AND STATISTICS OF NEIGHBORHOOD AUDITS

8.1. Introduction

This chapter presents descriptive summary statistics of the audit data. The neighborhood audit was conducted on 497 segments and approximately 182 miles.

8.2. Audit Safety Features

At locations where pedestrians are exposed to traffic, the interaction should be facilitated as safely as possible. Table 8-1 below presents a summary of safety infrastructure that were catalogued, reduced and used to estimate scores as illustrated in Section 4.5. As indicated in the same section, weights were applied to audit observations depending on how the data was collected. For example, there are typically four curb ramps catalogued at an intersection, unless a leg was missing. This resulted in large values which would overwhelm other constituents in the category, hence the weighting. Neighborhoods that had many intersections also had high curb ramp density such as 5^{th} & Carey. The lowest density of curb ramps was found in Via Greco neighborhood. Curb ramps enforced by the Project Civic Access (PCA) (US DOJ, 2007), are required at all pedestrian crossings to especially facilitate accessibility for people with disabilities.

TABLE 8-1 Summary of Audit Safety Features

AUDIT	Neighborhoods										
	5th & Carey	Euclid	Sonterra-Apts	Sunset & Boulder	DelWebb	DesertSky-Apts	San Destin	ViaGreco	Anthem	Historic Alta	SpanishTrail
Income Group	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**	**5**
Total number of segments	49.00	67.00	40.00	56.00	42.00	33.00	33.00	46.00	21.00	56.00	54.00
Total segment Length (miles)	17.67	25.43	14.73	18.39	14.02	12.04	12.43	13.97	8.25	19.06	25.65
Traffic controls per mile											
Traffic Signal density	3.28	2.79	4.01	0.76	0.86	1.58	2.17	0.29	0.48	3.73	1.83
Dedicated turning arrow (protected lefts)	5.21	5.43	7.13	1.31	1.57	3.16	4.18	0.57	0.61	6.30	3.43
Channelized (island) right turn lanes	0.68	0.47	0.68	0.33	0.14	0.17	0.00	0.00	0.00	0.63	0.08
Exclusive right turns	1.30	2.01	2.31	1.36	0.57	2.08	1.13	1.72	0.61	0.94	1.29
Exclusive right turns (channelized added)	1.98	2.48	2.99	1.69	0.71	2.24	1.13	1.72	0.61	1.57	1.36
Pedestrian Signals	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00
Pedestrian Signs	4.98	3.46	1.43	0.49	3.07	0.75	3.22	1.72	3.03	2.57	1.29
Pedestrian crosswalks	1.64	1.06	0.34	0.11	1.07	0.17	0.32	0.57	0.36	0.73	0.35
Curb Ramps	20.06	18.32	12.97	11.01	14.62	9.43	10.78	7.80	8.73	15.58	8.44
Yield, 2-Way stop sign	1.64	1.85	0.75	2.45	0.64	2.16	0.64	1.50	0.36	1.21	0.82
4-Way Stop signs	0.51	0.31	0.54	0.87	1.57	0.00	1.13	0.07	0.00	0.05	0.23
Traffic Circles	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Speed bumps/dips	0.85	1.65	0.34	0.71	0.29	1.41	0.32	0.57	0.00	1.89	0.27
Proportion of segments with chicanes or chokers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.26	0.00
Proportion of streets with raised median/median alerts	0.43	0.27	0.20	0.32	0.48	0.15	0.45	0.13	0.52	0.45	0.11
Proportion of segments with school zones	0.31	0.27	0.05	0.04	0.05	0.03	0.36	0.15	0.10	0.13	0.09
Proportion of segments with bike lanes	0.04	0.13	0.00	0.30	0.21	0.12	0.03	0.20	0.24	0.14	0.20
Proportion of segments with emergency zones	0.00	0.06	0.00	0.00	0.00	0.00	0.03	0.04	0.10	0.04	0.09
Proportion of segments with buffer....											
Trees	0.10	0.09	0.08	0.07	0.43	0.06	0.52	0.00	0.19	0.09	0.09
Fence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.02	0.00
Landscape(desert)	0.00	0.01	0.03	0.05	0.07	0.00	0.21	0.15	0.00	0.05	0.04
Permanent hedges	0.12	0.19	0.10	0.13	0.50	0.18	0.48	0.43	0.52	0.16	0.26
Temporary/flexible grass hedges	0.00	0.16	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00
Other safety elements											
Average no. of lanes	3.92	3.57	1.73	2.88	3.40	3.18	4.52	2.96	2.24	3.79	4.50
Proportion of 2-way segments	0.94	0.99	0.93	0.98	1.00	0.97	1.00	1.00	0.95	0.93	1.00
Proportion of >25mph segment	0.49	0.52	0.73	0.43	0.52	0.45	0.73	0.33	0.24	0.57	0.70
Proportion of segment with onstreet parking	0.47	0.46	0.35	0.50	0.36	0.18	0.09	0.15	0.00	0.38	0.07
Proportion of segment with streetlights	0.96	0.97	1.00	0.93	1.00	0.73	1.00	0.63	1.00	0.88	1.00
Overall Safety Subscore	**9.13**	**6.70**	**7.14**	**2.25**	**5.52**	**2.40**	**5.04**	**1.18**	**3.62**	**8.61**	**2.20**

Pedestrian signals and crosswalks were catalogued as infrastructure that facilitates safe interaction between pedestrian and vehicles. The neighborhood with the highest density of pedestrian signals was Sonterra, being close to UNLV and surrounded by high land use mix. Several studies have reported more pedestrian crashes at marked crosswalks than due to jaywalking (Dultz et al., 2013; Zegeer et al., 2004). The Manual of Uniform Traffic Control Devices (MUTCD) recommends no signal control at crosswalks located within 300 feet of traffic control signals, unless traffic progression is uninhibited (FHWA MUTCD, 2009). Some of the neighborhoods that could benefit from pedestrian signals include 5th & Carey and Euclid subject to traffic and safety studies.

Buffers are necessary to provide separation between traffic and pedestrians on sidewalks. Especially with recent incidents of errant vehicles hitting pedestrian while they wait for transit, (Velotta, 2015), buffers if resistant to impact, provide protection while serving as traffic calming measures. Buffers can be in the form of trees, landscaping between sidewalk and street, permanent barriers such as fences, and poles. Neighborhoods with the highest buffer densities were San Destin and DelWebb, while Sonterra Apartments had the least.

8.3. Audit Land Uses

The overall land use sub score expressed variety of land uses found within a neighborhood's study limits. It was estimated as the ratio of land use mix available within a buffer using Clark County Assessor’s parcel area data and the land uses provided in the survey. From Table 8-2 below, lower income neighborhood in income groups one and two had a more varied land use mix compared to higher income neighborhoods.

TABLE 8-2 Summary of Audit Land Uses

AUDIT	Neighborhoods										
	5th & Carey	Euclid	Sonterra-Apts	Sunset & Boulder	DelWebb	DesertSky-Apts	San Destin	ViaGreco	Anthem	Historic Alta	SpanishTrail
Income Group	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**	**5**
# of Transit stops	9	16	13	10	0	6	2	0	0	25	9
Landuse sub-score	**1.00**	**0.82**	**0.91**	**0.73**	**0.27**	**0.64**	**0.64**	**0.27**	**0.64**	**0.82**	**0.91**

Neighborhood with the least number of land uses were DelWebb and Via Greco were predominantly residential. 5th & Carey neighborhood has the ideal mix of land uses that had a higher likelihood of attracting walking trips. Anthem neighborhood had the highest number transit stops while DelWebb, Via Greco and Anthem neighborhoods had none.

8.4. Audit Directness Features

Directness features evaluated the time it took, and the ease with which pedestrian can get between their origin and destinations. Ease of walking, is with respect to the gradient of the walking routes. A summary of audited directness features is presented in Table 8-3. The proportion of gated communities along a segment represented circuitous routes that pedestrians have to use to get to their destinations. Sidewalk gradient represented the ease of getting between origin and destination. The lower the value, the gentler the sidewalk was. The average floor area ratio was used to express walking impedance due to presence of large parking lots in front commercial premises. A larger ratio represented shorter distances or smaller parking lots in front of commercial premises. As earlier indicated in Section 4.5, FAR being a ratio was weighted more to include its influence in the overall directness score.

DelWebb neighborhood ranked lowest in terms of directness given it had the highest average sidewalk gradient. In addition, there were only two types of land uses which constituted low FAR; as well as being walled, walking access to the land uses was inhibited even thought there were several ingress and egress points.

TABLE 8-3 Summary of Audit Directness Features

AUDIT	Neighborhoods										
	5th & Carey	Euclid	Sonterra-Apts	Sunset & Boulder	DelWebb	DesertSky-Apts	San Destin	ViaGreco	Anthem	Historic Alta	SpanishTrail
Income Group	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**	**5**
Proportion of segments with gated , walled communities	0.20	0.15	0.30	0.32	0.55	0.45	0.70	0.39	0.38	0.32	0.83
Average sidewalk gradients (flat=0, slight hill=1, steep h	0.10	0.19	0.28	0.02	1.29	0.21	0.45	0.24	0.90	0.13	0.19
Average Floor Area Ratio	0.13	0.17	0.20	0.06	0.01	0.11	0.07	0.03	0.07	0.22	0.20
Overall directness subscore	**0.28**	**0.38**	**0.44**	**0.13**	**0.01**	**0.31**	**0.13**	**0.06**	**0.14**	**0.49**	**0.44**

Via Greco neighborhood had similar circumstances only, that it had one ingress and egress point. San Destin neighborhood had the highest proportion of segments with gated or walled communities. Euclid Apartments had the lowest proportion of gated communities. Sunset & Boulder had the highest proportion of flat sidewalks, while Alta had the highest FAR.

8.5. Audit Continuity Features

Features under the continuity category estimated the completeness of a route providing an uninterrupted and obstruction-free trip. Incomplete facilities present safety risks such as walking in traffic while trying to maneuver around obstructions.

Intersection density had the highest values in the continuity category between 36 and 145 intersections/mile including signalized and unsignalized intersections that were mainly in a grid like pattern. A high intersection density represented higher route continuity. In some macro-scale studies, intersection density has been used to represent presence of sidewalks. However, as Table 8-4 shows, there segments with broken and incomplete sidewalks as well as dead ends, which are not necessarily captured in macro-scale studies' intersection density values. For example, Alta neighborhood with the highest intersection density also has a high proportion of segments with incomplete sidewalk.

TABLE 8-4 Summary of Audit Continuity Features

AUDIT	Neighborhoods										
	5th & Carey	Euclid	Sonterra-Apts	Sunset & Boulder	DelWebb	DesertSky-Apts	San Destin	ViaGreco	Anthem	Historic Alta	SpanishTrail
Income Group	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**	**5**
Int Density (in GIS) per sq mile	57.34	61.69	94.12	44.51	102.27	44.46	104.25	77.32	36.07	145.41	120.49
obstructions per mile											
Temporary signs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Permanent signs	0.01	0.02	0.06	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00
Tree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Utility Poles/hydrants	0.09	0.29	0.05	0.09	0.00	0.01	0.03	0.00	0.00	0.50	0.01
Magazine racks/cabinets	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
Transit shelters/benches	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parked cars	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Driveways	38.82	62.52	36.32	29.47	32.52	14.12	10.46	8.45	16.36	52.52	11.15
Proportion of segments with sidewalks	0.96	0.96	0.98	0.84	1.00	0.91	0.97	0.87	1.00	0.91	0.98
Proportion of segments with sidewalk breaks e.g dirt-pa	0.16	0.19	0.25	0.77	0.38	0.45	0.18	0.76	0.57	0.41	0.59
Average sidewalk width	1.92	1.73	2.00	1.77	2.00	1.76	1.94	1.54	1.62	1.73	1.96
Proportion of segments with deadend	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.13	0.04
Overall Continuity Subscore	**3.02**	**0.73**	**4.92**	**0.69**	**5.35**	**3.39**	**7.98**	**3.96**	**2.45**	**4.55**	**7.27**

The most prevalent obstructions per mile were street infrastructure such as utility poles and hydrants, permanent signs, and driveways. Euclid neighborhood had the highest number of driveways at 62.52 driveways per segment mile. This neighborhood is largely comprised of homes that have been converted to offices hence the large number of driveways on small pieces of land. In addition, mean street width was average with a lot of the street furnishing obstructing the sidewalks. Majority of average sidewalk width on segments with sidewalks was at least five feet compliant with Clark County Standards, though littered with street infrastructure that presented obstructions.

8.6. Audit Aesthetics and Amenities Features

More pedestrian activity can be found where the physical environment meets the comfort and convenience of the user. Cervero and Kockelman (1997) compared amenities as basic to pedestrian what is basic for motorists.

From Table 8-5 below, the neighborhood with the highest average score for Aesthetics and amenities was Anthem while Euclid scored the lowest. Anthem and DelWebb neighborhoods predominantly had well maintained sidewalks and lacked most of the physical and social disorders. In addition, trash cans and resting spots that were mainly found at transit stops in most neighborhoods were scattered along sidewalks in Anthem and DelWebb neighborhoods, whether transit stops were available or not. Majority of the segments audited in DelWebb neighborhood had trees that provided shade along the sidewalks. Conversely, even though Euclid neighborhood had shading on most of the sidewalks, majority of the audited segments exhibited physical and social disorders such as trash, graffiti and unmaintained lots and buildings. Previous studies reported some of the features that influence walking and cycling as;

low pollution levels, presence of trees, sidewalk maintenance as well as landscape attractiveness and diversity and presence of recreational facilities (Park, S., 2008; Shriver, K., 2003).

TABLE 8-5 Summary of Audit Aesthetics and Amenity Features

AUDIT	Neighborhoods										
	5th & Carey	Euclid	Sonterra-Apts	Sunset & Boulder	DelWebb	DesertSky-Apts	San Destin	ViaGreco	Anthem	Historic Alta	SpanishTrail
Income Group	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**	**5**
Amenities											
Proportion of segments with garbage cans	0.41	0.43	0.48	0.20	0.00	0.09	0.15	0.11	0.10	0.43	0.17
Proportion of segments with benches	0.12	0.21	0.13	0.07	0.02	0.00	0.00	0.11	0.05	0.18	0.00
Proportion of segments with working Water Fountain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Proportion of segments with bicycle racks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Proportion of segments with vendors/vending machines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Proportion of segments with covered transit shelters	0.41	0.39	0.48	0.14	0.00	0.09	0.06	0.00	0.00	0.34	0.17
Proportion of segments with timetable	0.08	0.01	0.03	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Proportion of segments with shading (trees, overhead	0.29	0.75	1.00	0.05	0.74	0.15	0.73	0.04	0.38	0.79	0.20
Cleanliness/presence of physical disorders											
Proportion of segments with abandoned cars	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Proportion of segments with buildings with broken/board	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Proportion of segments with broken glass	0.00	0.01	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Proportion of segments with beer/liquor bottles/cans	0.18	0.10	0.20	0.00	0.00	0.03	0.00	0.00	0.00	0.05	0.07
Proportion of segments with litter	0.57	0.63	0.70	0.27	0.00	0.12	0.03	0.11	0.00	0.41	0.28
Proportion of segments with neighborhood watch signs	0.14	0.13	-	0.04	0.00	0.09	0.45	0.02	0.05	0.00	0.13
Proportion of segments with umaintained compounds/ e	0.63	0.61	0.13	0.70	0.00	0.82	0.18	0.78	0.19	0.20	0.50
Proportion of segments with Graffiti	0.35	0.27	0.23	0.16	0.00	0.06	0.06	0.04	0.00	0.11	0.06
Average condition of Sidewalk conditions	2.29	1.67	2.20	2.32	3.00	2.61	2.88	2.15	3.00	1.93	2.93
OverallAmenities/Aesthetics subscore	**1.41**	**1.22**	**2.28**	**1.53**	**3.27**	**1.72**	**2.93**	**1.33**	**2.96**	**2.24**	**2.27**

8.7. Comparison of Audit Walking Environment Features and Resident Perception

After audit data was summarized and standardized, it was plotted against aggregated resident perceptions to observe how perceptions compared to objective audit observations. The graphs are plotted by safety, continuity, directness, and land use, and aesthetics and amenities categories. Brown et al. (2007) noted that facilities that were objectively rated as more walkable by trained auditors were also perceived in a similar manner by their survey participants. The graphs' plot area is divided into boxes of quality grades from poor to excellent in increasing order from left to right.

8.7.1. Comparison of Audit Safety Features and Safety Perception

From Figure 8-1 below, resident perception of safety features in walking environment was relatively similar to the features observed during the audit expect in three neighborhoods. There was no distinct pattern between audit observation and resident perceptions. There was also little variance between observations as well as resident safety perceptions. Anthem audit has limited accuracy due to limited access, not only for the auditors, but also for Google Staff who provided satellite imagery.

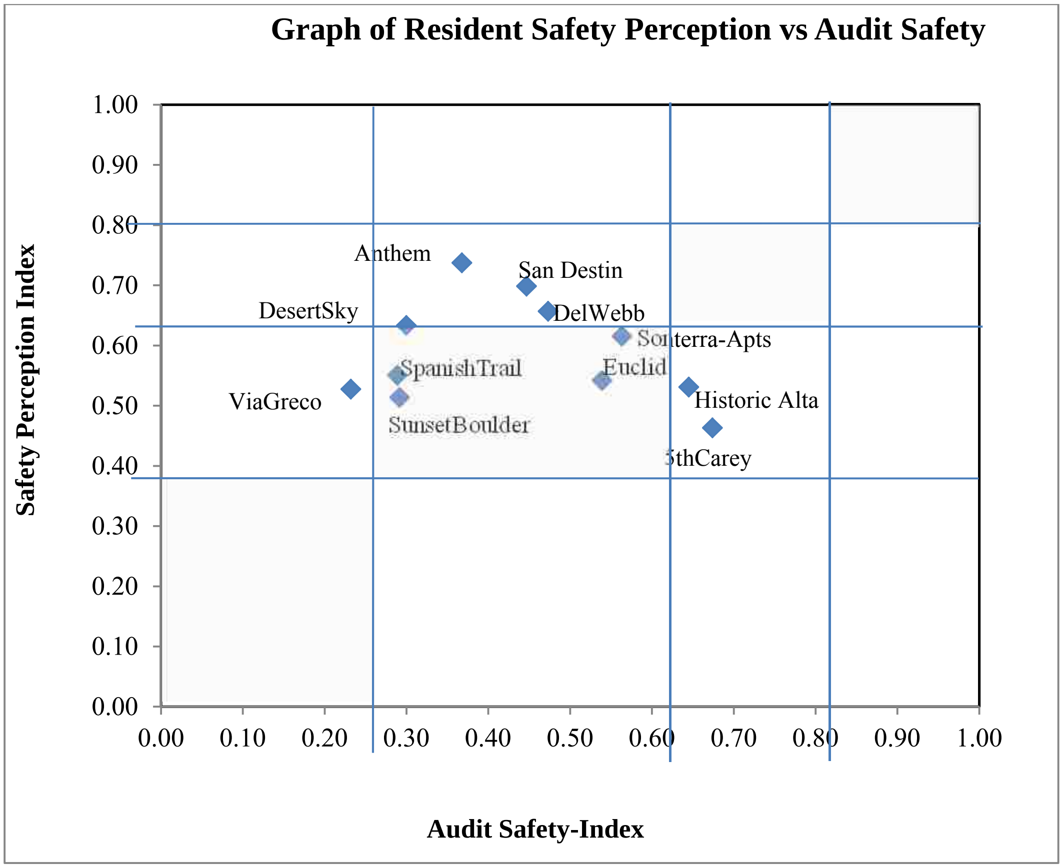


FIGURE 8-1 Comparison of audit safety vs resident safety perception.

In Via Greco, the audit data and resident perception mainly differed on street width and proportion of two-way streets. Audit observations indicated that the average number of lanes was 2.96 while respondents disagreed that the streets were wide. The highest number of lanes was 4.57 which imply higher traffic volumes. Audit observation indicated low traffic signal density of 0.29/mile confirmed by resident safety perception of availability on crossing aids and midblock crosswalks. Both audit observation and resident perception also coincide on a high proportion of segments with lighting and availability of buffer areas along the sidewalks.

In San Destin neighborhood, the audit data and resident perception mainly differed on street width. The neighborhood had the highest average number of lanes (4.5) which is accurate considering close proximity to Centennial and Aliente Parkways, as well as other major streets. Audit observation showed a traffic signal density of 2.17 confirmed by residents who agreed that there were crossing aids as well as midblock crosswalks available. There was also resident safety perception and audit observation consensus on availability of buffers, street parking, and raised median which not only serve as traffic calming measures but also provide refuge islands on wide streets.

5th & Carey residents' perception also differed from some of the audit observations. The audit indicated a traffic signal density of 3.28/mile which was the second highest among the neighborhoods and the highest pedestrian crosswalk density of 1.64 crosswalk/mile. However, majority of the residents strongly disagreed to availability of crossing aids and crosswalks. In addition, respondents felt refuge islands were inadequate audit observation indicated that the proportion of segments with refuge islands was 43%. Resident perception and audit observations coincided on availability of street parking, street width, availability of street lighting and buffers.

8.7.2. Comparison of Audit Land Use and Land Use Perception

There was distinct trend of increasing land use perception with increase in land use mix except for San Destin, Desert Sky Apartments, and Spanish Trail neighborhoods. From Figure 8-2 below, there was general consensus between resident perception of land uses and land use data obtained from Clark County Assessor's Parcel data. Except for Historic Alta and Spanish Trail, most of the higher income neighborhoods, seem to have relatively low land use mix. For example, in Spanish Trail neighborhood, residents had a low perception of land uses compared to the parcel data. Being a planned gated community, recreational facilities such as gyms are located within the gates. However, to access retail premises on Rainbow Boulevard and Durango Drive, residents have to walk or drive circuitous routes for utilitarian trips.

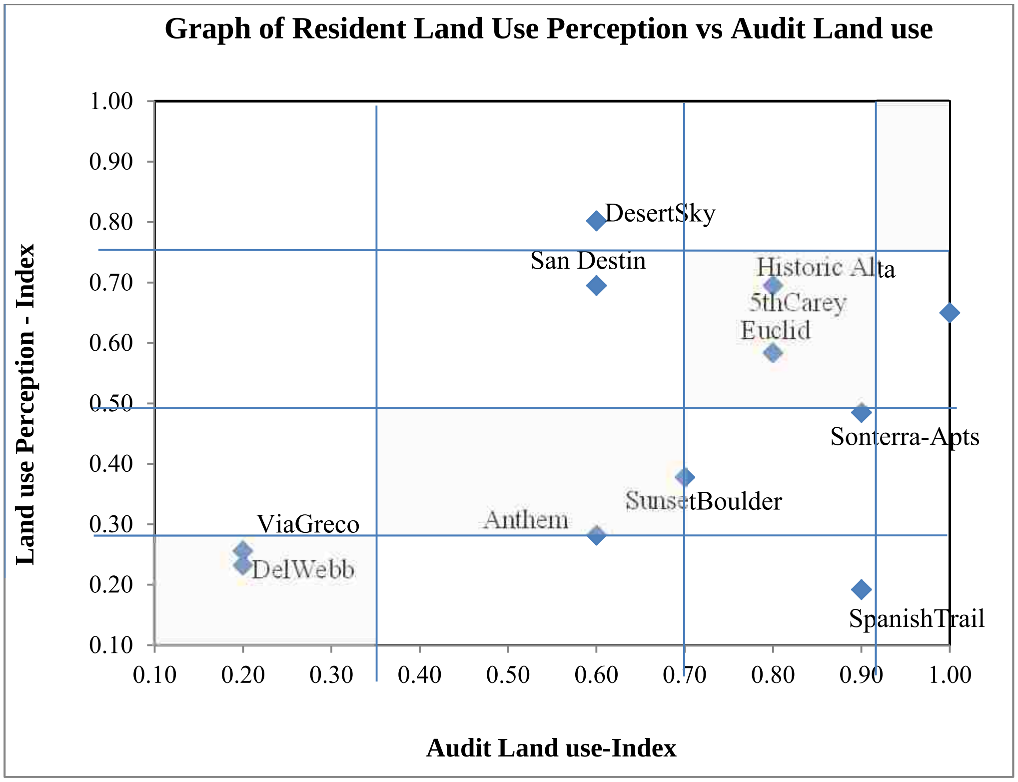


FIGURE 8-2 Comparison of audit land use vs resident land use perception.

In Desert Sky neighborhood, some of the land uses, such as the bank (Credit Union) were missing from the Assessors' Parcel data but present during site visit verification. Residents reported worship places, medical facilities which were not indicated in Assessor's parcel data for the neighborhood. In addition a post office which could be within a grocery store building was reported within the 15 minute walk from residences but was missing from the parcel data.

In San Destin, residents had a high perception of land uses within 15 minute walk of their residence compared to the six land uses found within the study boundary. There was a commercial plaza located relatively close to the neighborhood.

8.7.3. Comparison of Audit Directness and Resident Directness Perception

Resident perceptions of directness within their neighborhoods relatively coincided with audit directness. There was no distinct pattern as illustrated in Figure 8-3 or much variance between observations. This could imply that there are other parameters including directness features that influence directness perception. The neighborhoods whose resident perception differed from the audit data were DelWebb, San Destin, and Via Greco.

DelWebb neighborhood a retirement community was characterized by hilly sidewalks as well as being walled but with several egress and access points. In addition, commercial properties were few and located towards the boundary making walking access a challenge mainly for utilitarian trips. Most respondents in DelWebb also reported lack of midblock crosswalks to facilitate safe and quick access to the few commercial land uses within the neighborhood. There was general consensus on presence of sidewalks with steep gradients between audit observations and resident perception.

The San Destin neighborhood audit showed a low directness quality grade compared to the high directness perception of residents. The neighborhood itself was walled, with relatively flat sidewalks but had a small FAR value. The convenience store right next to the neighborhood had little parking space at the front therefore presented no challenges accessing the store. Other commercial premises within the neighborhood had large parking lots at the front of the premises. Residents overwhelmingly agreed there were no midblock crosswalks within the neighborhood which was confirmed during site visits.

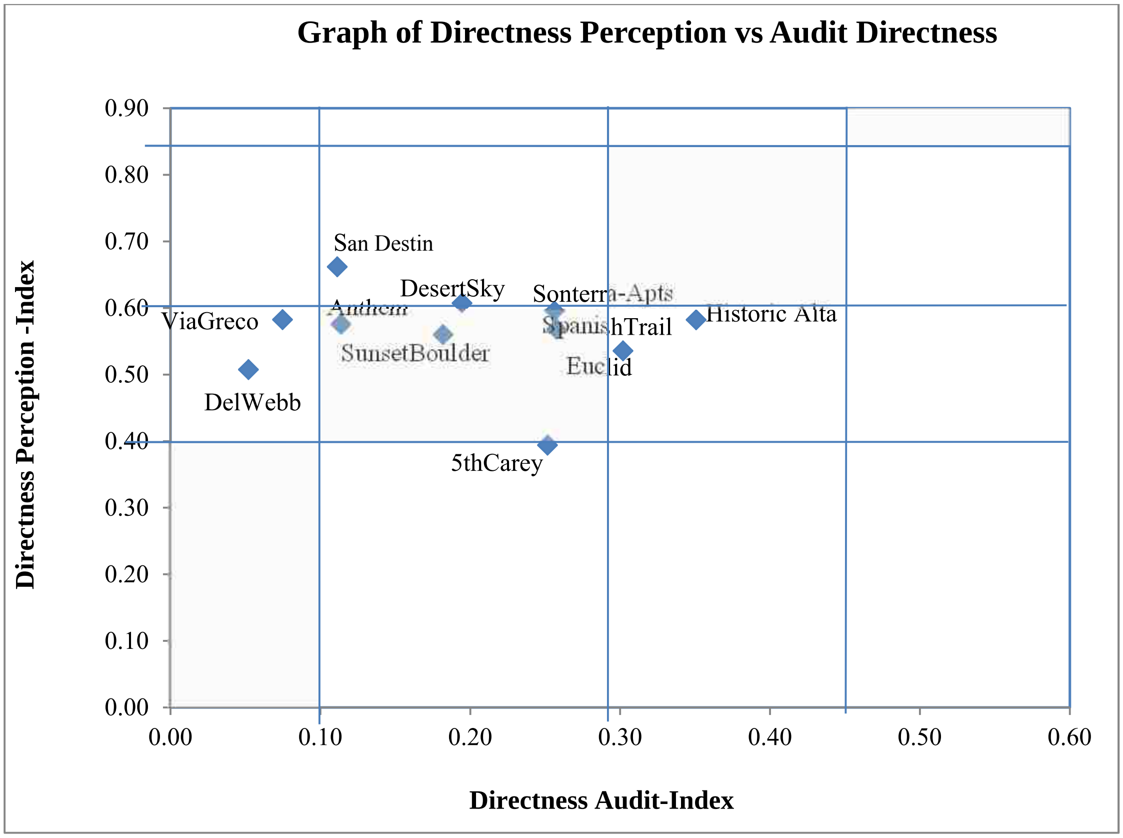


FIGURE 8-3 Comparison of audit directness vs resident directness perception.

Residents in Via Greco, a gated neighborhood with a single access/egress point also reported limited midblock crosswalks and pedestrian signs. The FAR for this neighborhood was 0.03 implying large parking lots in front of commercial premises. However, respondents reported no large parking lots making walking to the stores difficult. The low FAR value resulted from few (only two) commercial land uses whose building footprint on the parcel was small implying large parking lots in front of the two buildings. Audit observation matched resident perception with regards to restricted routes due to many enclosed communities as well as the gradient of the sidewalks which was relatively flat.

8.7.4. Comparison of Audit Continuity and Resident Continuity Perception

Resident perception of continuity compared reasonably well with audit observations, Figure 8-4. As earlier mentioned, restricted access to Anthem neighborhood limited audit accuracy of the walking environment. Alta being an older neighborhood (in Clark County jurisdiction) compared to the rest of the study locations has segments that lack standard sidewalks. There were segments that had utility poles right in the middle of the sidewalks. In addition, some of the audited segments had narrower that the standard five feet width. Residents' opinions differed from audit observation on sidewalk width and presence of obstructions. Their perceptions coincided with incomplete sidewalks due to presence of footpaths, cul-de-sacs, high driveway density which inhibit continuity of routes. The surrounding neighborhood had a grid pattern street network resulting to the highest intersection density in the study confirmed by the resident perception.

In Spanish Trail neighborhood, the main difference between audit observations and respondents perception was on distance between intersections. Spanish Trail is a gated master planned community. Therefore, though having the second highest intersection density, approximately 121 intersections/mile; residents are subjected to circuitous routes to access the numerous intersections. Both audit observations and resident perception in this neighborhood confirmed presence of foot paths which inhibits continuity of trips. Conversely, there were wide sidewalks, low driveway density, small proportion of dead-end streets and few obstructions on pedestrian paths confirmed by resident perception of continuity.

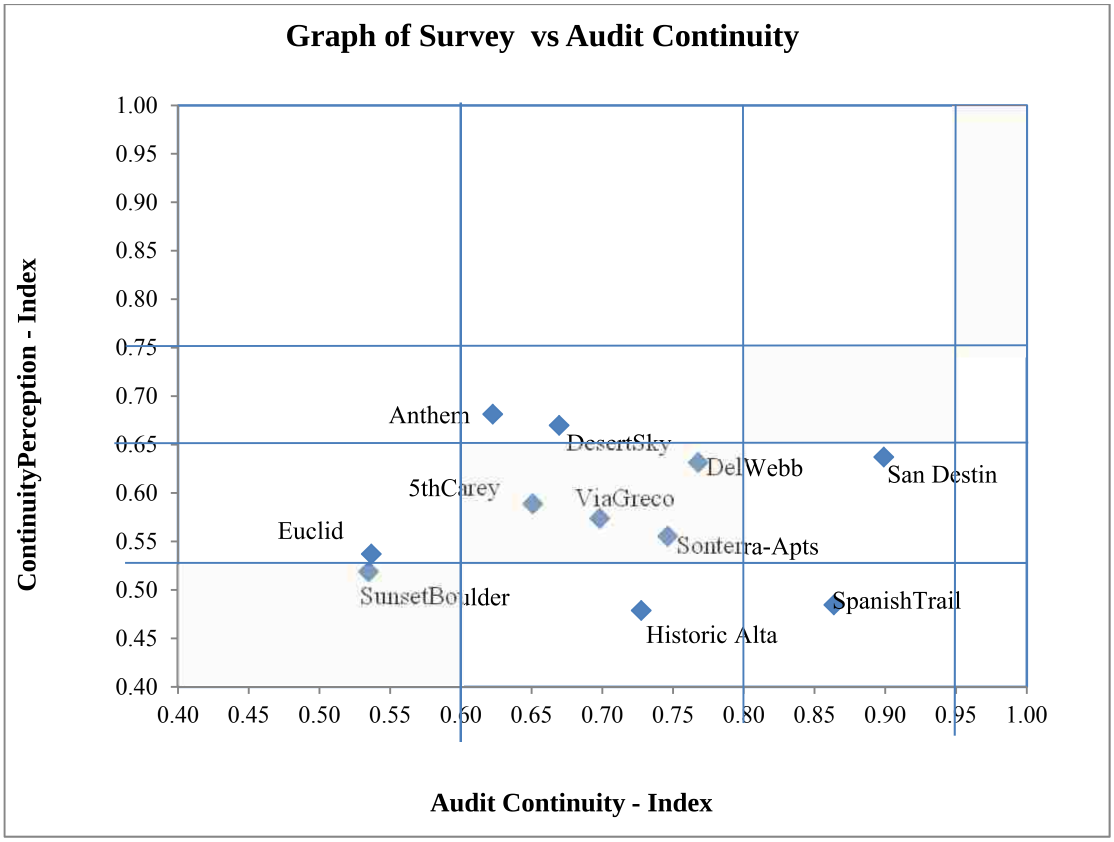


FIGURE 8-4 Comparison of audit continuity vs resident continuity perception.

8.7.5. Comparison of Audit Aesthetics & Amenities and Resident Perception

From Figure 8-5, there was little variation between audit observations as well resident perceptions implying generally similar conditions. Out of the 11 neighborhood, 4 had differing perception of visual interest and amenities compared to audit observations. Most walking environments had a quality grade of B and C in the amenities and aesthetics category.

In Sonterra neighborhood, aesthetics and amenities perception mainly differed with audit observation on landscaping. Some of the audited segments had empty lots, which are unsightly as well as having empty buildings with graffiti. Within the enclosed community, the neighborhood was generally appealing compared to the surrounding area that was mainly commercial. Similar to Historic Alta neighborhood, the randomly selected neighborhood was appealing, but as a whole there were segments with empty lots having trash, segments with litter as well as unshaded areas.

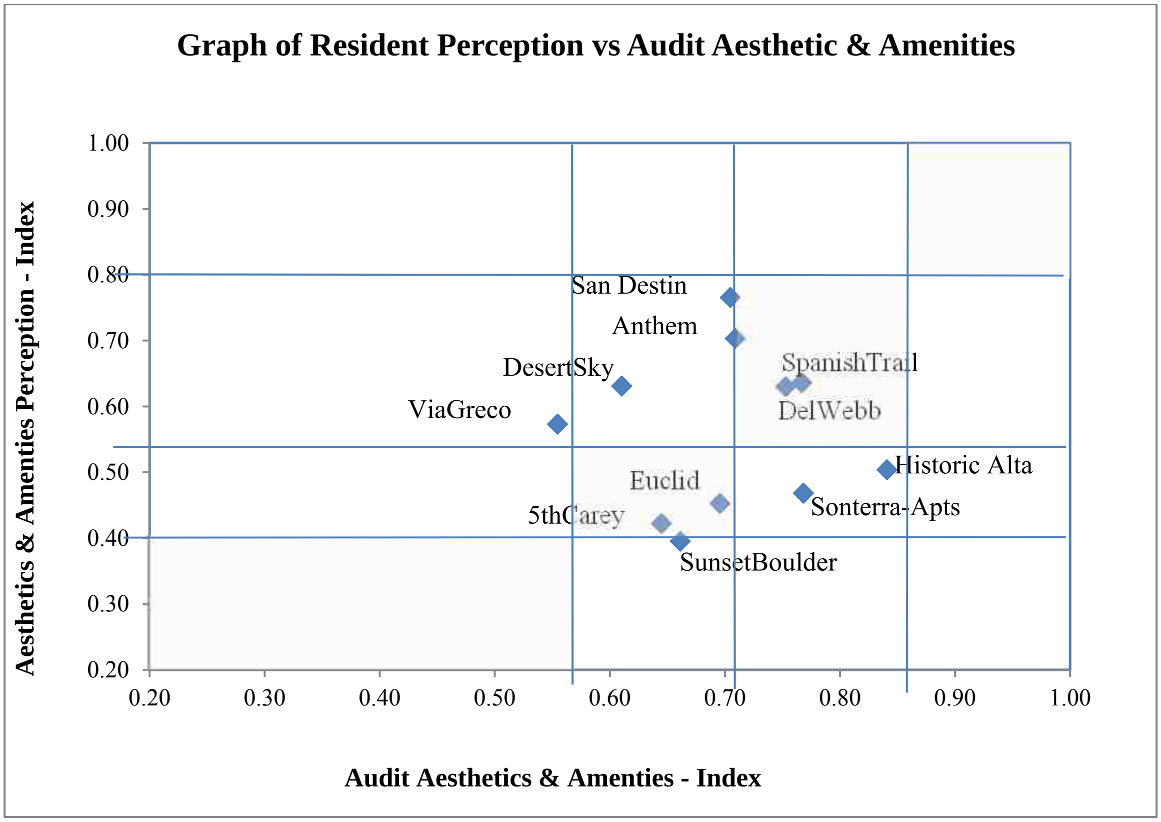


FIGURE 8-5 Comparison of audit aesthetics and amenities versus aesthetics and amenities perception.

In Via Greco neighborhood audit observation and resident perception differed on shading and landscaping. The proportion of segments with shading was 0.4%, while residents reported trees along the streets in the neighborhood. In addition, residents reported attractive views and landscaping while the audit showed at least 50% of the audited segments had unmaintained/empty lots. Most of the segments were under construction or had unmaintained lots. Audit observations and resident perception concurred on availability of transit stops, which came with benches therefore providing rest spots as well as trash cans. Respondents confirmed clean and well maintained sidewalks as well as rest stops.

Similarly, in Desert Sky Apartments neighborhood, respondents reported shading and landscaping which was opposite of what was observed in the audit. The neighborhood had many segments with unmaintained or empty lots, but asphalt pavements sidewalks were provided on some segments that were not developed. Audit observations and resident perception concurred on availability of transit stops which came with benches therefore providing rest spots as well as trash cans. Residents reported clean sidewalks or walking environment while the audit showed segments that were littered Table 8-5. However it could be that areas where respondents walked were cleaner compared to audit segments or street cleaning/ trash collection hadn't been done when the image was recorded.

8.8. Summary

1. Overall, there was little variance comparing the audit observations for safety, continuity, directness, and aesthetics and amenities, and the corresponding perception categories. Intuitively, increase of category features should result in an increase in the corresponding perception category. The lack of trend suggests other factors that have an influence in perception of various categories.
2. There was an evident trend illustrated in land use perception with increase in land use mix for most of the neighborhoods, which is expected. Lower income neighborhoods in groups one and two had a more varied land use mix compared to higher income neighborhoods. The audit observation tended to coincide with resident perception on various categories in some

neighborhoods. However in every category, there were neighborhoods that differed somewhat on some features, which is expected. Audit accuracy was limited in Anthem neighborhood due to restricted access even for satellite imagery. Perception of residents in San Destin and Via Greco neighborhoods was different on several categories. It is expected their overall perception and audit indices will differ when the categories are combined.

CHAPTER 9

PEDESTRIAN SAFETY ANALYSIS RESULTS

9.1. Introduction

This chapter presents the results of pedestrian safety analysis. The pedestrian crash indices developed using Equation 5-1 were compared with safety indices obtained from auditing safety infrastructure within each neighborhood. Differences between the two safety estimates were compared for significance (α=0.1) using a two tailed paired-sample t-test.

9.2. Pedestrian Safety Analysis

From Figure 9-1 below, it is evident that there is no particular trend between neighborhoods with high audit safety indices and respective neighborhood crash indices.

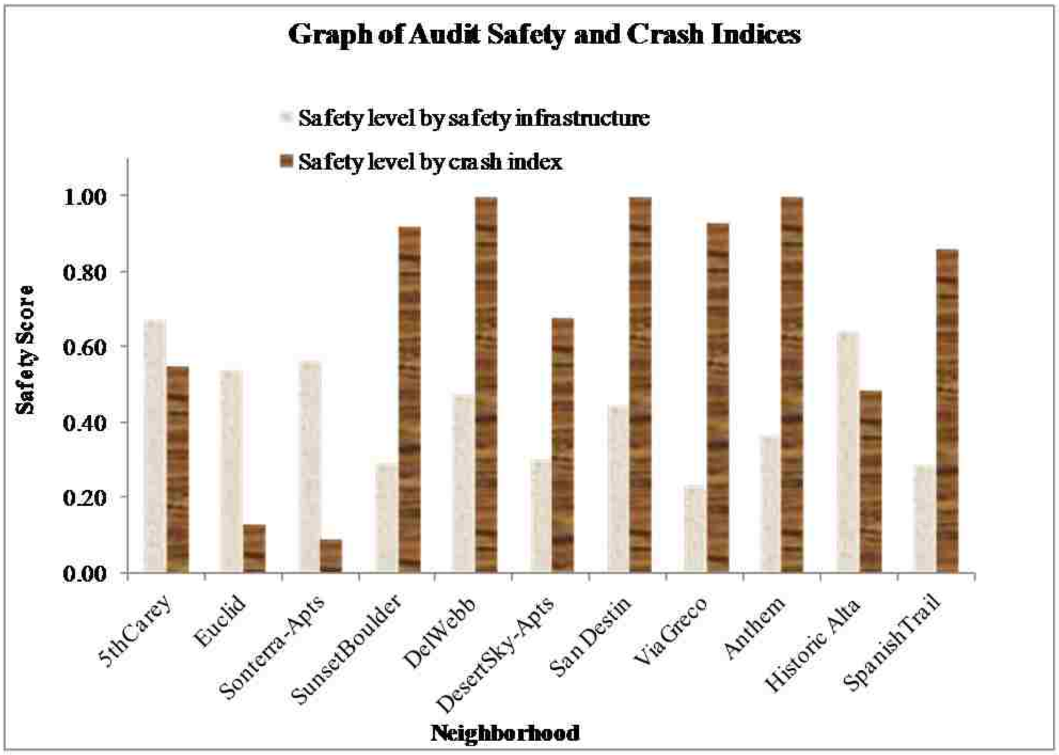


FIGURE 9-1 Graph of audit safety and crash indices.

Neighborhoods with high audit safety indices such as 5th & Carey, Euclid, Alta and Sonterra also have high crash indices as well. Conversely, three of the neighborhoods without crashes had low safety scores. Differences between neighborhood audit safety indices and corresponding crash indices were statistically significant at ($p=0.074$, $\alpha=0.1$) using a two tailed paired-sample t-test. Safety levels based on safety infrastructure alone could result in masking potential safety problems within the walking environment. Inclusion of crash data is therefore recommended for improved representation of the walking environment safety.

Previous studies involving crash data mostly focused on roadway geometry and its association to crash risk (Cho et al., 2009). Using the 11 crash indices from selected neighborhoods, the association between walking environment features in selected neighborhoods and related crash indices was estimated using Pearson's *r* correlation coefficient in SPSS (Version 22) as illustrated in Table 9-1 below.

TABLE 9-1 Pearson's Correlation Values between Crash Indices and Safety Related Infrastructure

Safety Infrastructure	**Pearson's r**	**p-value**
Presence of transit stops	0.669	0.02
Presence of buffer(hedges)	-0.705	0.02
2-way directional traffic	-0.487	0.13
Intersection traffic signals	0.786	0.00
Presence of exclusive rights turn	0.697	0.02
Presence of exclusive channelized right turns	0.866	0.00
Presence of raised medians	-0.275	0.41
Presence of pedestrian signals	0.626	0.04
Presence of midblock crosswalks	0.279	0.41
Presence of unsignalized stops	-0.259	0.44
Presence of bike lanes	-0.573	0.07
Presence of driveways	0.712	0.01
Floor Area Ratio FAR	0.706	0.02
Land use diversity	0.587	0.06

There was a strong positive and statistically significant relationship between bus stops and crashes, Table 9-1. In Las Vegas, there have been several instances of vehicles hitting pedestrians on sidewalks (Velotta, 2015). To separate transit users and pedestrians on sidewalks from traffic, buffers such as crash barriers can be installed as treatments. As illustrated above, buffers have a negative strong relationship with crash risk; implying increasing buffers will reduce crash risk.

Conflicting opinions exist on the merits of two-way versus one-way streets. Cunneen and O'toole (2005) reported a considerable 38% decrease in accidents when two way streets were converted to one-way streets. Conversely, Walker et al (2000) in their review reported typical 30-40% more vehicle/pedestrian conflicts on one-way networks. The strong inverse relationship shown between two-way streets and crash risk indicates that an increase in the proportion of two way streets lowers potential crash risk. Lum and Soe (2004) reasoned that crossing one-way streets presented greater challenges due to increased pedestrian-vehicular conflict points. However, a high proportion of audited segments had two-way traffic, which could result in the negative sign.

Intersection infrastructures such as right turn lanes as well as channelized right turn lanes have positive relationships with crash risk. Unless expressly prohibited, right turn lanes have permitted operations yielding to pedestrians. Studies show increases in right turn crashes when right turn on red (RTOR) are permitted at intersections (Preusser, Leaf, DeBartolo, & Blomberg, 1981). Lord (2002) determined that the RTOR maneuver was not as dangerous; representing a very small proportion of signalized intersection crashes and should therefore be implemented judiciously. Channelized right turns which also serve as refuge islands on wide streets have a significant positive relationship with crash risk. Intuitively, drivers at exclusive right turns tend to be more focused on opposing traffic rather than pedestrians resulting right-turn crashes. Conversely, raised medians have a negative association with the crashes, though not statistically significant one. Pulugurtha et al. (2012) reported that raised medians or refuge areas at marked crosswalks showed 46% reduction in pedestrian crashes.

Pedestrian signals and midblock crosswalks have positive relationships with crash risk; though the midblock crosswalk association is not statistically significant. Dultz et al. (2013)

found that 44 % of reported street injuries occurred at signalized crosswalks compared to 32 % of jaywalkers. Cho et al., (2009) reasoned that when in high-perceived risk areas, pedestrians could be exercising increased caution and alertness. Schneider al., (2003) proposed that the association of higher crosswalk density and increased crashes could be a result of risky pedestrian and driver behavior near marked crosswalks, weak crosswalk design, or other factors (Schneider et al., 2003). Zeeger et al. (2015) also reported that "few motorists yielded to pedestrians, before or after installation of marked crosswalks". However, a small increase in pedestrian scanning behavior after marked crosswalks were installed was noted.

The bike-lanes and unsignalized intersections safety features have a negative relationship with the crash risk implying an increase in such lowers crash risk. Unsignalized intersections are typically located at low traffic volume intersections. Intuitively, the stop and go operation helps reduce traffic speeds and in relation lowers crash risk though the association is not statistically significant. Bike lanes reduce lane width as well as providing additional buffer between pedestrians and vehicular traffic.

As expected driveways which typically interrupt pedestrian trips have a positive association with crash risk increasing pedestrian-vehicular conflict points. Similarly, FAR and land-use both have a positive relationship with crash risk. Larger and more varied commercial land-uses are bound to attract more pedestrian trips thereby increasing pedestrian exposure.

9.3. Summary

Results indicated that neighborhoods with the high safety scores had varying crash indices. Safety levels based on safety infrastructure alone could result in masking potential safety problems within the walking environment. Inclusion of crash data is therefore recommended for improved representation of the walking environment safety. Correlation of safety infrastructure showed a negative relationship between crash risk and features such as buffers, medians, traffic calming measures as well as two-way traffic. Features that had a positive relationship with crash risk included land use mix, FAR, presence of transit stops, traffic signals, exclusive and channelized right turns, midblock crosswalks and driveways.

CHAPTER 10

RESULTS OF WALKABILITY INDEX ESTIMATION

10.1. Introduction

This section presents indices that were estimated using fuzzy logic for both audit and survey categories as well as the comprehensive walkability index and quality grades.

10.2. Infrastructure Index

The infrastructure category was comprised of amenities and aesthetics, directness and continuity categories which were combined in fuzzy logic to obtain an infrastructure value. In developing the infrastructure index, the assigned weights were assigned in decreasing order from directness to continuity then amenities and aesthetics categories. Generally, the quality grade for infrastructure was between "B" and "D" for both audit and survey data, Figure 10-1.

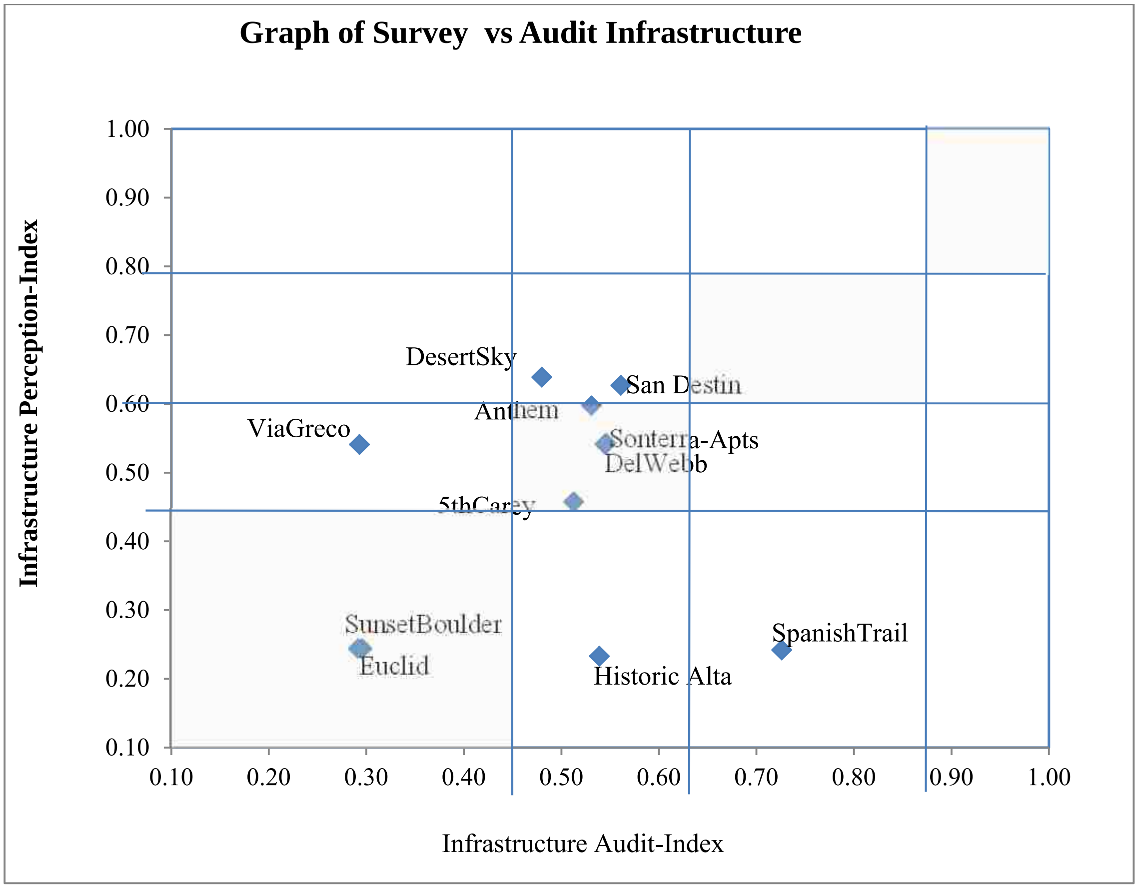


FIGURE 10-1 Comparison of audit versus resident perception of infrastructure.

Infrastructure being a category obtained through combination, its expected differences in respondents' perceptions and audit observations would be propagated to the overall combined category. In Via Greco neighborhood, resident perceptions differed from audit observation on directness and amenities and aesthetics. In the Historic Alta neighborhood, resident perceptions differed from audit observation in the continuity, amenities and aesthetics categories. In the Spanish Trail neighborhood, resident perceptions differed from audit observation in the continuity category.

10.3. Audit Safety Index

In Chapter 9 a paired sample, two tailed test confirmed significant differences between audit observation of safety features and crash indices for the neighborhoods. This implies that there is a need to include crash data into walkability evaluations to enhance safety evaluations of walking environments. In conducting neighborhood audits, subjective weights were necessary because of the approach used to collect and record the data. To facilitate the influence of variables whose data values were small, such as FAR, weights were assigned not only this study, but other as well (Cain et al., 2014; Pikora et al.,, 2003). Intuitively inclusion of crash data into walkability analyses brings objectivity even without significant results. However further tests were conducted to determine whether presence of crash risk altered neighborhood walkability ranking. Figure 10-2 below illustrates study neighborhoods arranged in order of walkability quality index.

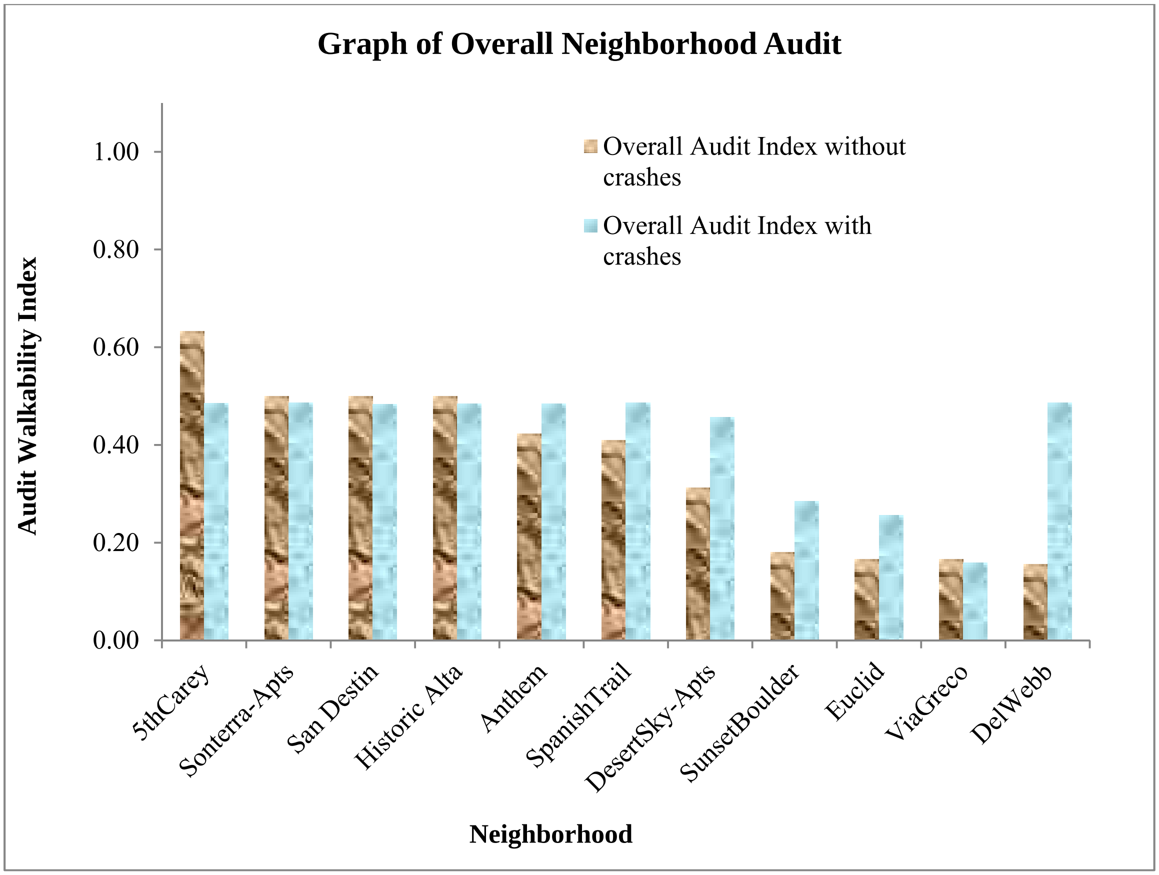


FIGURE 10-2 Comparison of overall audit walkability index with and without crash data.

Absence of crash data, the 5th and Carey neighborhood had the highest audit walkability index, followed by Sonterra Apartments and DelWebb ranking last. When crash data was introduced into analyses, DelWebb neighborhood ranked among the neighborhoods with the highest walkability index while 5th & Carey drops to the fourth position. Using a paired sample, the difference between walkability indices without crash data are significantly higher compared to those with crash data ($p=0.07$, $\alpha=0.1$, one tailed test).

10.4. Walkability Index

In developing the comprehensive walkability index, weights were assigned to different categories to reflect their relative importance to walkability. Delphi experts in Pikora et al.

(2003) interviews ranked in descending order of safety, attractiveness and destinations as categories of importance to walking. In this study, weights in decreasing order were assigned to safety, land-uses then infrastructure and combined in fuzzy logic to obtain overall walkability and survey indices. Finally, in the last tier of weighting to obtain the comprehensive index, a higher weight was assigned to the survey index on the rationale that resident perceptions influenced the final decision to walk.

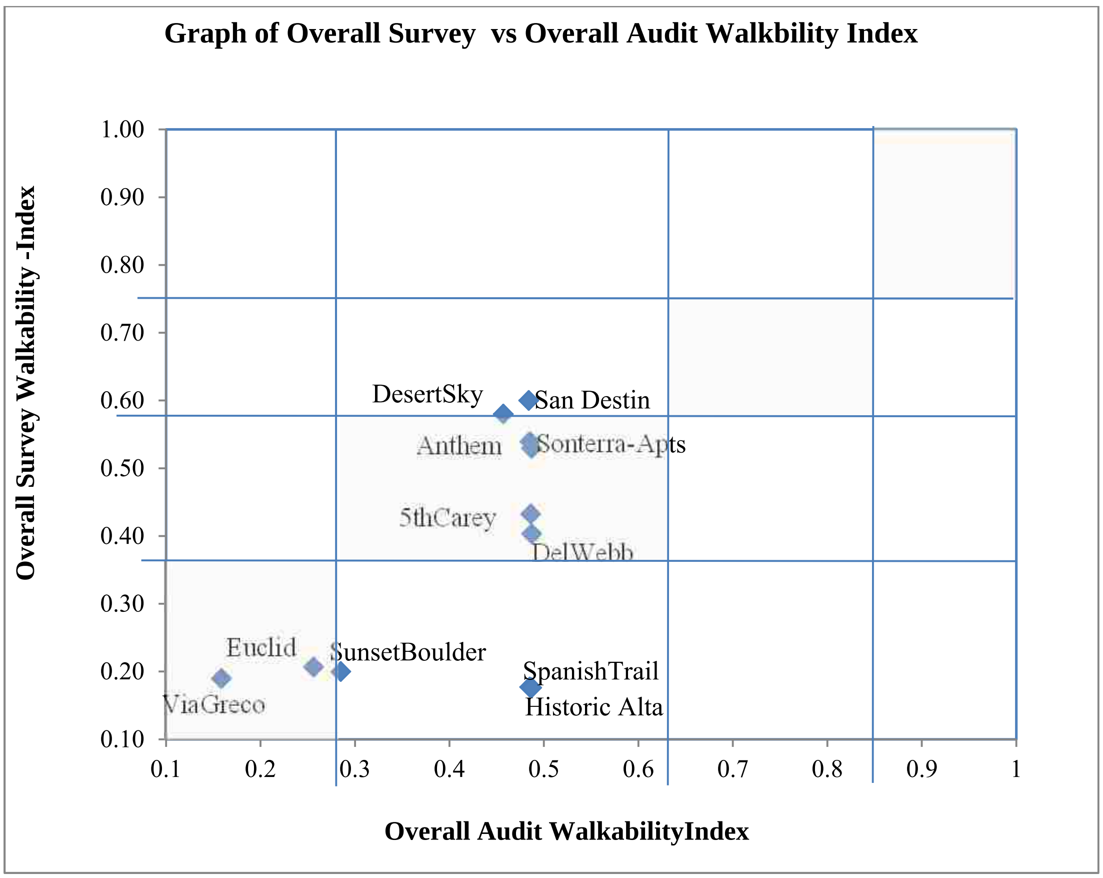


FIGURE 10-3 Comparison of overall walkability indices for audit and survey.

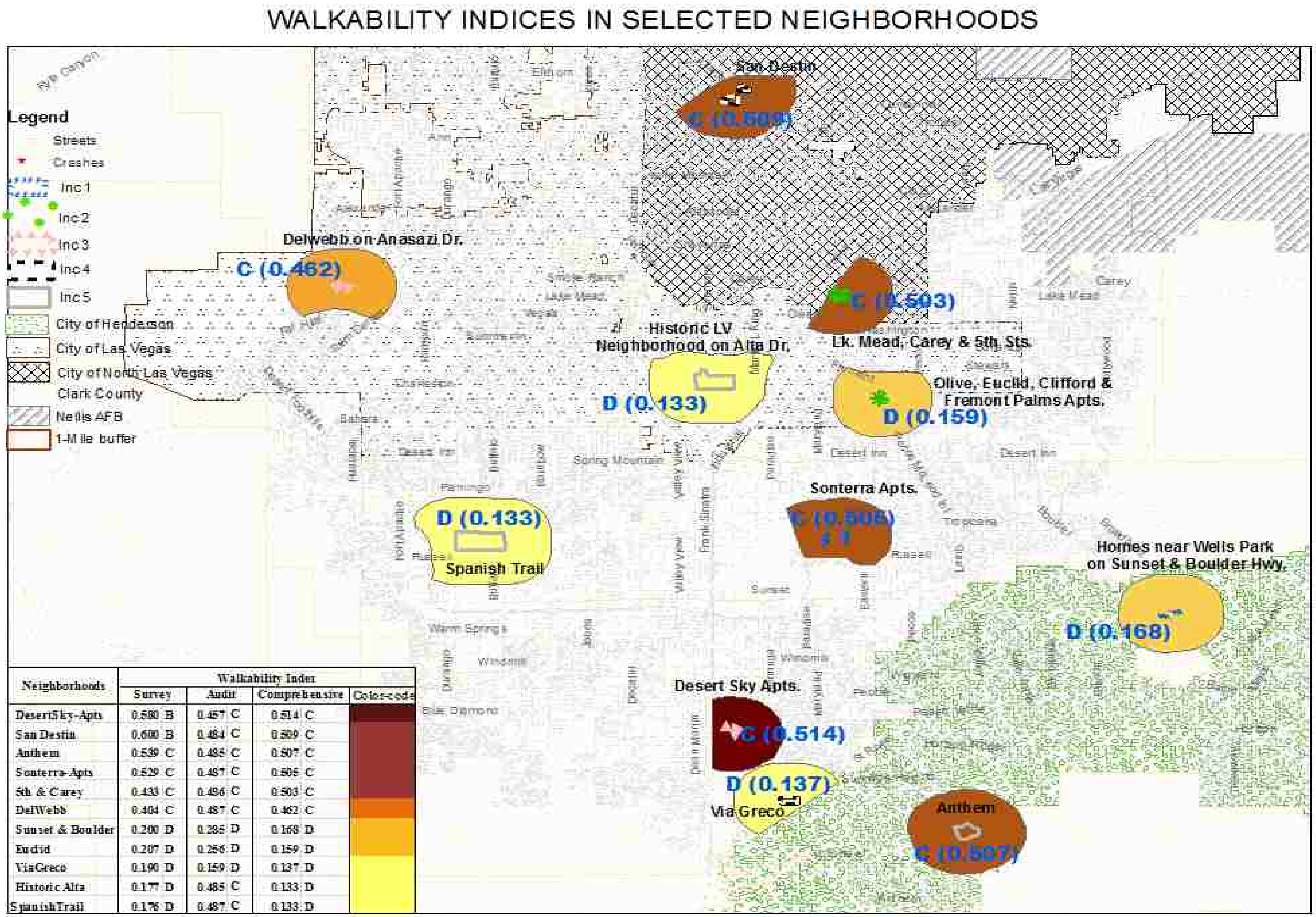
Figure 10-3 illustrates the overall walkability indices for various neighborhoods. Audit observations were generally similar to resident perception implying either approach to evaluating walkability could be optimized to estimate the other. Only two neighborhoods exhibited differences between audit observations and residents' perceptions. Other studies have reported no correlation between pedestrian perceptions and objectively measured audit and GIS indices (Hajna et al., 2013).

There was little variation among neighborhoods that are closer in median income. For example, Euclid in income group one and Sunset & Boulder neighborhoods ranked closer together. Income group five Spanish Trail and Historic Alta also ranked closer together. In Alta neighborhood, resident had a poorer perception of safety features in the walking environment compared to audit observations in the safety category. In addition, Alta residents had poorer perception of continuity and aesthetics and amenities elements that featured in their walking environment.

10.5. Walkability Analysis

The survey perception and audit walkability indices and quality grades are illustrated in Figure 10-4. Individual category scores and indices constituting the comprehensive walkability index for the 11 selected neighborhoods are provided in Table 10-1. The neighborhoods are arranged in increasing income group order from one to five. Columns 2-18 show the various category scores and the respective quality grade labels for resident perceptions. The overall survey walkability index is shown in columns15 and 16. Columns 17 to 30 show the same categories with scores, indices and quality grades obtained using the audit observations. The overall audit walkability index is shown in column 33. Columns 31 and 32 illustrate the comprehensive walkability index and quality grade for each neighborhood.

In the land-use category, neighborhoods with the lowest quality grade each had two types of commercial land-uses within the study boundary. Neighborhoods with the highest land-use quality grade had at least nine commercial land-uses. Differences in audit observations of land uses and resident perceptions could stem from the fact land uses used were within a 0.75 mile buffer of a neighborhood which in resident perception might not be as close as a 15-minute walk. Higher land-use mix is associated with more walking opportunities as evidenced in literature (Kuzmyak et al., 2006).



Neighborhoods	Walkability Index			
	Survey	Audit	Comprehensive	Color-code
DesertSky-Apts	0.580 B	0.457 C	0.514 C	
San Destin	0.600 B	0.484 C	0.509 C	
Anthem	0.539 C	0.485 C	0.507 C	
Sonterra-Apts	0.529 C	0.487 C	0.505 C	
5th & Carey	0.433 C	0.486 C	0.503 C	
DelWebb	0.404 C	0.487 C	0.462 C	
Sunset & Boulder	0.200 D	0.285 D	0.168 D	
Euclid	0.207 D	0.266 D	0.159 D	
ViaGreco	0.190 D	0.159 D	0.137 D	
Historic Alta	0.177 D	0.485 C	0.133 D	
SpanishTrail	0.176 D	0.487 C	0.133 D	

FIGURE 10-4 Neighborhood walkability indices and quality grades.

TABLE 10-1 Descriptive Scores and Quality Indices and Grades for Selected Neighborhoods

	Neighbourhoods	SURVEY							AUDIT							
		Landuse	Directness	Continuity	Amenities & Aesthetics	*Infrastructure Index*	*Safety*	**Survey Walkability Index**	Land use	Directness	Continuity	Amenities & Aesthetic	*Infrastructure Index*	*Safety Index*	**Audit Walkability Index**	**Comprehensive Walkability Index**
1	5th & Carey	0.65 B	0.39 D	0.59 C	0.39 D	*0.46 C*	*0.46 C*	**0.433 C**	1.00 A	0.25 C	0.65 C	0.64 C	*0.51 C*	*0.61 B*	**0.486 C**	**0.503 C**
2	Euclid	0.58 B	0.54 C	0.54 D	0.44 C	*0.24 D*	*0.54 C*	**0.207 D**	0.80 B	0.30 B	0.54 D	0.70 C	*0.30 D*	*0.19 D*	**0.256 D**	**0.159 D**
3	Sonterra-Apts	0.48 C	0.60 C	0.56 C	0.44 C	*0.54 C*	*0.61 C*	**0.529 C**	0.90 B	0.26 C	0.75 C	0.77 B	*0.55 C*	*0.09 D*	**0.487 C**	**0.505 C**
4	Sunset & Boulder	0.38 C	0.56 C	0.52 D	0.39 D	*0.24 D*	*0.51 C*	**0.200 D**	0.70 B	0.18 C	0.53 D	0.66 C	*0.29 D*	*0.50 C*	**0.285 D**	**0.168 D**
5	DelWebb	0.23 D	0.51 C	0.63 C	0.61 B	*0.54 C*	*0.66 B*	**0.404 C**	0.20 D	0.05 D	0.77 C	0.75 B	*0.55 C*	*0.70 B*	**0.487 C**	**0.462 C**
6	DesertSky-Apts	0.80 A	0.61 B	0.67 B	0.62 B	*0.64 B*	*0.63 B*	**0.580 B**	0.60 C	0.19 C	0.67 C	0.61 C	*0.48 C*	*0.39 C*	**0.457 C**	**0.514 C**
7	San Destin	0.69 B	0.66 B	0.64 C	0.76 B	*0.63 B*	*0.70 B*	**0.600 B**	0.60 C	0.11 C	0.90 B	0.70 C	*0.56 C*	*0.70 B*	**0.484 C**	**0.509 C**
8	ViaGreco	0.26 D	0.58 C	0.57 C	0.57 C	*0.54 C*	*0.53 C*	**0.190 D**	0.20 D	0.07 D	0.70 C	0.55 D	*0.29 D*	*0.39 C*	**0.159 D**	**0.137 D**
9	Anthem	0.28 D	0.57 C	0.68 B	0.69 B	*0.60 C*	*0.72 B*	**0.539 C**	0.60 C	0.11 C	0.62 C	0.71 C	*0.53 C*	*0.71 B*	**0.485 C**	**0.507 C**
10	Historic Alta	0.69 B	0.59 C	0.48 D	0.53 C	*0.23 D*	*0.55 C*	**0.177 D**	0.80 B	0.35 B	0.73 C	0.84 B	*0.54 C*	*0.39 C*	**0.485 C**	**0.133 D**
11	SpanishTrail	0.19 D	0.57 C	0.48 D	0.64 B	*0.24 D*	*0.55 C*	**0.176 D**	0.90 B	0.26 C	0.86 B	0.77 B	*0.73 B*	*0.44 C*	**0.487 C**	**0.133 D**

In the directness category, quality indices varied between level "B" and "D" for both audit and survey. Directness was estimated from FAR, sidewalk gradient and proportion of segments with walled or gated communities. In some neighborhoods, directness was further limited by the few land uses available. A large proportion of the segments audited had walled or gated communities. Only one neighborhood (DelWebb) had steep sidewalks, confirmed by the residents. In Andrew Allan's (2001) study, permeability indices were developed on the rationale that "pedestrians do not have the time or stamina for unnecessary circuitous routes".

Features evaluated under continuity category measured the potential for an obstruction free trip. In here lies the strength of audit evaluations. Unlike macro-scale level studies, use of audit tools enables evaluation of presence of obstructions such as driveways and street furniture as well as presence and condition of sidewalks. Though useful, driveways not only hinder walkability but increase pedestrian-vehicular conflict points while obstructions pose threats especially for pedestrian with disabilities. Further, Table 9-1 indicates a strong positive significant relationship between crash risk and street furniture as well as driveways. A study of Downtown Las Vegas reported sidewalks that are narrow, broken, cluttered with utility poles and offer no buffer from adjacent fast-moving traffic (Kimley-Horn, 2008). In the neighborhoods having lower continuity quality grade, driveways, obstructing street furnishings and missing or poor condition sidewalks were prevalent. To improve walkability in such neighborhoods, ADA compliant walking facilities should be provided.

In the amenities and aesthetic category, presence of physical and social disorders as well as transit stops and associated furnishings were evaluated. The quality grade varied between "B" and "D" for audit observations and resident perceptions. Articulate buildings, attractive landscaping, well-maintained streets and buildings can contribute to a pleasant visual environment encouraging both recreational as well as utilitarian walking.

The comprehensive walkability index integrating resident perception and audit observations, weighted perception higher than audit observations. Intuitively, the resident is the one who makes the pedestrian decision based on their perception of the walking environment; hence a higher weight for their perception in the final comprehensive index. The comprehensive walkability grade was between "C" and "D". Neighborhoods with the lowest quality index included Sunset& Boulder, Euclid, Via Greco, Historic Alta and Spanish Trails. The final comprehensive audit index and grade is not necessarily the goal, but eases the path to goal achievement which is providing walkable environments. With both audit and survey points of view, practitioners are able to back track and identify which particular categories need interventions. For example in Sunset & Boulder neighborhood with a comprehensive quality grade of "D", both audit observations and resident perceptions indicated a quality grade "D" for continuity. This category could be the starting point in addressing walkability issues, such as providing complete sidewalks with standard five foot widths. Respondents also reported presence of physical disorders such as litter and drug paraphernalia. Additional cleaning schedule for such neighborhoods can planned in an effort to address respondents' comments subject to funding availability.

10.6. Summary

1. The comprehensive walkability index was obtained by combining the overall audit and survey walkability grades. The survey and audit indices were each obtained by combining infrastructure, safety and land use indices. The infrastructure category was comprised of amenities and aesthetics, directness and continuity categories which were combined in fuzzy

logic to obtain an overall value. Neighborhoods whose respondents' perception on infrastructure differed from audit observations exhibited a little variation. Generally, the quality grade for infrastructure varied between levels "B" and "D" for both audit and survey data.

2. The safety audit index was obtained by combining the safety score - obtained by measuring safety infrastructure in the walking environment and the crash index - which was a function of population and commercial land use in a buffer. Even without significant results, inclusion of crash data into walkability analyses brings objectivity. When crash data was introduced into analyses, neighborhoods with high walkability indexes dropped in walkability ranking. Using a paired sample, the difference between walkability indices without crash data are significantly higher compared to those with crash data ($p=0.07$, $\alpha=0.1$, one tailed test).
3. Overall audit walkability index was generally similar to resident perception implying either approach to evaluating walkability could be optimized to estimate the other. There was little variance among neighborhoods that are closer in median income. The comprehensive walkability grade varied between quality grades "C" and "D".
4. The final comprehensive audit index is not necessarily the goal, but eases the path to goal achievement which is providing walkable environments. With both audit and survey points of view, practitioners are able to back track and identify which particular categories need interventions. Some of the features that audit observations and respondent perception coincided on that needed addressing include access to land uses, presence and condition of sidewalks, presence of obstructions, presence of buffers as well as shading and appealing aesthetics.

CHAPTER 11

RESULTS OF STATISTICAL MODELING FOR NEIGHBORHOOD PERCEPTIONS

11.1. Introduction

This chapter presents results and discussion of statistical modeling - performed in R software - of the walking frequency and perception of safety, directness, continuity, amenities and aesthetics, and land use categories. The objective of the walking frequency model was to identify different perceptions that account for the choice of walking frequencies. Statistical models were calibrated to estimate parameters that influence the identified perceptions.

11.2. Description of Variables

There were two levels of data in this study; level one being units of respondents' perceptions of their walking environment. The second level was audit observations aggregated by neighborhoods. As such respondents from the same neighborhood had the same values for audit categories. The level one respondent perception functioned as the response variable while socio-demographic data and level two audit measurements were the predictor variables.

11.3. Walking Frequency Model

The data used in walking frequency model was level one data for individual respondents. In the survey, participants were requested to indicate their walking frequency as shown in the survey in Appendix I. The responses were combined into three groups of walking frequency for easier data management and interpretation. The first group was comprised of respondents who walked daily or nearly every day and those who walked a few times a week. The moderate category was comprised of respondents who walked a few times a month. The last category was comprised of respondents who indicated they rarely or never walked. Multinomial logistic regression was used to model the walking frequencies as a function of perceptions of the walking environment. The model assumed that the probability of respondent "i" having a walking frequency "s" depended on respondent *i's* perceptions of x_{i1},.......,x features in the walking environments as illustrated in Equation 11-1.

$$P(Y_i = s) = \frac{e^{\eta_{is}}}{\sum_{t=1}^{g} e^{\eta_{it}}}$$

Equation (11-1)

Where $\eta_{is} = \sum_{k=1}^{p} x_{ik}\beta_{ks}$ is a linear predictor,

β_{ks} is the coefficient for each combination of covariate k and outcome category s,

η_{is} is a separate linear predictor for each outcome category compared to a set reference category.

Having combined the initial five categories in the survey to three categories, concerns typically raised with the independence of irrelevant alternatives assumption was addressed. The IIA assumption that is implicit in the model assumes that, all else being equal a person's choice between walking frequently and seldom would be unaffected by the presence of the option of walking moderately. All five perception categories were included in the model as illustrated in Equation 11-2. Results for multinomial logit model are provided in Table 11-1.

$$P(Y_i = s) = b_{10} + b_{11}(Landuse\_perception) + b_{12}(Aesthetics\_perception)$$

Equation (11-2)

TABLE 11-1 Coefficients for Walking Frequency Model

Parameter	Moderate Walking Frequency				Frequent Walking Frequency			
	Odds Ratio	Std. Error	P-value	Probability	Odds Ratio	Std. Error	P-value	Probability
(Intercept)	556.59	62.81	0.92	-	280.05	62.77	0.93	-
Transit-use (no)	0.00	62.68	0.88	0.18	0.00	62.68	0.88	0.70
Landuse-perception	2.93	0.66	***0.10***	***0.20***	2.25	0.58	0.16	0.76
Continuity-perception	0.24	1.49	0.34	0.19	0.76	1.29	0.83	0.77
Directness-perception	0.56	1.56	0.71	0.18	1.06	1.35	0.97	0.78
Safety-perception	0.72	1.33	0.81	0.19	0.92	1.14	0.94	0.77
Aesthetics-perception	19.96	1.24	**0.02**	**0.22**	9.32	1.08	**0.04**	**0.73**

Walking frequency versus land use perception

Table 11-1 illustrates the odds as well as the probabilities of respondents' walking frequency due to a unit increase in land use and aesthetics and amenities perceptions. Ceteres paribus, the probability of a respondent's walking frequency being moderate due to a unit increase in land use perception was 20%. The unit increase would be from strongly agree, to being in the "a bit of agree and disagree category", a relationship that's statistically significant (α=0.1). Figure 11-1 better illustrates the odds ratio of walking frequencies transformed into predicted probabilities.

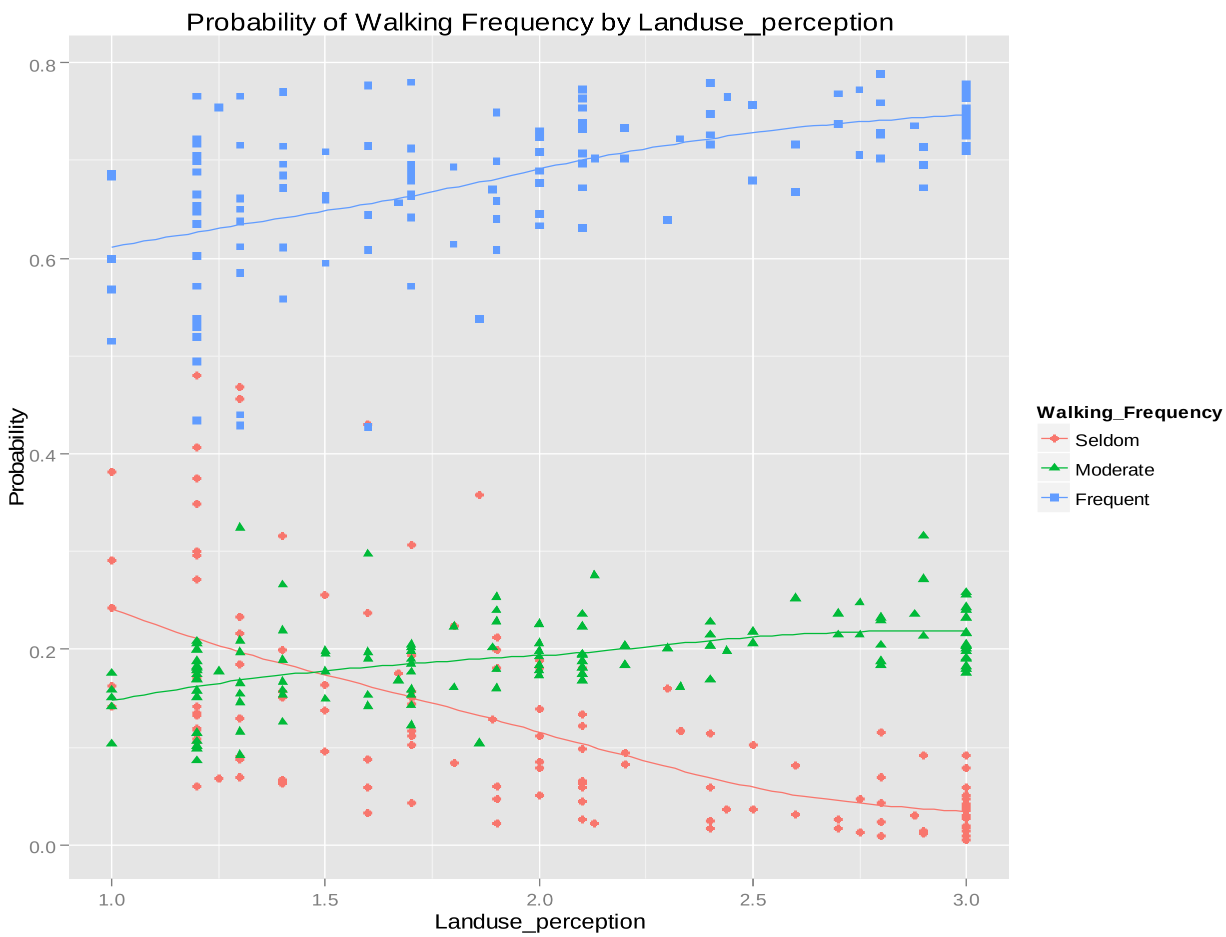


FIGURE 11-1 Probability plot of walking frequency versus land use perception.

There's an upward trend of frequent and moderate walking as land use perception increases while the probability of walking seldom reduces. Kuzmyak, et al. (2006) reported an association between walking frequency and higher land-use mix which afforded more walking opportunities. The authors suggested mixing commercial and residential parcels as well as good regional transit connections which would manage VMT growth and reduce demand for new capacity. The land use model, model indicated more sensitivity to small land use changes in neighborhoods with fewer land uses. Neighborhoods that reported low land use perception, such as DelWebb and Via Greco (Table 10-1) might have an increased likelihood of walking with increased land use mix of which the neighborhoods had two land use types.

Walking frequency versus aesthetics and amenities perception

Table 11-1, indicates a significant relationship (α=0.05), between walking frequency and aesthetics and amenities perception. Similar to land use perception, due to a unit increase in aesthetics and amenities perception, the probability of respondents being in the moderate walking frequency category is 20%. There's a higher probability (69%) of respondents being in the frequent walking category due to a unit increase in aesthetics and amenities perception. Predicted probabilities are plotted for illustration in Figure 11-2.

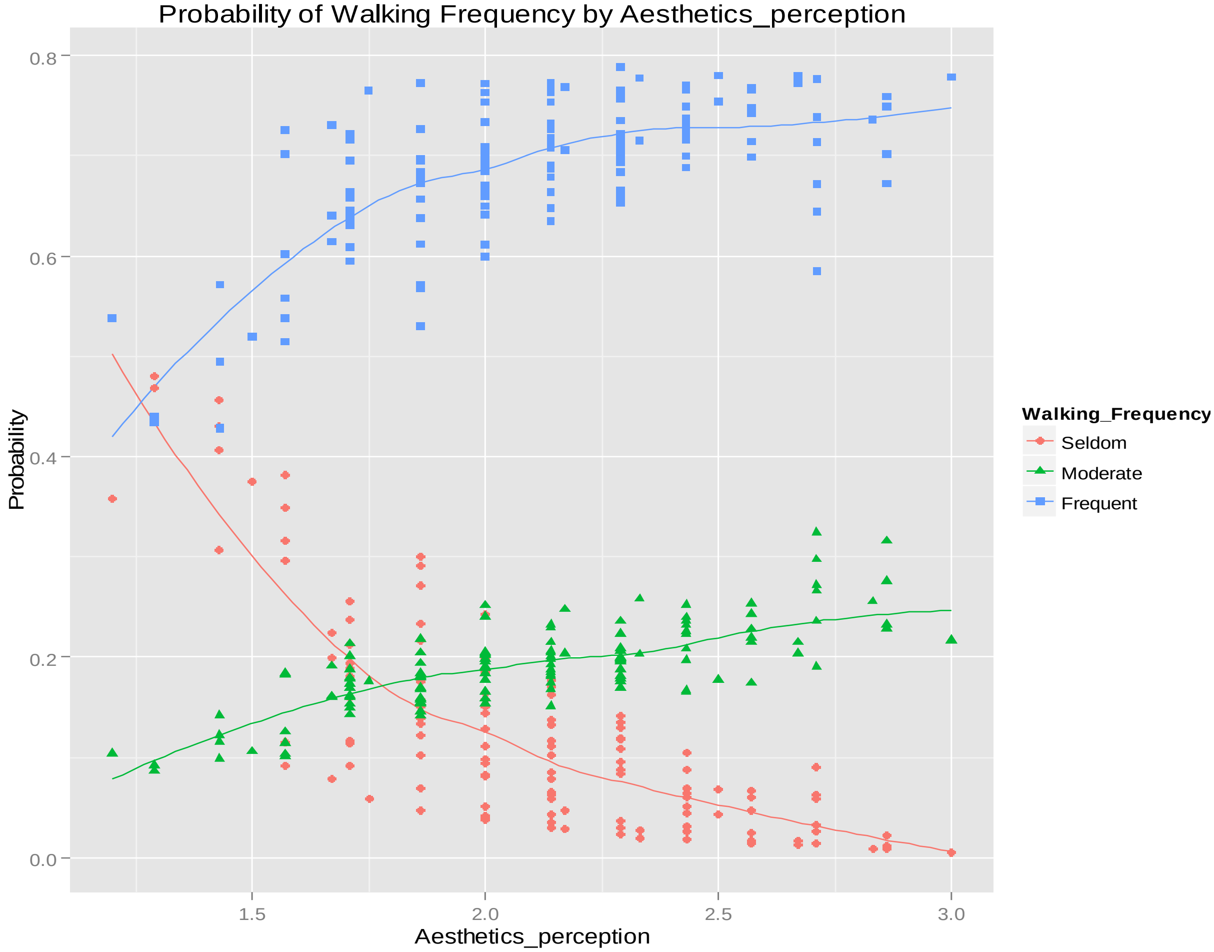


FIGURE 11-2 Probability plot of walking frequency vs aesthetics and amenities perception.

From Figure11-2, an upward trend is evident for frequent and moderate walking frequencies with increase in aesthetics and amenities perception. This implies the probability of increasing walking frequency to the moderate and frequent categories with enhanced aesthetics and amenities which in turn reduces the probability of seldom walking.

Though included in the model, transit, safety, directness, and continuity perceptions were not statistically significant which could be as a result of correlation illustrated in Table 11-2. However, intuitively, the variables do influence walking frequency. It is reasonable to expect a correlation between land use and directness perceptions, given that directness estimates how quickly and easily pedestrians can get to their destinations. Table 11-2 shows the weak but significant relationship.

TABLE 11-2 Correlation Matrix for Resident Perceptions

Correlations						
		Landuse-perception	Directness-perception	Continuity-perception	Aesthetics-perception	Safety-perception
Landuse-perception	Pearson Correlation	1				
	Sig. (2-tailed)					
Directness-perception	Pearson Correlation	0.24**	1			
	Sig. (2-tailed)	0.00				
Continuity-perception	Pearson Correlation	0.02	0.21**	1		
	Sig. (2-tailed)	0.77	0.01			
Aesthetics-perception	Pearson Correlation	0.19*	0.30**	0.49**	1	
	Sig. (2-tailed)	0.02	0.00	0.00		
Safety-perception	Pearson Correlation	0.07	0.51**	0.42**	0.42**	1
	Sig. (2-tailed)	0.41	0.00	0.00	0.00	

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Aesthetics and amenities perception had weak to moderate relationships with directness, safety and continuity. It is reasonable to expect a relationship between a complete, continuous and well maintained walking environment and aesthetics of the said walking environment. However the relationship between directness and safety perception which is moderately strong and significant is different from expectation. Intuitively, cul-de-sac, enclosed communities restrict direct access to land uses. Conversely, within the enclosed communities, due to restricted traffic access, traffic flows as well as speed limits are low which is conducive for pedestrian activity. In additions the walls surrounding communities serve as buffers between residences and vehicles that veer-off the road. Transit and walking are synonymous expect maybe in cases of park-and-ride facilities that were absent in this study.

Model diagnosis

Due to inclusion of perception variables that are not statistically significant, goodness-of-fit assessments are likely to exhibit inadequacy. However, a chi-square of 52 with 28 degrees of freedom derived using Equation (11-3) and an associated p-value of less than 0.0002 indicates that the model as a whole fits significantly better than an empty model.

$$X^2 = \sum_{i=1}^{n} Dres_i^2$$

Equation (11-3)

11.4. Perception Models

The study was designed as a repeated measures study where respondents' perceptions were collected by selected income groups and neighborhoods. Multiple measurements per neighborhood generally result in correlated errors violating the statically independence of consecutive errors assumption. To correct the within-subject correlation violation, each respondent should ideally have individual intercepts and or slope (Seltman, 2015). This would typically result in uncorrelated errors around each respondent's regression line modeled conditionally on each random effect. However, treating each respondent as a fixed effect with their own intercept consumes substantial degrees of freedom. In addition, comparison of resident perception and audit observation exhibited little variance except in land use perception.

Therefore a single variance parameter representing the spread of random intercepts around the common intercept of each group was estimated. The analysis was conducted using a mixed model approach comprising of fixed and random parameters expressed as:

$$y_i|\gamma_i = X_i\beta + Z_i\gamma_i + \varepsilon$$

Equation (11-4)

Where

β is the estimated intercept for each fixed parameter X_i,

Z_i is the intercept for each random effect

γ_i is the random effect

ε is the error term

Fixed effects parameters describe variability of population means between any set of treatments, while the random effect parameters represent the general variability among subjects. In addition to the level one data, level two data aggregated at neighborhood level was used in the analysis. For respondents coming from the same neighborhood, a singular variable was used for the audit observations.

11.5. Perception Model Calibration

The modeling procedure was as follows. The first step was to identify different perception that influence walking frequency. Perception models were calibrated then calibrated to identify influences of different perception which would result in increasing walking frequencies.

1. Data was organized in a wide format such that each row corresponded to a respondent or observation.
2. Stepwise regression model was fitted to identify predictor variables that could be included in a final perception model.
3. Initially, neighborhood differences were modeled assuming different intercepts for each neighborhood. An intra-class correlation coefficient (ICC) cutoff of 0.1 was used to determine whether the random effect explained enough variance within the model to warrant a mixed effects model. ICC can be described as the ratio of variance explained by the random effect out of total variance, where total variance is the explained variance (by the random effect) plus residual variance explained by the fixed effects. ICC is 1.0 only when there is no variance due to the random effect and no residual variance to explain (Hayes, 2006).
4. If the random effects warranted a mixed effects model, a random slope model was tested. The random slopes model allowed neighborhoods to have different intercepts as well differing slopes. This model proved to be rather expensive in light of limited data especially for the low income neighborhoods with less than 10 responses. From the perception box plots, the difference could reasonably be modeled using a single variance value representing the spread of perception. However due to significant neighborhood design differences, the effect of different predictor variables was modeled using random slopes, resulting in a fixed intercept random slopes model. This was on the basis that the effect of different walking environment features elicits varying perception responses. For

example, neighborhoods that were gated/walled, adding more entrances/exits around the community would probably most likely result in more walking to nearby stores compared to neighborhoods that were already accustomed to uninhibited access.

5. All audit categories were initially modeled using fixed intercept and random slopes combination. This was to determine variables that had enough variability between neighborhoods for the mixed effects model. Finally, the most practically useful combination of variables as fixed and random effects was selected. Due to data expenses, only one variable was selected for random effects. Anova likelihood test was used to compare between the different predictor variables to determine the best combination of variables.
6. After significant and or practically useful variables were selected, the final model was tested to determine goodness of fit using diagnostics such as residual and normality plots. Cook's distances were also plotted to determine the presence of influential outliers.

11.6. Models Results

The results are arranged in the same format for all the response variables for perception categories as discussed above.

11.6.1. Safety Perception Model

Using a linear regression model, 9 coefficients for audit parameters were undefined because of singularities. In addition, in comparison to neighborhood 1, neighborhoods 8 and 9 were also undefined due to singular values, Table 11-3.

TABLE 11-3 Table of Linear Regression Output for Safety Perception

Variable	Estimate	Std. Error	t value	Pr(>|t|)	Significance
(Intercept)	1.20	4.67	0.26	0.80	
Gender-Female	-0.15	0.07	-2.12	0.04	*
Age3	-0.05	0.10	-0.48	0.63	
Age4	0.03	0.10	0.34	0.73	
Age5	-0.10	0.11	-0.89	0.37	
Mean-age	NA	NA	NA	NA	
Income-group	-0.03	0.27	-0.12	0.91	
Log(meanincome)	0.11	0.50	0.21	0.83	
Neighborhood2	-0.07	0.26	-0.28	0.78	
Neighborhood3	0.07	0.18	0.37	0.71	
Neighborhood4	0.08	0.13	0.60	0.55	
Neighborhood5	0.48	0.11	4.22	0.00	***
Neighborhood6	0.24	0.15	1.53	0.13	
Neighborhood7	0.45	0.22	2.05	0.04	*
Neighborhood8	NA	NA	NA	NA	
Neighborhood9	0.38	0.15	2.60	0.01	*
Neighborhood10	0.04	0.14	0.28	0.78	
Neighborhood11	NA	NA	NA	NA	
Walking_frequency-Moderate	-0.04	0.12	-0.34	0.73	
Walking_frequency-Frequent	0.05	0.09	0.58	0.56	
Transit-no	-0.24	0.11	-2.08	0.04	*
Residency <5yrs	-0.02	0.08	-0.20	0.85	
Residency 5+ yrs	0.07	0.11	0.65	0.52	
Car_availability-sometime	-0.07	0.24	-0.28	0.78	
Car_availability-always	0.06	0.22	0.25	0.80	
Amenities-audit	NA	NA	NA	NA	
Continuity-audit	NA	NA	NA	NA	
Directness-audit	NA	NA	NA	NA	
Safety-audit	NA	NA	NA	NA	
Crash-index	NA	NA	NA	NA	
Infrastructure-index(FL)	NA	NA	NA	NA	
Safety-index(FL)	NA	NA	NA	NA	
Landuse	NA	NA	NA	NA	
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

TABLE 11-4 Stepwise Regression Output for Safety Perception

Step: AIC=-260.82

safetysurvey ~ gender + neighborhood + transit

	Df	Sum of Sq	RSS	AIC
<none>			10.38	-260.8
+ Mean-age	1	0.05	10.33	-259.4
+ Walking-frequency	2	0.16	10.22	-258.7
- Gender	1	0.40	10.78	-258.4
+ Car-availability	2	0.13	10.25	-258.3
+ Residency	2	0.05	10.33	-257.5
- Transit	1	0.51	10.89	-257.1
- Neighborhood	10	3.79	14.17	-244.1

From stepwise regression Table 11-4, variables selected for the safety perception model included gender, neighborhood and transit. The neighborhood variable was further tested for variability between groups to warrant a mixed effects model. From Table 11-5 the variation between neighborhoods accounts for about 19% of the variation in safety perception. With increase in group variation, use of single-level analysis methods such as ordinary multiple regression are inadequate to model the non-independence between level two and level one variables.

TABLE 11-5 Random Intercept Model for Safety Perception

Formula: Safety-perception~ Gender + Transit + (1 | neighborhood)

REML criterion at convergence: 85.2

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.10	-0.63	0.02	0.48	2.63

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	(Intercept)	0.02	0.15	**0.19**
Residual		0.10	0.32	**0.81**

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	2.42	0.11	69.39	22.16	<2e-16	***
Gender-female	-0.15	0.06	112.02	-2.39	0.02	*
Transit-no	-0.17	0.09	114.78	-1.80	0.07	.

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

	(Intercept)	Gender-female
Gender-female	-0.47	
Transit-no	-0.76	0.11

TABLE 11-6 Fixed Intercept-Random Slopes Model for Effect of Aesthetic & Amenities Features on Safety Perception

Safety-perception ~ Gender + Transit + Log(meanincome) +
(0 + Amenities-audit | neighborhood)

REML criterion at convergence: 84.9

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.17	-0.63	-0.02	0.53	2.61

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	Amenities-audit	0.00	0.05	0.03
Residual		0.10	0.31	0.97

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	1.21	0.78	10.23	1.54	0.15	
Gender-female	-0.13	0.06	112.86	-2.12	0.04	*
Transit-no	-0.22	0.10	115.98	-2.27	0.02	*
Log(Mean-income)	0.11	0.07	10.48	1.53	0.16	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

	(Intr)	Gender-female	Transit-no
Gender-female	-0.12		
Transit-no	0.12	0.10	
Log(Mean-income)	-0.99	0.05	-0.22

TABLE 11-7 ICC for Other Variables Modeled as Random Effects in Safety Perception

Variable	Neighborhood Variance	Residual Variance
Amenities-audit	3%	97%
Continuity-audit	1%	99%
Directness-audit	**44%**	**56%**
Safety-audit	1%	99%
Crash-index	2%	98%
Infrastructure-index(FL)	**50%**	**50%**
Safety-index(FL)	**46%**	**54%**
Landuse	**56%**	**44%**

*FL - Index comprised of categories combined in Fuzzy Logic

All audit categories were modeled as random effects to identify variables with sufficient variation between neighborhoods for final mixed effects model as illustrated in Table 11-6. The effect of aesthetics and amenities by neighborhood explained little of the variation of safety perception. From Table 11-7, directness features and land uses, had substantial variation between neighborhoods that that accounted for variation in safety perception. The overall audit safety also associated with reducing crash risk; and infrastructure indices that were obtained from fuzzy logic (FL) also accounted for some variation in the safety perception model.

Intuitively, directness is highly correlated with land uses given that it measures ease and quick access to the land uses. Directness features were associated with safety perception with regards to street hierarchy predominant within enclosed neighborhoods. Typically, there is lower traffic volume due to inhibited access such as cul-de-sacs, as well as minor streets within enclosed neighborhoods. This results in a safer walking environment within the gated neighborhood as opposed to outside where higher volume streets are found (Burden, 1999). Infrastructure, obtained by combining continuity, directness, aesthetics and amenity features in fuzzy logic, was mainly driven by the directness category in this case and could therefore be represented as such in the model. Crashes did not qualify in the model, given there were three neighborhoods that lacked pedestrian crashes. Intuitively, not all residents in a given neighborhood might be aware of pedestrian crashes. The overall safety index was used to represent safety measures and potential crash risk. As earlier indicated, AIC and practically useful and (or) significant variables were used for selecting the final model. The final model selected and resulting output was as follows;

$$Safety\_perception_{ij} = \gamma_j^0 + \gamma_j^1 Directness\_audit_i + \beta_1 Gender + \beta_2 Transit + \beta_3 Safety\_index + \varepsilon_{ij}$$

Equation (11-5)

Where

i indexes the *i*th respondent and *j* indexes the neighborhood.

TABLE 11-8 Final Safety Perception Model

Safety_perception ~ Gender + Transit + (0 + Directness-audit | neighborhood) + Safety_index (FL)

REML criterion at convergence: 87.9

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.99	-0.64	-0.05	0.55	2.37

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	Directnessaudit	0.10	0.31	**0.50**
Residual		0.10	0.31	**0.50**

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	2.00	0.14	18.70	14.18	0.00	***
Gender-female	-0.16	0.06	112.27	-2.56	0.01	*
Transit-no	-0.23	0.09	111.94	-2.48	0.01	*
Safety-index(FL)	0.99	0.21	26.49	4.60	0.00	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

*FL - Index comprised of categories combined in Fuzzy Logic

Starting with the fixed effects in TABLE 11-8, holding all other effects constant, the safety perception of women was 0.16 units less compared to men (the reference category) which is statistically significant (α=0.05). Similarly, the safety perception of non-transit users was 0.23 units less than that of transit users. The low safety perception could be the reason why these respondents don't use transit. Alternatively, it could be interpreted that transit users are more familiar with the walking environment and therefore have a higher safety perception compared to non-transit users. Holding all other variables constant, a unit increase in overall safety measures which includes reducing crash risk increased safety perception by about one unit. Intuitively, increase in safety infrastructure should significantly increase safety perception.

Random effects explained half the variance in safety perception. Intuitively due to significant differences in neighborhood design - such as gated/walled communities and land use diversity - it is reasonable to expect that gates/walls and land uses will elicit more or less perception of safety as earlier discussed. Coefficients for the fixed intercept-random slopes models are presented in Table 11-9. The first two columns in the table identify the neighborhoods, which are arranged by income groups one to five. Column three shows the single variance value estimated to portray the spread of safety scores from audit observations within neighborhoods. Column four indicates the effect of directness-audit on safety perception. Columns four to seven are the fixed effect variables described above. Coefficients for other perception models are presented in the same format.

TABLE 11-9 Coefficients for Final Safety Perception Model

	Neighborhood	(Intercept)	Directness-audit	Gender-female	Transit-no	Safety-index(FL)
1	5th&Carey	2.00	-0.41	-0.16	-0.23	0.99
2	Euclid	2.00	0.06	-0.16	-0.23	0.99
3	Sonterra-Apts	2.00	0.24	-0.16	-0.23	0.99
4	Sunset&Boulder	2.00	-0.30	-0.16	-0.23	0.99
5	DelWebb	2.00	0.01	-0.16	-0.23	0.99
6	DesertSky-Apts	2.00	0.19	-0.16	-0.23	0.99
7	San Destin	2.00	0.03	-0.16	-0.23	0.99
8	ViaGreco	2.00	-0.05	-0.16	-0.23	0.99
9	Anthem	2.00	0.08	-0.16	-0.23	0.99
10	Historic Alta	2.00	0.07	-0.16	-0.23	0.99
11	SpanishTrail	2.00	-0.06	-0.16	-0.23	0.99

TABLE 11-10 Confidence Intervals for Final Safety Perception Model

Parameter	Confidence Interval (2.5%)	Confidence Interval (97.5%)
Random effect (Neighborhood)	0.00	0.70
Residual	0.27	0.36
(Intercept)	1.70	2.28
Gender-female	-0.30	-0.04
Transit-no	-0.42	-0.05
Safety-index(FL)	0.51	1.45

*FL - Index comprised of categories combined in Fuzzy Logic

From Table 11-9, the negative coefficients imply an inverse relation such that neighborhoods with low initial safety perception are likely to be more sensitive to small changes in directness features. 5th & Carey, Sunset & Boulder, and Spanish Trail had the lowest safety perception compared to the rest of the neighborhoods and average directness scores in the audit. Via Greco neighborhood had both low perception and directness-audit score. 5th & Carey and Sunset & Boulder neighborhoods are not gated and about 50% of audited segments had speed limits of 25mph or greater. In addition, both neighborhoods have low FAR values with many land uses implying large parking lots in front of commercial premises hence increased exposure to crash risk. Spanish Trail and Via Greco neighborhoods are gated, with high speed/volume streets near the neighborhoods. Spanish Trail has many land uses which were more than 15-minute walk from residences on Rainbow Boulevard and Durango Drive. Via Greco has few land uses within the neighborhood stud-limit. In both neighborhoods, residents are likely to be more sensitive to small changes in access to land use. These changes would most likely enhance safety perception as indicated by the negative coefficients by reducing exposure to safety risks. Table 11-10 illustrates the significance of obtained coefficients for the safety perception model.

Safety perception model diagnostics

Diagnosis tools used to assess the final model for goodness fit included residual and quantile (q-q) plots, and histogram. The histogram tested for normality while the random and q-q plots tested for homogeneity and presence of outliers in the model. Cook's distances were used to determine the presence of influential outliers. From the histogram (plot A) and random (plot B) in Figure 11-3 below, the residuals are generally normal, homoscedastic and randomly distributed.

The Q-Q plots by neighborhood (plot D) also show general normality trend. The random plots by neighborhood (plot E) illustrate variables that were most influential on safety perception in a particular neighborhood. For example, gender and transit were most significant in neighborhoods one (5th & Carey), five (DelWebb, a retirement community) and nine (Anthem). In neighborhoods two (Euclid), three (Sonterra Apt), and ten (Historic-Alta), safety infrastructure and crash risk had more impact on resident safety perception.

Cook's distances (plot C) show two outliers (observations 33 and 34) further away from the rest. The observations are not influential outliers since Cook's distance is less than 1. The model indicated a more favorable safety perception by transit users, of which observation 32 had the greatest initial distance from the mean of female transit-users. Observation 33 had the lowest safety perception of female no-transit users. No substantial change was noted when observations were dropped and are therefore included in the dataset.

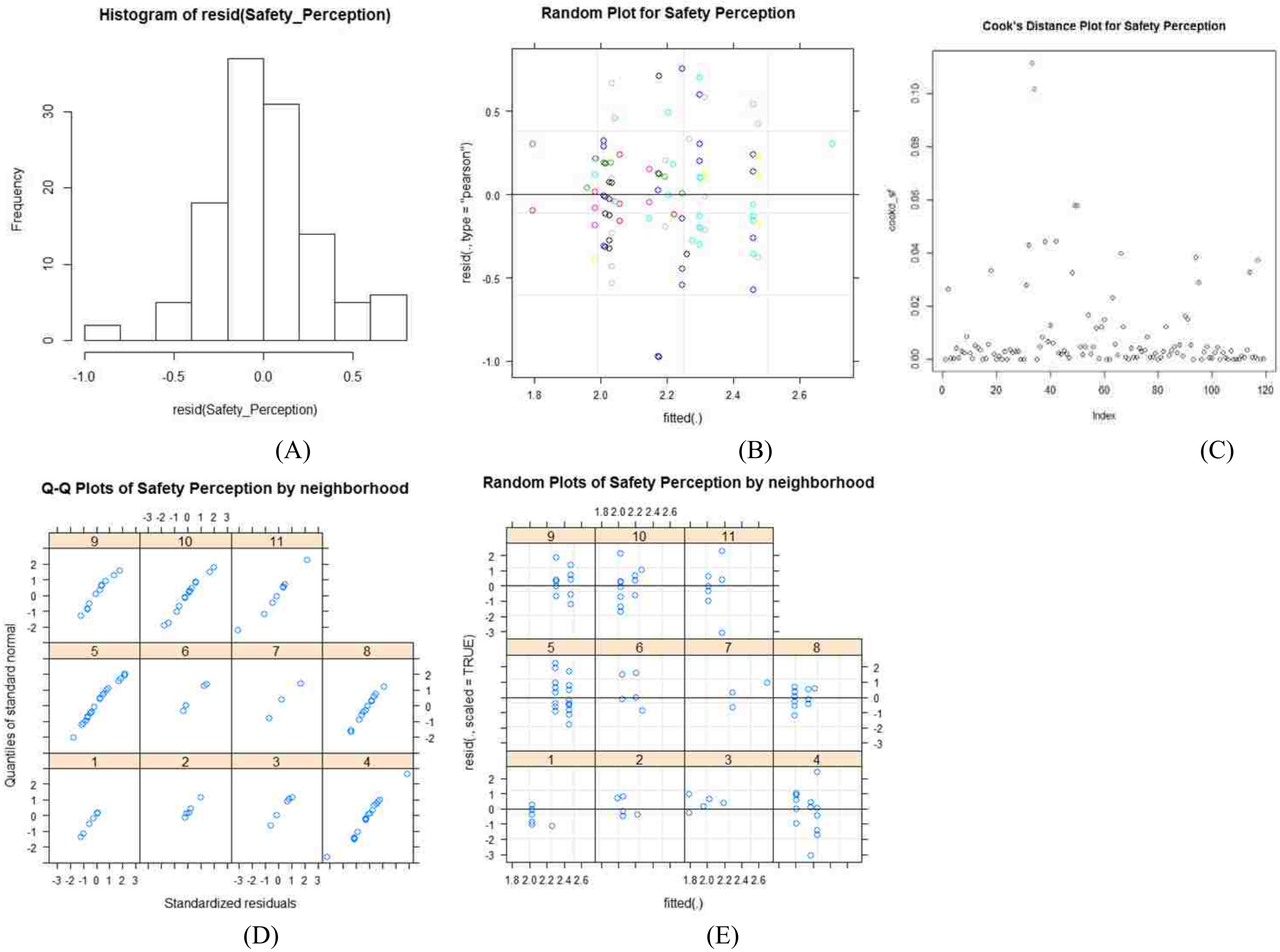


FIGURE 11-3 Diagnosis plots for final safety perception model

11.6.2. Land Use Perception Model

Similar to the safety perception model Table 11-3, all variables were regressed against land use perception to identify those that useful in explaining variability of land use perception. The output is attached in Appendix V. From stepwise regression Table 11-11, walking frequency and neighborhood were useful in describing variability of land use perception.

TABLE 11-11 Stepwise Regression Output for Land Use Perception

Step: AIC=-134.13 landusesurvey ~ neighborhood + walking-frequency				
	Df	Sum of Sq	RSS	AIC
<none>			30.38	-134.13
- Walking frequency	2	1.26	31.64	-133.34
+ Gender	1	0.25	30.13	-133.11
+ Caravailability	2	0.72	29.66	-132.96
+ Meanage	1	0.21	30.17	-132.94
+ Residency	2	0.65	29.73	-132.68
+ Transit	1	0.13	30.25	-132.63
- Neighborhood	10	25.45	55.82	-82.33

TABLE 11-12 Random Intercepts Model for Land Use Perception

Formula:Landuse_perception ~ Walking-frequency + (1 | neighborhood)

REML criterion at convergence: 278.3

Scaled residuals:

Min	1Q	Median	3Q	Max
-4.07	-0.54	-0.05	0.58	3.08

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	(Intercept)	0.19	0.44	**0.38**
Residual		0.32	0.56	**0.62**

Number of obs: 149, groups: neighborhood, 11

Fixed effects:

	Estimate	Std. Error	df	t-value	Pr(>|t|)	
(Intercept)	1.71	0.19	30.66	9.01	0.00	***
Walking_frequency-Moderate	0.34	0.18	138.62	1.94	0.05	.
Walking_frequency-Frequent	0.24	0.15	138.00	1.60	0.11	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

	(Intercept)	Walking_frequency-Moderate
Walking_frequency-Moderate	-0.55	
Walking_frequency-Frequent	-0.65	0.71

TABLE 11-13 ICC for Other Variables Modeled as Random Effects in Land Use Perception

Variable	Neighborhood Variance	Residual Variance
Amenities-audit	8.3%	91.7%
Continuity-audit	4.8%	95.2%
Directness-audit	**92.8%**	7.2%
Safety-audit	4.6%	95.4%
Crash-index	**70.7%**	29.3%
Infrastructure-index (FL)	**75.3%**	24.7%
Safety-index (FL)	**74.4%**	25.6%
Landuse	**73.1%**	26.9%

*FL - Index comprised of categories combined in Fuzzy Logic

A random intercept model was fitted to confirm the need for a mixed model. Table 11-12 above illustrates a substantial amount of variance between neighborhoods accounting for land use perception. Each audit category was fitted as a random effect as previously illustrated earlier to determine audit observation categories whose neighborhood variation accounted for substantial variation in land use perception. Variables that exhibited neighborhood variation included directness, crash risk, infrastructure, overall safety, and land use, Table 11-13. The high infrastructure variance was likely driven by directness since it was a combination of directness, continuity, aesthetics and amenities audit observations. The final model selected and resulting output was as follows;

$$Land\ use\_perception_{ij} = \gamma_j^0 + \gamma_j^1 Landuse_i + \beta_1 Walking\_frequency + \beta_2 Directness\_audit + \varepsilon_{ij}$$

Equation (11-6)

Where

i indexes the i^{th} respondent and *j* indexes the neighborhood.

TABLE 11-14 Final Land Use Perception Model

Landuse-perception ~ Walking_frequency + (0 + Landuse | Neighborhood) + Directness-audit

REML criterion at convergence: 208

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.55	-0.61	0.04	0.64	3.00

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	Landuse	0.27	0.52	**0.48**
Residual		0.29	0.54	**0.52**

Fixed effects:

	Estimate	Std. Error	df	t-value	Pr(>|t|)	
(Intercept)	1.11	0.17	69.23	6.32	0.00	***
Walking_frequency-Moderate	0.27	0.18	107.45	1.51	0.13	
Walking_frequency-Frequent	0.30	0.15	106.60	2.01	0.05	*
Directness-audit	1.81	0.49	7.70	3.71	0.01	**

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

In Table 11-14, holding all other fixed effects constant, the land use perception of respondents who walked moderately was 0.27 units higher compared to those who seldom walked. The land use perception of respondents who walked frequently was much higher (0.3 units) compared to respondents who seldom walked. Intuitively, more frequent walking provides more opportunities for statistically significant land use familiarity (α=0.05). Easier and quick access to the provided land uses enhances land use perception as well. The strong and statistically significant direct relationship between directness and land use perception indicates that better land use accessibility is likely to improve land use perception.

In the random effects, variation of land uses by neighborhood explains almost half the variance in land use perception. From audit observations, neighborhoods with the highest and lowest land uses each had 11 and two land uses respectively. It is reasonable to expect different responses from residents in neighborhoods with more land uses and those with few. For example, if said land uses have a large footprint, they are more noticeable compared to smaller buildings without specialized services or functions. Moreover, larger land uses might require vehicular use (e.g. Wal-Mart tends to have large parking lots) influencing transportation modes. Cervero and Kockelman (1997) reported potential, for linked trips in locations with in-neighborhood stores. Convenient stores between transit stops and residential neighborhoods provides walking opportunities to the stores, and allows patrons to link work and shopping trips on foot, on the return trip home. A fixed intercept was used to represent the spread of various land uses while random slopes were used to model effect of land uses on resident perception. Table 11-15 shows the different coefficients for the land use perception model.

TABLE 11-15 Coefficients for Final Land Use Perception Model

	Neighborhood	(Intercept)	Landuse	Walk-Moderate	Walk-frequent	Directness-audit
1	5th&Carey	1.11	0.19	0.27	0.30	1.81
2	Euclid	1.11	-0.11	0.27	0.30	1.81
3	Sonterra-Apts	1.11	-0.08	0.27	0.30	1.81
4	Sunset&Boulder	1.11	-0.02	0.27	0.30	1.81
5	DelWebb	1.11	-0.24	0.27	0.30	1.81
6	DesertSky-Apts	1.11	0.80	0.27	0.30	1.81
7	San Destin	1.11	0.59	0.27	0.30	1.81
8	ViaGreco	1.11	0.08	0.27	0.30	1.81
9	Anthem	1.11	-0.32	0.27	0.30	1.81
10	Historic Alta	1.11	-0.10	0.27	0.30	1.81
11	SpanishTrail	1.11	-0.73	0.27	0.30	1.81

TABLE 11-16 Confidence Intervals for Final Land Use Perception Model

Parameter	Confidence Interval (2.5%)	Confidence Interval (97.5%)
Random effect (Neighborhood)	0.19	0.87
Residual	0.47	0.62
(Intercept)	0.77	1.44
Walking_frequency-Moderate	-0.08	0.63
Walking_frequency-Frequent	0.00	0.60
Directness-audit	0.87	2.79

Intuitively, neighborhoods with a low land use mix are likely to be more sensitive to land use changes within their neighborhood. The negative coefficients in Table 11-15 indicate that low land use perception is significantly associated with more sensitivity to small land use changes (95% confidence interval) Table 11-16. High resident land use perception in neighborhoods such as 5th & Carey, Desert Sky Apartments, and San Destin coincided with audit observations. In such neighborhoods, small changes might be unnoticeable hence the direct relationship indicated by positive coefficients. Neighborhoods such as Sonterra, Euclid, Sunset &

Boulder Anthem, Spanish Trail and Historic Alta indicated improved land use perception with small changes in land uses. Of these neighborhoods, Spanish Trail, Sonterra, and Anthem are gated; therefore land uses might be further than 15-minute walk of residences that was inquired of in the survey. In Historic Alta and Sunset & Boulder neighborhoods, land uses were generally located on one side of the neighborhood also making them probably a little further than a 15-minute walk. In Via Greco neighborhood, respondents had low land use perception which coincided with the relatively low audit land use observations. To improve perception in this neighborhood whose land uses were mainly comprised of small cafes, cocktail lounges and club houses, bigger land use changes would be required.

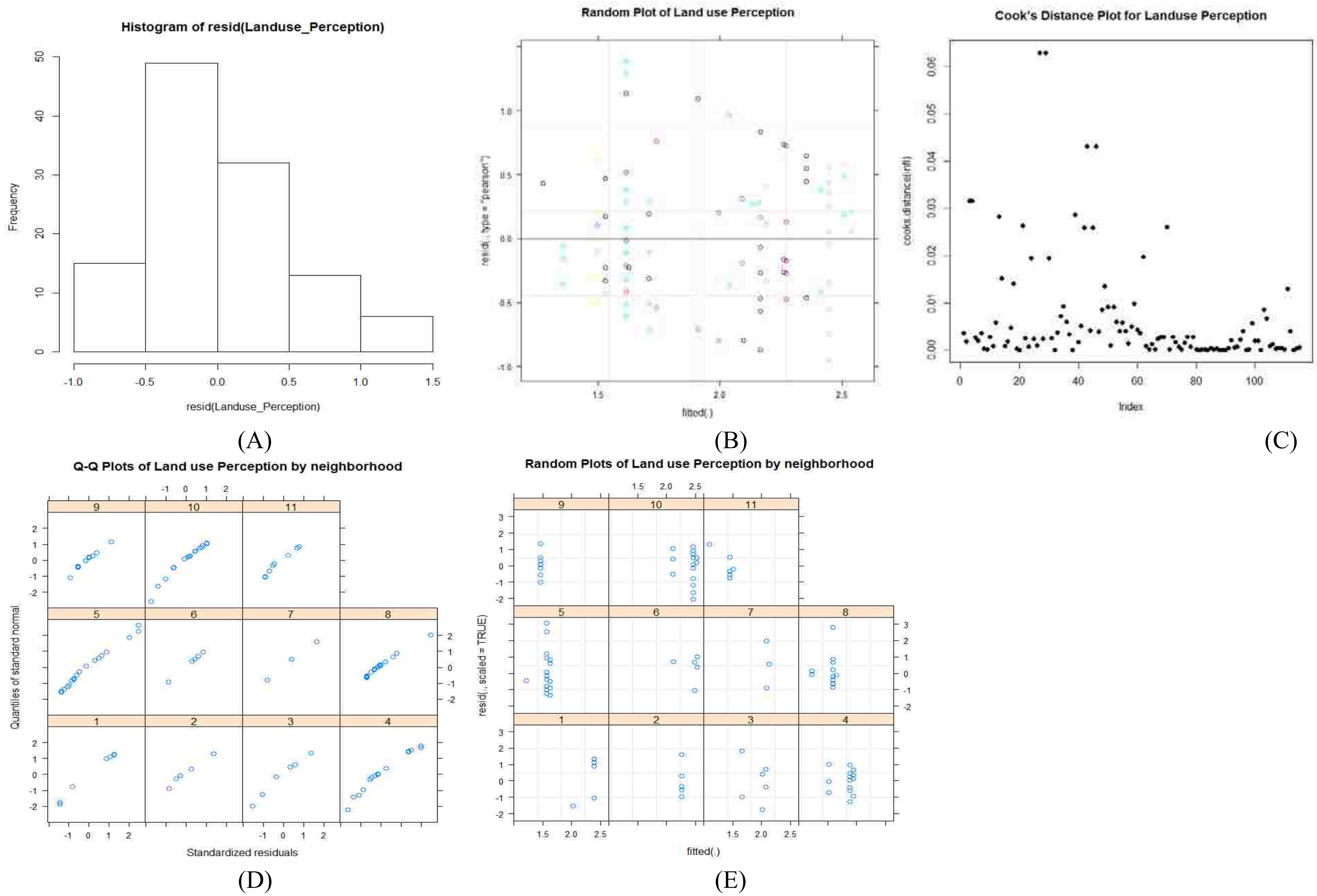


FIGURE 11-4 Diagnostics plots for final land use perception model

Land use perception model diagnostics

Similar to safety perception model, histograms, random and q-q plots were used to assess the land use perception model goodness-of-fit as shown in Figure 11-4. The land use perception model histogram of residuals (plot A) as well as the q-q plots by neighborhood (plot C) exhibit relatively normal distribution of residuals. The random plot of the land use perception (plot B) shows no presence of variance issues. When plotted by neighborhood, walking frequency (categorical variable) influences land use perception in some neighborhoods more than others (plot D). Directness to land uses influenced resident land use perception of Sonterra and Desert Sky Apartments neighborhoods that had among the highest directness scores compared to other neighborhoods. Cook's distance plot (plot E) was set up to flag noteworthy observations such as outliers. The two distant points (Observations 27 and 29) indicated the lowest perception value for respondents who walk moderately and the median value for respondents who frequently walk in income group four. Cook's distances for the observations are less than 1, hence not considered influential outliers. In addition, no substantial change was noted when dropped therefore not included in the dataset.

11.6.3. Amenities & Aesthetics Perception Model

The following section presents results for the amenities and aesthetics model in the same format outlined in Section 10.4. The Ordinary Least Squares (OLS) regression models was fitted as illustrated in Table 11-3 whose output in attached in Appendix V. Output for stepwise regression, and mixed models are presented below.

TABLE 11-17 Stepwise Regression Output for Aesthetics & Amenities Perception

Step: AIC=-241.85
Aesthetic-Perception~ Gender + Neighborhood + Walking-frequency + Transit

	Df	Sum of Sq	RSS	AIC
<none>			11.79	-241.85
+ Caravailability	2	0.39	11.40	-241.83
- Gender	1	0.20	11.99	-241.82
+ Mean-age	1	0.08	11.71	-240.63
- Walking frequency	2	0.63	12.42	-239.69
+ Residency	2	0.07	11.72	-238.56
- Transit	1	0.55	12.33	-238.51
- Neighborhood	10	4.75	16.54	-221.89

TABLE 11-18 Random Intercept Model for Aesthetics & Amenities Perception

Formula: aesthetics-perception ~ Walking-frequency + (1 | Neighborhood)

REML criterion at convergence: 104.9

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.56	-0.54	-0.01	0.48	3.29

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	(Intercept)	0.03	0.19	**0.23**
Residual		0.12	0.35	**0.77**

Number of obs: 118, groups: neighborhood, 11

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	1.86	0.11	46.46	17.57	< 2e-16	***
Walking_frequency-Moderate	0.32	0.12	108.58	2.71	0.01	**
Walking_frequency-Frequent	0.26	0.10	108.29	2.69	0.01	**

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:

	(Intr)	Walking_frequency-Moderate
Walking_frequency-Moderate	-0.621	
Walking_frequency-Frequent	-0.762	0.673

TABLE 11-19 ICC for Other Variables Modeled as Random Effects in Aesthetics & Amenities Perception

Variable	Neighborhood Variance	Residual Variance
Amenities-audit	3.5%	96.5%
Continuity-audit	2.9%	97.1%
Directness-audit	**80.7%**	19.3%
Safety-audit	2.1%	97.9%
Crash-index	**78.2%**	21.8%
Infrastructure-index(FL)	**60.2%**	39.8%
Safety-index(FL)	**50.0%**	50.0%
Landuse	**42.4%**	57.6%

*FL - Index comprised of categories combined in Fuzzy Logic

From stepwise regression model, variables obtained that can explain the variance in aesthetics and amenities perception included gender, neighborhood and walk frequency. From the mixed effects model, variability between neighborhoods accounted for about 23% of the variability of aesthetics and amenities perception. From Table 11-19, directness features, crash-index, infrastructure-index (FL), overall audit safety index and land uses, had substantial variation between neighborhoods that that accounted for variation in aesthetics and amenities perception. The model with the most practically useful variables was used to select using anova tests as the final performing model. The final land use perception model together with the output was as follows:

$$Ameneties\ \&\ Aesthetics\ Perception_{ij} = \gamma_j^0 + \gamma_j^1 Safety - index(FL)_i + \beta_1 Walking - frequency + \beta_2 Transit + \beta_3 Landuse + \beta_3 Infrastructure + \varepsilon_{ij}$$

Equation (11-7)

Where

i indexes the i^{th} respondent and j indexes the neighborhood.

TABLE 11-20 Final Aesthetics & Amenities Perception Model

Aesthetic-perception ~ Walking-frequency + Transit + (0 +Safety-index(FL) | Neighborhood) + Entropy + Infrastructure-index(FL)

REML criterion at convergence: 93.2

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.52	-0.65	0.01	0.57	3.07

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	Safety-index (FL)	0.02	0.14	**0.14**
Residual		0.11	0.34	**0.86**

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	1.80	0.19	15.49	9.39	0.00	***
Walking_frequency-Moderate	0.26	0.11	110.87	2.26	0.03	*
Walking_frequency-Frequent	0.23	0.10	111.01	2.44	0.02	*
Transit-no	-0.18	0.10	110.87	-1.78	0.08	.
Landuse	-0.65	0.16	5.50	-3.93	0.01	**
Infrastructure-index(FL)	1.36	0.33	8.29	4.12	0.00	**

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

*FL - Index comprised of categories combined in Fuzzy Logic

From the fixed effects in Table 11-20, respondents who walked moderately had 0.26 units higher perception of aesthetics and amenities compared to those who seldom walked, ceteris paribus. Similarly, respondents who walked frequently also had 0.23 units higher perception of aesthetics and amenities compared to those who seldom walked. Compared to transit users, non-transit users had 0.18 units less perception, ceteris paribus. Though not statistically significant (α=0.05), the transit parameter was included in the model due to the relationship to walking. Intuitively, transit users mainly walk to access transit unless accessing transit at a park-and-ride facility.

All things held constant, a unit increase in land uses reduced aesthetics and amenities perception by 0.65. In some cases the type of business such as service garage, flea market, influences how pleasant the surroundings are. Intuitively, commercial properties that are associated with a lot of traffic are more likely to be physical disorders such as trash. A unit increase in infrastructure resulted in 1.36 unit increase in aesthetics and amenities perception. Infrastructure was a fuzzy index value comprised of directness, continuity and aesthetics and amenities features.

The overall audit safety modeled as a random effect by neighborhood, explained approximately 14% of the variance in aesthetics and amenities perception Table 11-20. The remaining variance was explained by the fixed effects discussed above. Table 11-21 presents the final Aesthetics & Amenities model coefficients.

TABLE 11-21 Coefficients for Final Aesthetics & Amenities Perception Model

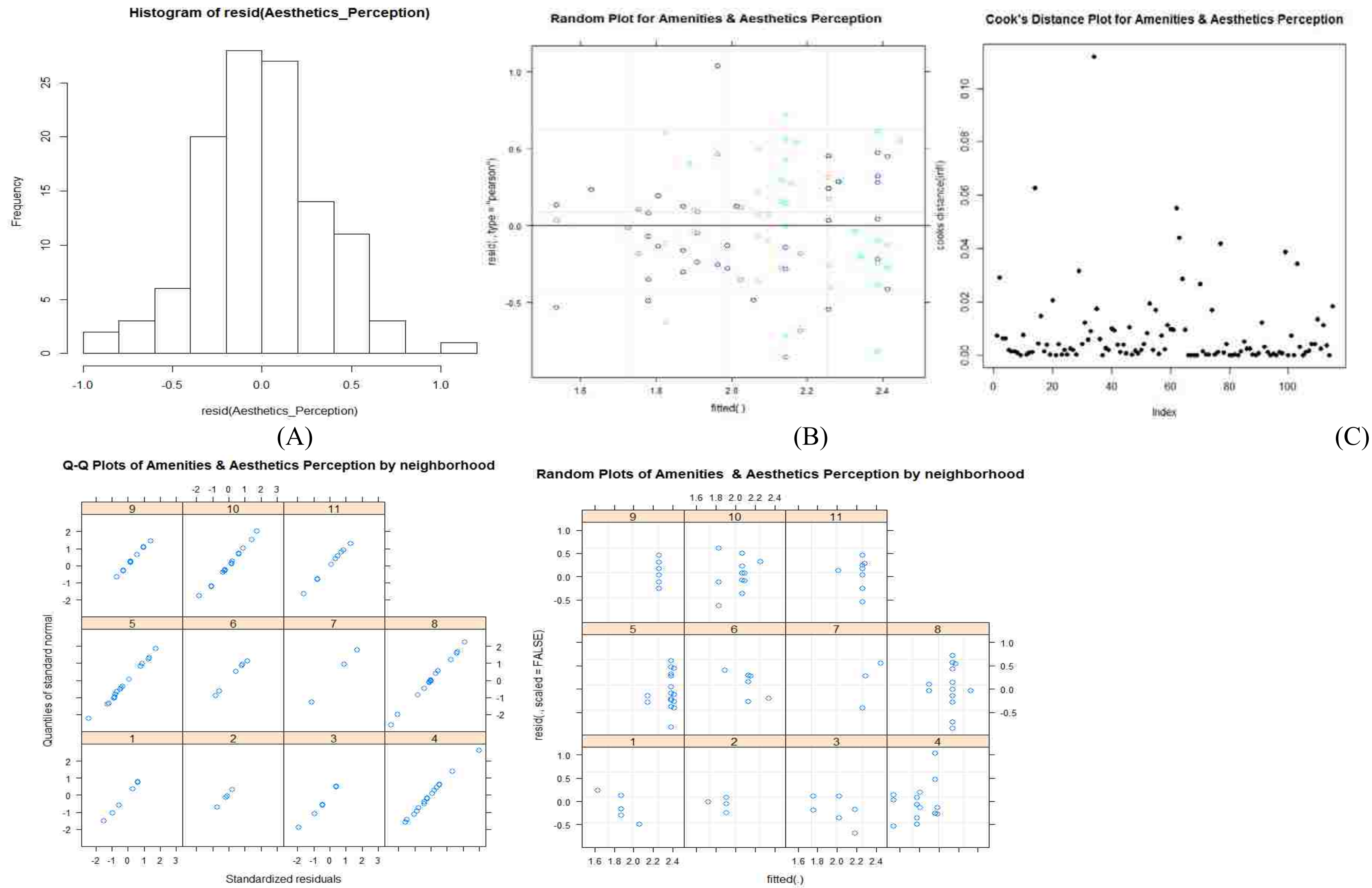
	Neighborhood	(Intercept)	Safety-index (FL)	Walking_ frequency - Moderate	Walking_ frequency - Frequent	Transit-no	Land use	Infrastructure-index (FL)
1	5th & Carey	1.80	-0.03	0.26	0.23	-0.18	-0.64	1.36
2	Euclid	1.80	-0.01	0.26	0.23	-0.18	-0.64	1.36
3	Sonterra-Apts	1.80	-0.03	0.26	0.23	-0.18	-0.64	1.36
4	Sunset & Boulder	1.80	-0.02	0.26	0.23	-0.18	-0.64	1.36
5	DelWebb	1.80	-0.14	0.26	0.23	-0.18	-0.64	1.36
6	DesertSky-Apts	1.80	0.05	0.26	0.23	-0.18	-0.64	1.36
7	San Destin	1.80	0.05	0.26	0.23	-0.18	-0.64	1.36
8	ViaGreco	1.80	0.04	0.26	0.23	-0.18	-0.64	1.36
9	Anthem	1.80	0.10	0.26	0.23	-0.18	-0.64	1.36
10	Historic Alta	1.80	0.02	0.26	0.23	-0.18	-0.64	1.36
11	SpanishTrail	1.80	0.02	0.26	0.23	-0.18	-0.64	1.36

TABLE 11-22 Confidence Intervals for Final Aesthetics & Amenities Perception Model

Parameter	Confidence Interval (2.5%)	Confidence Interval (97.5%)
Random effect (Neighborhood)	0.29	0.38
(Intercept)	1.45	2.14
Walking_frequency-Moderate	0.04	0.49
Walking_frequency-Frequent	0.08	0.44
Transit-no	-0.36	0.03
Landuse	-0.84	-0.36
Infrastructure-index(FL)	0.78	1.79

*FL - Index comprised of categories combined in Fuzzy Logic

From Table 11-21, the negative coefficients indicates that neighborhoods with initial low aesthetics and amenities perception are likely to be more sensitive to small changes in infrastructure that enhances safety and reduces crash risk a statistically significant relationship Table 11-22. Except for DelWebb neighborhood in income group three, income groups one and two neighborhoods had low aesthetics and amenities perception. Having better aesthetics and amenities perception compared to the other neighborhoods, DelWebb residents are likely to be more sensitive to bigger change in safety infrastructure. In addition the coefficient illustrating magnitude of change is much smaller for this neighborhood - which reported no pedestrian crashes - compared to other neighborhoods that would be sensitive to small changes in safety infrastructure. Among the neighborhoods likely to be less sensitive to small changes in infrastructure, Anthem neighborhood had the largest coefficient. In this neighborhood, no pedestrian crashes were reported as well as having safety features that can double for aesthetics such as landscaped buffers. Safety infrastructures such as landscaped buffers, intersection geometry that usually comes with sidewalks and ramps as well as lighting can enhance visual acuity of the walking environment.



(D) (E)

FIGURE 11-5 Diagnostic plots for final aesthetics & amenities perception model

Aesthetics & amenities model diagnostics

As with the previous models, diagnostic plots included q-q and random plots, a histogram, as well as Cook's distance plot, Figure 11-5. The aesthetics and amenities perception histogram (plot A) and the q-q plots by neighborhood (plot D) indicated normality of residuals. The random plot of residuals (plot B) indicated randomness, implying no presence of heteroscedasticity. The random residual plots by neighborhood (plot E) illustrated some of the variables that had substantial influence on aesthetics and amenities perception. For example, walking frequency was most influential in Euclid, DelWebb, Anthem and Spanish Trail illustrated by the vertically ordered residuals. The furthest point (observation 34) was flagged as noteworthy in Cook's distance plot E since it had the highest aesthetics and amenities perception of frequent non-transit users in Sunset & Boulder neighborhood.

11.6.4. Directness Perception Model

The following section presents model results for directness perception. The results are ordered as outlined earlier Section 11.5. The Ordinary Least Squares (OLS) regression model was fitted as illustrated in Table 11-3 whose output in attached in Appendix V. Output for stepwise regression, and mixed models are presented below.

TABLE 11-23 Stepwise Regression Output for Directness Perception

Step: AIC = -256.51
Directness-perception ~ Gender + Directness-audit + Infrastructure-index(FL) + Log(Mean-income)

Parameter	Df	Sum of Sq	RSS	AIC
<none>			11.33	-256.5
- Gender	1	0.21	11.54	-256.45
+ Transit	1	0.15	11.18	-256.08
+ Residency	2	0.29	11.04	-255.47
+SafetyAudit	1	0.02	11.31	-254.72
+ Safety-index(FL)	1	0.01	11.32	-254.66
+ Entropy	1	0.01	11.32	-254.62
+ Continuity-audit	1	0.01	11.32	-254.60
+ Crash-index	1	0.00	11.33	-254.53
+ Mean-age	1	0.00	11.33	-254.52
+ Amenities-audit	1	0.00	11.33	-254.52
- Log(meanincome)	1	0.41	11.74	-254.44
+ Car-availability	2	0.16	11.17	-254.10
+ Walking-frequency	2	0.10	11.23	-253.49
- Directness-audit	1	0.54	11.87	-253.18
- Infrastructure-index(FL)	1	1.02	12.35	-248.59
+ Neighborhood	7	0.36	10.97	-246.18

*FL - Index comprised of categories combined in Fuzzy Logic

From stepwise regression Table 11-23, the model indicated that neighborhoods could help explain the variance in directness perception. Intuitively, it is reasonable to expect different responses or behavior from residents of gated/walled communities versus residents whose access is uninhibited by such. The Las Vegas valley favors gated communities as seen during the audits. At least 15% of the segments audited had a gated or walled neighborhood within the study limits. For this model especially, a mixed model is essential to determine whether changes in the walking environment in different neighborhoods would have any impact on resident directness perceptions.

TABLE 11-24 Random Intercepts Model for Directness Perception

Formula: Directness_perception ~ (1 | Neighborhood)

REML criterion at convergence: 76.9

Scaled residuals:

Min	IQ	Median	3Q	Max
-6.21	-0.54	0.09	0.58	2.57

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	(Intercept)	0.01	0.08	0.06
Residual		0.11	0.33	0.94

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	2.12	0.04	52.29

The random intercept model showed that the variation in neighborhoods accounted for only 6% of the overall variation in directness perception, contrary to expectation Table 11-24. With 6% variation between neighborhoods, a single value (fixed intercept), representing the limited spread of neighborhood design and random slopes modeling the effect of neighborhood design of resident directness perception were fitted. As stated earlier, it is reasonable to expect gated community residents to respond differently to features in the walking environment compared to those whose access to destinations is uninhibited. For example, in gated communities, traffic speeds and volumes are lower due to low classification and narrower streets making the enclosed atmosphere much safer. Outside the walls, streets belong to higher hierarchies, such as collectors and arterials, with higher speed-limits and volumes. In Las Vegas, there are street network features many major arterials providing for up to six and eight traffic lanes with high posted limits at 45mph or above which favors drivers over pedestrians (Coughenour et al., 2014, Nambisan & Dangeti, 2008). Out of the four neighborhoods that weren't gated, only one had more than ten respondents. In light of the dataset limitation, audit categories were each fitted separately as random effects to identify neighborhood variation that would account for directness perception.

TABLE 11-25 ICC for Other Variables Modeled as Random Effects in Directness Perception

Variable	Neighborhood Variance	Residual Variance
Amenities-audit	0.7%	99.3%
Continuity-audit	0.3%	99.7%
Directness-audit	**25.0%**	75.0%
Safety-audit	0.2%	99.8%
Crash-index	2%	98%
Infrastructure-index(FL)	**20.5%**	79.5%
Safety-index(FL)	**17.6%**	82.4%
Landuse	9.4%	90.6%

*FL - Index comprised of categories combined in Fuzzy Logic

The land use, infrastructure, and directness categories were flagged as potential random effects parameters, Table 11-25. Amenities & Aesthetics and Continuity categories didn't exhibit any variance implying only directness was driving the variance exhibited in infrastructure category. The directness-audit category indicated substantial variance to warrant a mixed effects model. Anova test and AIC criterion were used to select the final combination of practically useful variables for directness model. The final directness perception model together with the output was as follows:

$$Directness\ Perception_{ij} = \gamma_j^0 + \gamma_j^1 Entropy_i + \beta_1 Car - availability + \beta_2 Directness - audit + \varepsilon_{ij}$$

Equation (11-8)

Where

i indexes the i^{th} respondent and j indexes the neighborhood.

TABLE 11-26 Final Directness Perception Model

Directness-perception~ Caravailability + (0 + Landuse | neighborhood) + Directness-audit

REML criterion at convergence: 10.9

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.56	-0.79	-0.08	0.63	3.34

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	Land use	0.01	0.12	**0.20**
Residual		0.06	0.24	**0.80**

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	2.14	0.13	27.82	16.94	0.00	***
Car_availability-sometime	-0.21	0.14	42.42	-1.57	0.12	
Car_availability-always	-0.07	0.12	26.40	-0.63	0.54	
Directness-audit	0.31	0.16	11.99	1.94	0.08	.

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

From the fixed effects in Table 11-26, in comparison to respondents who seldom had vehicles available, those who sometimes had vehicles available had 0.21 units lower perception of directness. Similarly, those who always had vehicles available to them had 0.07 units lower directness perception compared to respondents who seldom had vehicles available. However the relationship was not statistically significant (α=0.05, 0.1). Intuitively, if directness to destinations is inhibited, it is reasonable to expect use of other transport modes if they are available hence inclusion of the car-availability variable in the model. In addition, of respondents who indicated their mode of transport, only 20 out of 137 reported using transit, implying majority had vehicle access available. Ideally, directness-audit would have been a random effect parameter if the data supported this supposition given the difference in neighborhood design. However most of the segments audited had enclosed communities. In addition, from the histogram comparing audit scores versus directness perception, it was evident that the spread wasn't as great as initially hoped; therefore a single variance value wouldn't mask the neighborhood design variance. The directness coefficient implies that an increase in directness features such as reducing sidewalk slope, proportion of enclosed communities and enhancing access to destinations will result in a 0.31 units increase in directness perception.

The model with land use as random effect yielded the final combination of variables explaining the variance in directness perception. Intuitively, directness implies access to land uses. Land uses in different neighborhoods explained approximately 20% of the directness perception model variance while fixed effects explained the rest.

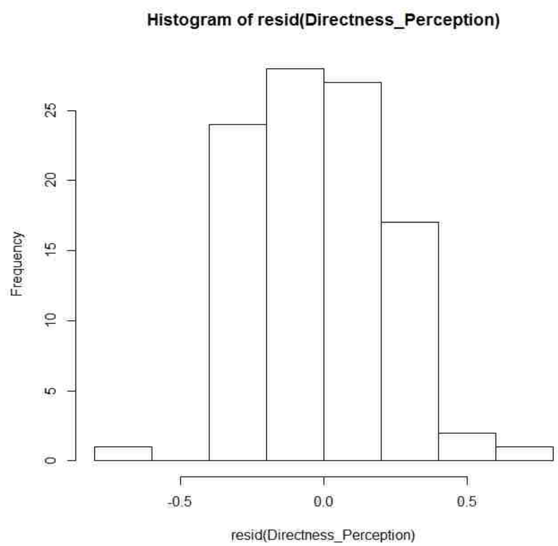
TABLE 11-27 Coefficients for Final Directness Perception Model

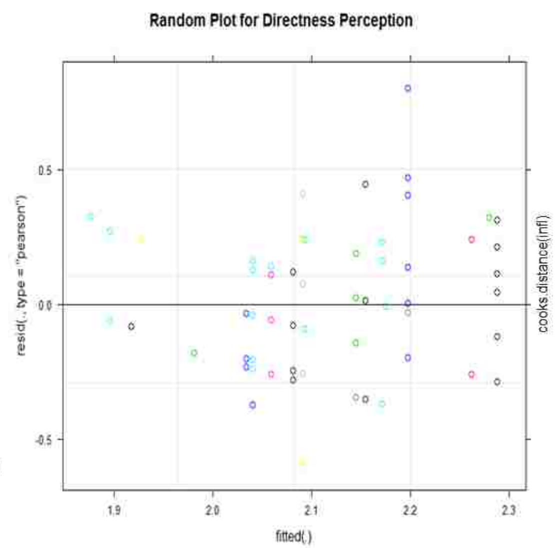
	Neighborhood	(Intercept)	Landuse	Car_availability-sometime	Car_availability-always	Directness-audit
1	5th & Carey	2.14	-0.13	-0.21	-0.07	0.31
2	Euclid	2.14	-0.06	-0.21	-0.07	0.31
3	Sonterra-Apts	2.14	-0.07	-0.21	-0.07	0.31
4	Sunset & Boulder	2.14	0.08	-0.21	-0.07	0.31
5	DelWebb	2.14	-0.04	-0.21	-0.07	0.31
6	DesertSky-Apts	2.14	0.05	-0.21	-0.07	0.31
7	San Destin	2.14	0.01	-0.21	-0.07	0.31
8	ViaGreco	2.14	0.04	-0.21	-0.07	0.31
9	Anthem	2.14	-0.01	-0.21	-0.07	0.31
10	Historic Alta	2.14	0.11	-0.21	-0.07	0.31
11	SpanishTrail	2.14	-0.05	-0.21	-0.07	0.31

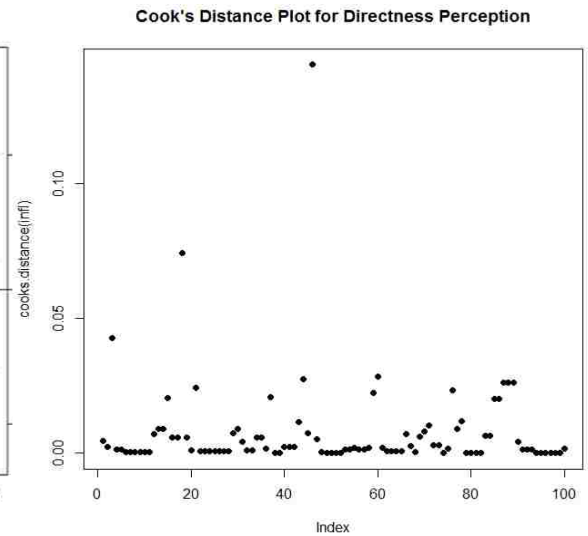
TABLE 11-28 Confidence Intervals for Final Directness Perception Model

Parameter	Confidence Interval (2.5%)	Confidence Interval (97.5%)
Random effect variance (neighborhood)	0.1	0.20
Residual effect variance (fixed effects)	0.21	0.28
Car_availability-sometime	1.94	2.11
Car_availability-always	-0.12	0.31
Directness-audit	0.05	0.62

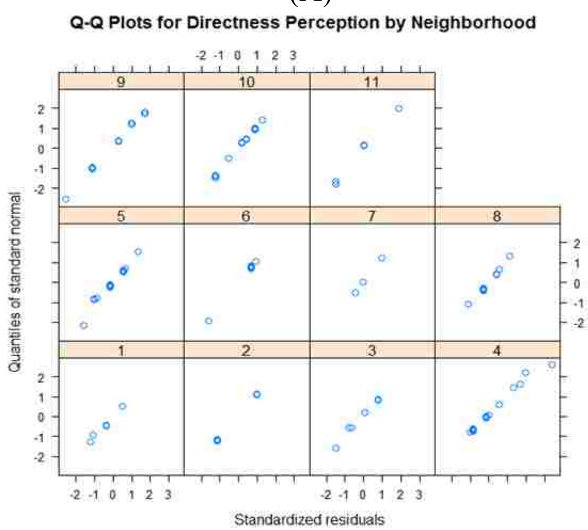
From Table 11-27, the negative sign on the coefficients for 5th& Carey, Euclid, Sonterra Apartments, DelWebb, Anthem and Spanish Trail neighborhoods indicated low perception of directness within their neighborhoods. Low directness perception implied that residents in such neighborhoods were likely to be more sensitive to small changes in land uses. The relationship is statistically significant as indicated in Table 11-28. The low directness perception in DelWebb, Sonterra, Anthem and Spanish Trail is expected since they are gated; therefore available destinations might be further than the inquired about 15minutes. In addition, there were few land uses within the DelWebb study limits as well as having predominantly hilly sidewalks within the neighborhood. Interestingly, 5th & Carey and Euclid neighborhoods though having the highest land use mix score reported low directness perception. Since respondents were asked about land uses within a 15-minute walk of the residences; it could be residents in these two neighborhoods felt the land uses that they frequented were further than a 15-minute walk. Adding few more land uses that are easily accessible will likely improve directness perception of the residents in such neighborhoods.

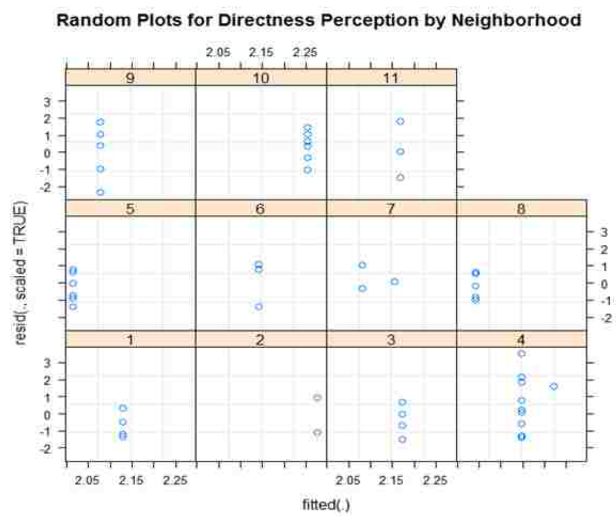






(A) (B) (C)





(D) (E)

FIGURE 11-6 Diagnostics plots for final directness perception model

Directness perception model diagnostics

The final directness model was assessed for goodness-of-fit as shown Figure 11-6. The residuals in the histogram (plot A) are reasonably normally distributed though there's a hint of tail to the right implying there were a few residents who were particularly enthusiastic about directness in their neighborhood. The quantile plots by neighborhood (plot C) also exhibit a reasonable normal trend.

The random plot of residuals (plot B) is reasonably random, exhibiting no signs of variance issues. Random plots by neighborhood (plot D) are as expected indicating the most significant variable explaining directness perception in each neighborhood. Car-availability was not statistically significant ($\alpha = 0.05$) but it influenced directness perception in neighborhoods four and seven. Directness-audit was singular for each neighborhood is seen as a straight line of residuals. The furthest point (observation 46) was flagged as noteworthy in the Cook's Distance plot E. This observation indicated the least directness perception in DelWebb neighborhood which is hilly and walled, but with several entrance/exit points.

11.6.5. Continuity Perception Model

The following section presents model results for continuity perception. The results are ordered as outlined earlier in 11.5. The Ordinary Least Squares (OLS) regression model was fitted as illustrated in Table 11-3, whose output in attached in Appendix V. Output for stepwise regression, and mixed models are presented below.

TABLE 11-29 Stepwise Regression Output for Continuity Perception

Step: AIC=-306.16

Continuity-perception ~ Neighborhood + Car-availability

	Df	Sum of Sq	RSS	AIC
<none>			7.52	-284.22
+ Transit	2	0.15	7.37	-282.54
+ Mean-age	1	0.02	7.50	-282.50
+ Gender	1	0.01	7.51	-282.33
+ Walking-frequency	1	0.00	7.52	-282.22
- Car-availability	2	0.07	7.44	-281.35
+ Residency	2	0.05	7.47	-281.02
- Neighborhood	10	2.88	10.40	-267.62

TABLE 11-30 Random Intercepts Model for Continuity Perception

Continuity-perception ~ (1 | neighborhood)

REML criterion at convergence: 41.3

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.44	-0.53	0.003	0.69	2.71

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	(Intercept)	0.02	0.14	**0.20**
Residual		0.07	0.27	**0.80**

Fixed effects:

Estimate	Std.	Error	t-value
(Intercept)	2.14	0.05	42.77

The stepwise regression Table 11-29 indicated car-availability and neighborhood variables as potential variables for the final model. The neighborhood variable as a random effect explained approximately 20% of the variance in continuity perception; therefore a mixed model is warranted, Table 11-30. Each audit category was separately fitted as a random effect as illustrated in Table 11-6 to determine their effect on continuity perception.

TABLE 11-31 ICC for Other Variables Modeled as Random Effects in Continuity Perception

Variable	Neighborhood Variance	Residual Variance
Amenities-audit	2.6%	97.4%
Continuity-audit	1.7%	98.3%
Directness-audit	**72.3%**	27.7%
Safety-audit	1.1%	98.9%
Crash-index	9%	91%
Infrastructure-index(FL)	**52.6%**	47.4%
Safety-index(FL)	**51.4%**	48.6%
Landuse	**39.1%**	60.9%

*FL - Index comprised of categories combined in Fuzzy Logic

Potential variable from the audit categories for the final continuity perception model included land use, overall safety, and directness which was apparently the main component in the infrastructure category, Table 11-31. Separately, the safety score - measuring safety features in the walking environment - and crash index contributed little to the variance of continuity perception. However, when combined to form the audit safety index, the category explained approximately 50% of continuity perception variance. Intuitively, elements such as sidewalk continuity, obstructions and driveways play a role in pedestrian safety, hence the correlation of continuity perception and safety. Land uses provide destinations that pedestrian routes continue to as well as sidewalks required by relevant jurisdictions codes. The final continuity perception model together with the output was as follows:

$$Continuity\ Perception_{ij} = \gamma_j^0 + \gamma_j^1 Landuse_i + \beta_1 Mean-age + \beta_2 Infrastructure-index + \beta_2 Safety-index + \varepsilon_{ij}$$

Equation (11-9)

Where

i indexes the i^{th} respondent and *j* indexes the neighborhood.

TABLE 11-32 Final Continuity Perception Model

Continuity-perception ~ Mean-age + (0 + Landuse | neighborhood) + Infrastructure-index(FL)+ Safety-index(FL)

REML criterion at convergence: 11.1

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.15	-0.65	0.04	0.59	3.07

Random effects:

Groups	Name	Variance	Std.Dev.	ICC
Neighborhood	Land use	0.01	0.12	**0.27**
Residual		0.05	0.23	**0.73**

Number of obs: 102, groups: neighborhood, 11

Fixed effects:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	1.59	0.14	11.01	0.00	***
Mean-age	0.00	0.00	0.95	0.35	
Infrastructure index(	0.51	0.28	1.86	0.10	.
Safety-index(FL)	0.41	0.19	2.16	0.06	.

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

*FL - Index comprised of categories combined in Fuzzy Logic

From the fixed effects in Table 11-32, increase in age had very little influence continuity perception, implying no relationship between age and continuity perception. Continuity features demonstrated the potential for an unobstructed trip. Obstruction such as street furniture, driveways and broken paths present route interruptions which can pose safety risks when pedestrians are trying to maneuver around. This is especially the case for older and disabled pedestrians on walking aids or wheelchairs. Las Vegas City, also known as the "silver state" has a substantial population of the elderly population (US-Census-Bureau, 2015). In fact, of respondents who reported their age group, 85% were above the age of 40, such that the data is skewed toward older groups. Therefore, for applicability and generalizability of the model at other locations mean-age was added as a practically useful parameter that can explain variance in continuity perception.

A unit increase in features in the infrastructure category comprised of directness, continuity and amenities and aesthetics categories results in 0.51 units of continuity perception. Increasing features comprising infrastructure category, such as complete sidewalks, transit and associated furnishings, express, complete and uninterrupted access to destinations improves continuity perception. A unit increase in safety infrastructure that also reduces crash risk resulted in 0.41 units increase in continuity perception. Safety infrastructure such as presence of ramps that are now required for ADA compliance as well as placement of street furniture out of the pedestrian route can enhance continuity perception (Markesino & Barlow, 2007).

In the random effects, the effect of land uses in neighborhoods explained approximately 27% of continuity perception. Property owners are typically required to provide and maintain sidewalks that meet jurisdictions codes on their side of the right-of-way (Lergaza, D. 2000). As such commercial properties are typically associated with sidewalks. However, they are also associated with driveways which present safety risks for pedestrians as motorists are typically looking out for oncoming traffic rather than pedestrians and cyclists crossing the driveway. Coefficients for the continuity model are presented in Table 11-33.

TABLE 11-33 Coefficients for Final Continuity Perception Model

	Neighborhood	(Intercept)	Landuse	Mean-age	Infrastructure index(FL)	Safety-index(FL)
1	5thCarey	1.59	-0.01	0.00	0.51	0.41
2	Euclid	1.59	0.07	0.00	0.51	0.41
3	Sonterra-Apts	1.59	-0.01	0.00	0.51	0.41
4	SunsetBoulder	1.59	-0.08	0.00	0.51	0.41
5	DelWebb	1.59	0.00	0.00	0.51	0.41
6	DesertSky-Apts	1.59	0.14	0.00	0.51	0.41
7	San Destin	1.59	-0.04	0.00	0.51	0.41
8	ViaGreco	1.59	-0.02	0.00	0.51	0.41
9	Anthem	1.59	0.09	0.00	0.51	0.41
10	Historic Alta	1.59	-0.08	0.00	0.51	0.41
11	SpanishTrail	1.59	-0.08	0.00	0.51	0.41

TABLE 11-34 Confidence Intervals for Final Continuity Perception Model

Parameter	Confidence Interval (2.5%)	Confidence Interval (97.5%)
Random effect variance (neighborhood)	0.02	0.24
Residual effect variance (fixed effects)	0.20	0.27
(Intercept)	1.32	1.86
Mean-age	-0.001	0.01
Infrastructure index(FL)	0.15	0.82
Safety-index(FL)	0.19	0.69

*FL - Index comprised of categories combined in Fuzzy Logic

As indicated by the negative coefficients in Table 11-33 neighborhoods with a high land use mix are likely to be less sensitive to small changes in continuity features. The relationship is statistically significant using a 95% confidence interval Table 11-34. Neighborhoods such as 5th & Carey, Sonterra Apartments, Sunset & Boulder, San Destin, Spanish Trail and Historic Alta all had at least six different land uses within the neighborhood study limits. However even with many land uses, continuity perception was low, given at least 40% of the audited segments in the neighborhood had no sidewalks, incomplete or broken sidewalks. The six neighborhoods discussed above, all but Historic Alta, 5th & Carey and Sunset & Boulder were enclosed communities, implying land uses within 15-minute walk of residences might be a bit further. Via Greco neighborhood had very few land uses as well as low continuity perception. It is reasonable to expect more sensitivity to small changes in continuity features. This would imply land uses for pedestrian routes to be continuous to. DelWebb had average perception of continuity, since it had a high intersection density; sidewalks were mainly complete and in fair condition. The low number of land uses implies few driveways as well. Substantial changes in land use and respective infrastructure would enhance continuity perception in this neighborhood. Euclid neighborhood had the highest driveway density, moderate intersection density, and the second lowest average sidewalk width which was with littered with utility poles. Even with among the highest land use mix value, substantial changes in land use would be needed to improve continuity perception in the neighborhood.

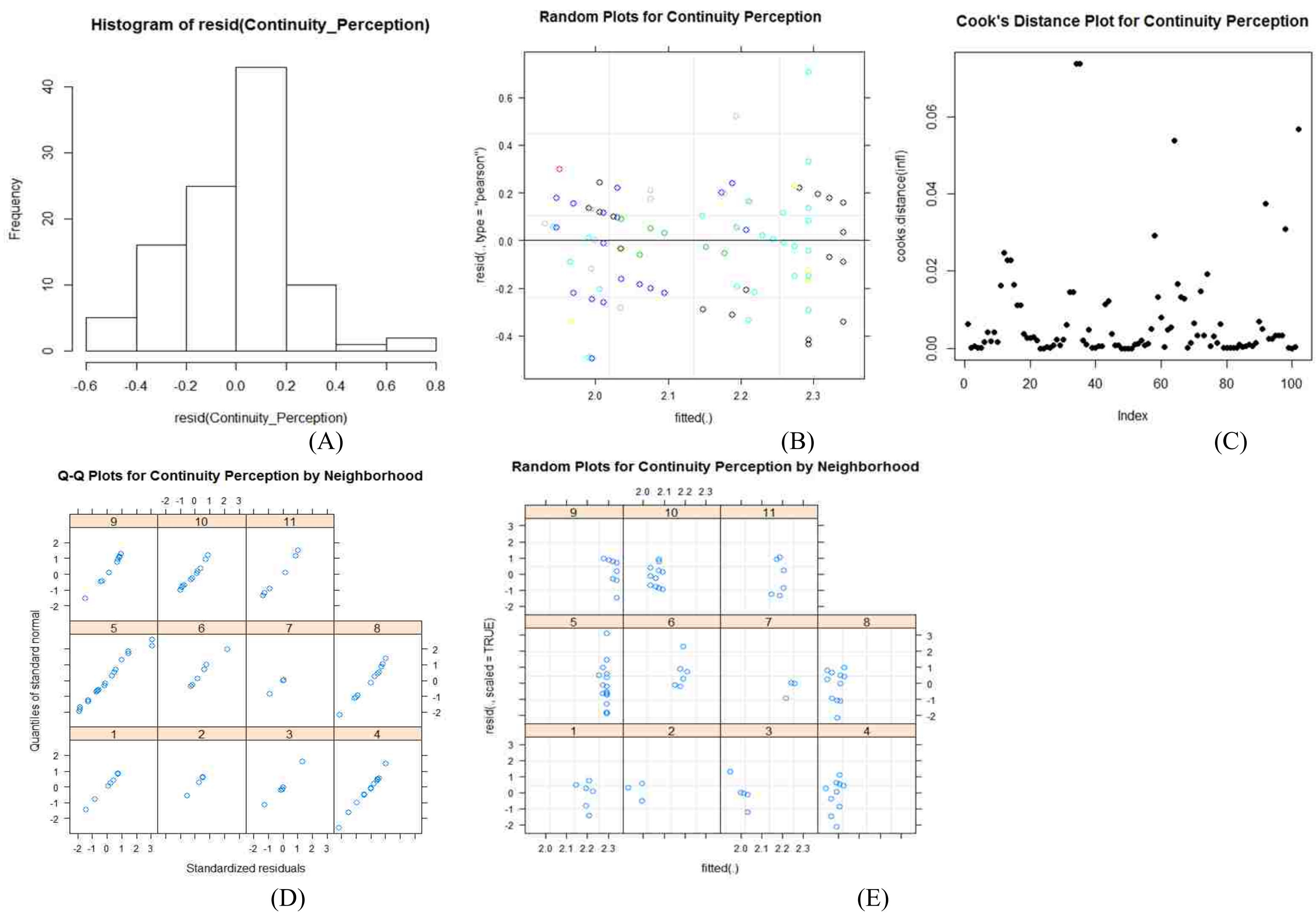


FIGURE 11-7 Diagnosis plots for final continuity perception model

Continuity perception model diagnostics

The final directness model was assessed for goodness-of-fit as shown Figure 11-7. The residuals in the histogram (plot A) are reasonably normally distributed. The quantile plots by neighborhood (plot C) also exhibit a reasonable normal trend. The random plot of residuals (plot B) is reasonably random, exhibiting no signs of variance issues. Random plots by neighborhood (plot D) are as expected. The variables that made up the model were all singular (level two data). A few points deviate from the rest of the observations, but are not influential outliers.

11.6.6. Application of Statistical Models

This section illustrates the application of calibrated perception models using Euclid neighborhood in income group one. Euclid had a low comprehensive walkability quality grade. From the perception quality indices in Table 10-1, continuity, and amenities and aesthetics perceptions had the lowest quality indices in the neighborhood. From the walking frequency model, continuity was not statistically significant. However, aesthetics and safety perception was significantly correlated with continuity perception. Therefore, features that improve aesthetics & amenities perception are likely to improve continuity perception as well and increase walking frequency.

Aesthetics & Amenities perception model was comprised of safety, infrastructure (continuity, directness, and amenities and aesthetic audit categories), and land use mix obtained from audit observations and transit-use, Table 11-20. Features that are likely to improve aesthetics & amenities perception in Euclid neighborhood are illustrated in the Figure 11-8 below.

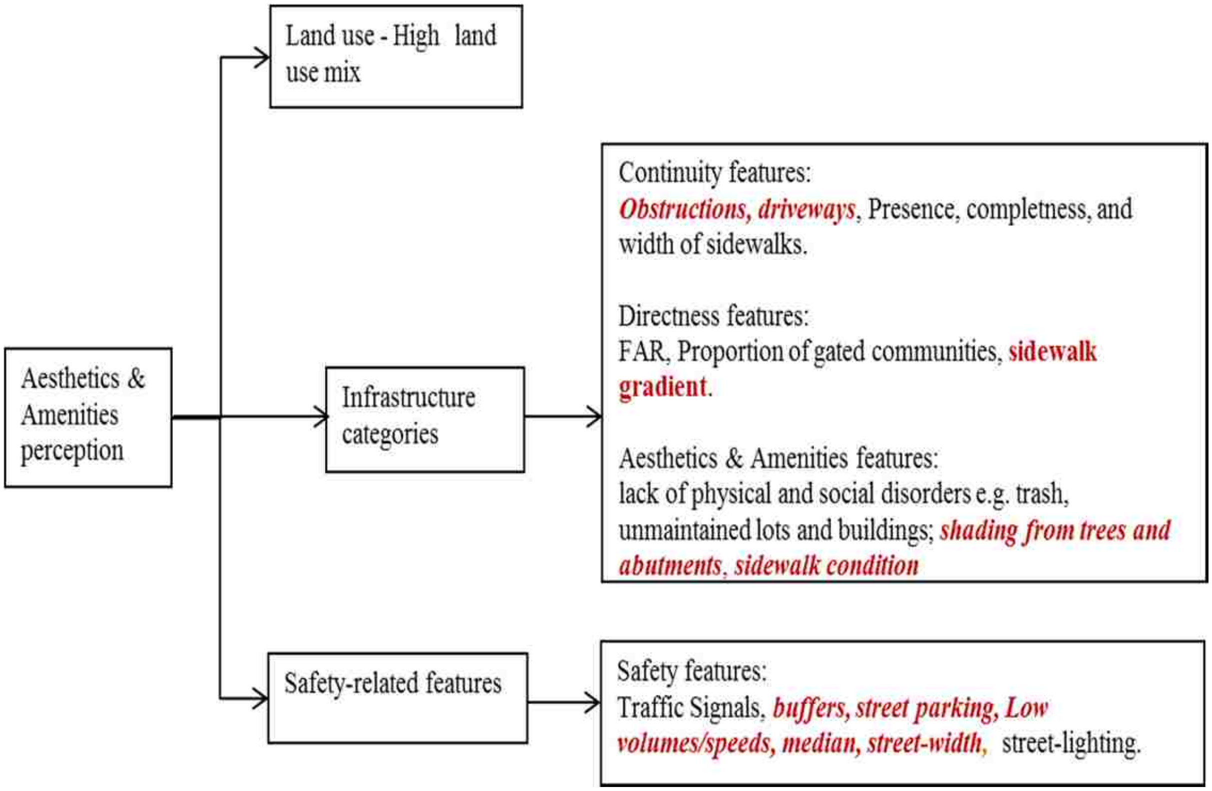


FIGURE 11-8 Features to be improved that enhance aesthetics and amenities perception in Euclid neighborhood.

11.7. Summary

This chapter presented statistical modeling results of the walking frequency; and perception of safety, directness, and continuity, amenities and aesthetics, and land use categories. The study design used was repeated measures in which multiple measurements were taken from each neighborhood. To address the violation of the independence of consecutive errors assumption, mixed models were adopted to model resident perceptions as a function of socio-demographic variables as well as audit observations. The modeling procedure involved identifying perceptions that can influence walking frequency. Though not all perception categories were statistically significant, mixed models were calibrated for each perception category. The procedure included stepwise regression, random intercept regression to determine if neighborhoods exhibited substantial between-groups variability to warrant a mixed effects model. All audit observation categories were modeled as random effects to determine their effect on resident perception of the walking environment. AIC and practically useful and (or) significant variables were used to identify the final combination of variables for the final model for a perception category as listed below.

1. The final safety perception model was comprised of gender, transit use, safety related infrastructure and directness-audit as a random effect. Non-transit users, and female respondents had a lower perception compared to transit users and male respondents respectively. Safety related infrastructure had a direct relationship with safety perception. An inverse relationship was observed between directness-audit features and safety perception. Neighborhoods with low safety perception were likely to be more sensitive to small changes in directness features compared to neighborhood with higher safety perceptions.
2. The final land use perception model was comprised of walking frequency, directness-audit variables and observed audit land uses as a random effect. Walking frequency and directness-audit were positively associated with land use perception. Neighborhoods with a low land use mix were likely to be more sensitive to land use changes within their neighborhood.
3. The final aesthetics and amenities perception model was comprised of walking frequency, transit use, audit observed land uses, infrastructure and overall audit safety. Infrastructure category was comprised of directness, continuity and aesthetics and amenities features. Overall safety was comprised of crash risk and audited safety related

infrastructure. There was a direct relationship between waking frequency and infrastructure variables while transit and land use variables exhibited an inverse relationship. The random effect relationship showed that neighborhoods with initial low aesthetics and amenities perception are likely to be more sensitive to small changes in infrastructure that enhances safety and reduces crash risk

4. The final directness perception model was comprised of car availability, directness features and audit observed land uses. Car-availability had an inverse relationship with directness perception while directness features had a direct relationship with directness perception. Low directness perception implied that residents in such neighborhoods were likely to be more sensitive to small changes in land uses.
5. The final continuity perception model was comprised of age, infrastructure, safety index and land use as random effect. All the fixed variables, age, infrastructure and overall safety had a direct relationship with continuity perception. There was in inverse relationship between land use and continuity perception such that neighborhoods with a high land use mix were likely to be less sensitive to small changes in continuity features. The final perception model for each category was finally tested to determine goodness-of-fit using diagnostic tools such as Cook's distance, residual and normality plots.

CHAPTER 12

CONCLUSIONS AND RECOMMENDATIONS

12.1. Introduction

This Chapter presents a summary of the study as well as recommendations. The main objective of the study was to develop a comprehensive walkability index, which quantified the walking environment in its entirety. The comprehensive walkability index reflects the condition of the walking environment as well as residents' perception of it. In quantifying walkability, the sub-objectives of the study were to address the following limitations of the existing walkability evaluations:

1. Integrate crash risk into safety evaluations of the walking environment.
2. Incorporate subjective perceptions and objective observations into evaluating the suitability of the walking environment.
3. To provide frameworks for estimating perception influence on walking for both recreational and utilitarian purposes. Statistical models were calibrated to identify features in the built environment that influence perceptions of safety, directness, continuity, aesthetics and amenities, and land use.

The study integrated crash data into safety evaluations. It would be reasonable to expect a low crash index in neighborhoods with high safety score for safety related infrastructure. However results indicated that some neighborhoods with high safety scores also had high crash indices. Safety levels based on safety infrastructure alone could result in masking potential safety problems within the walking environment. In addition, when crash data was introduced into analyses, neighborhoods with high walkability indexes dropped in ranking. Inclusion of crash data into walkability analyses not only reflects safety risks, but brings objectivity into safety evaluations.

Generally, audit and perception quality indexes coincided except in four neighborhoods, where residents' perception was either lower or higher than audit observations. The fuzzy logic approach to estimating resident perceptions of the walking environment enabled analysis of imprecise information to obtain logical output through computing with words. As such, survey data was analyzed in an approximate framework similar to the human ability to manipulate and reason with perceptions. The comprehensive walkability index obtained by combining the overall audit and resident perception walkability indices in fuzzy logic is presented as a linguistic label as well as numerical value.

The study calibrated parameters of the perception models using audit observations collected from the eleven neighborhoods. The study used repeated measures design in which multiple measurements were taken from each neighborhood. To address the violation of the independence of consecutive errors assumption, hierarchical linear mixed models implemented in R, were adopted to model resident perceptions as a function of socio-demographic variables as well as audit observations. In addition, a multinomial logit model was also calibrated to estimate perceptions that influence walking frequency.

12.2. Summary of Statistical Findings

Comparison of crash and safety related infrastructure indices indicate that the two safety level indicators convey different information. Safety related infrastructure does not completely reflect potential pedestrian crash risk in the walking environment. Comparison of audit quality walkability indices, with and without crash data indicates statistically significant differences in walkability indexes. Neighborhoods with initial high walkability indexes ranked much lower after crash data integration. Cho et al. (2009) and Schneider et al. (2003) reported locations perceived as safe having higher crash risk compared to locations perceived as unsafe. Even without statistical significance, crash data provides more objectivity to audit quality indexes depending on data collection and reduction.

In Pikora et al.'s (2003) study, the most important issues related to walking were ranked in decreasing orders of personal safety, aesthetics and destinations. In Park's (2008) study coefficients with the highest values were in order of sense of security and safety, appealing aesthetics and easy access to land use. Results from the current study indicate that aesthetic and amenities perceptions and land use have a significant relationship with walking frequency.

Both aesthetics and amenities and land use perception were correlated with safety, directness and continuity perceptions, implying improving the perception of one category was bound to have an impact on another perception category. Directness-audit parameter serves as both a disincentive and incentive to walking. To land use perception, increasing directness features results in uninhibited access to land uses which increases walking frequency. Conversely, increase in uninhibited access results in lower safety perception. Intuitively, enclosed communities have lower traffic flows as well as speed limits that are conducive for pedestrian activity as well as providing buffers from errant traffic.

12.3. Conclusions

Generally, results indicate the need for a transactional evaluation approach in which the pedestrian behavior is multiply influenced by environmental features, perception of the walking environment, as well as social and cultural aspects. These conclusions are made based on the following observations:

1. Perception categories that significantly influenced walking frequency were land use, and aesthetics and amenities. The safety, directness and continuity perception categories were not significant but had weak to moderate significant associations with land use and aesthetics perception. This implies improving perception of one category is bound to improve or negatively impact the perception of a correlated category. For example land use perception was correlated with directness perception - which is intuitive, given that directness measured quick and easy access to land uses. Conversely, directness was moderately correlated with safety. Therefore, considering interaction among the perception categories, models were calibrated for each perception category.
2. Safety perception was influenced by directness features, safety related infrastructure and social-demographic variables such as gender and transit use. To improve safety perception, safety related infrastructure as well as directness features that limit safety hazards can be implemented. In addition safety perception was significantly correlated with directness, continuity and aesthetics perceptions.
3. A higher land use mix was determined to improve land use perception. In addition, features that enable quick and easy access to the variety of land uses are likely to improve not only directness but land use perception as well. This would imply flatter sidewalk gradient, smaller parking lots in front of commercial premises and better access at and in enclosed communities.
4. Aesthetics and amenities perception was influenced by walking environment infrastructure including directness, continuity, as well as appealing environment. A complete and well maintained facility is not only visually appealing but enhances quicker access between origin and destinations for utilitarian trips. In addition completeness of the walking

environment is synonymous with safety, such that pedestrian don't have to maneuver around obstructions putting them at risk from traffic.

5. Directness perception was influenced by car availability, directness features and land use mix. It is also reasonable to expect, an inverse relationship between car-availability and directness. Where directness to a varied land use mix is inhibited, vehicles offer alternative transportation options. As earlier mentioned, directness was also correlated with safety and continuity perception. A complete and or continuous walking environment offers uninhibited access to land uses.

6. Continuity perception was influenced by age, infrastructure, safety index and land use mix. In recent years, property owners are required by relevant jurisdictions' codes to provide and maintain sidewalks.

12.4. Study Limitations and Future Research Recommendations

The walking frequency and perception models developed in this study address some of the limitations of the existing walkability evaluations. The following is a summary of the limitations of this study and recommendations for future related research.

1. The crash index was estimated as a function of population and commercial land use within a neighborhood buffer. Some of the neighborhoods had no crash data, for the period used. Ideally, the key variable for prediction crashes is exposure; derived from vehicle and pedestrian volumes which were not readily available in this study. It is recommended that future studies obtain traffic and or pedestrian counts to estimate crash rates.

2. Some of the neighborhoods had a low response rate, such that generalizability based on a very small sample becomes questionable. Owing to resources, mail back surveys with

reminders would have a better response rate compared to online and dropping survey packages at residences.

3. This being a pilot study, overall stated quality grade of resident perception of their walking environment should be obtained in future studies. This can be used for calibrating fuzzy logic output.

APPENDIX I

NEIGHBORHOOD WALKABILITY SURVEY INSTRUMENT

HOWARD R. HUGHES COLLEGE OF ENGINEERING
CIVIL & ENVIRONMENTAL ENGINEERING & CONSTRUCTION

Walkability Survey ENGLISH

Encuesta de Transitabilidad

La versión en Español de esta encuesta está en el centro el folleto.

HOW WALKABLE IS YOUR NEIGHBORHOOD?

Instructions:

You have a choice of either completing this paper copy of the survey or, complete it online at http://tinyurl.com/pxbknkf. If you choose to take the online survey, kindly remember to fill in the following neighborhood code **C5XP** . Please read each statement carefully and respond as best as you can.

Please remember that even if you do not walk regularly, it is important that you still complete this survey so your local government agencies can improve the adequacy and safety of the walking facilities and environment.

Thank you and please proceed to answer the following questions.

A. Why do you walk?

When you walk in your neighborhood, what are the reasons you walk? Please put a check mark (√) for each circumstance corresponding to your answer

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
Enjoy the outdoors				
Walk my dog				
Visit neighbors				
Getting out with relatives and friends				
Exercise				
Going to the bus stop				
Going to a specific place (work, store, post office, school, hospital, etc.)				

B. Access to Services

Think about the places that are within a walking distance of your home. Are these destinations within a 15 minute walk of your home? Please put only one check mark (√) for your answer to each question.

Grocery Store/ Supermarket				
Restaurant/Cafes or other places to eat				
Park or Recreational Facility (including basketball court, golf, pool - indoors or outdoors)				
Retail store or other shopping				
Banks				
Post Office				
Medical clinic, pharmacy				
Workplaces such as offices or businesses				
Places of Worship				
Bus stop				
Your place(s) of work				

C. Streets in my neighborhood

Think about getting around in your neighborhood. How convenient is it to go from place to place? Please put a check mark (√) corresponding to your answer.

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
The distance between intersections in my neighborhood is usually short (100 yards or less; the length of a football field or less).				
There are many alternative walking routes for getting from place to place in my neighborhood. (I don't have to go the same way every time).				
The streets in my neighborhood are hilly, making it difficult to walk in.				
The streets in my neighborhood have many cul-de-sacs (dead-end streets).				
Please answer this question only if your neighborhood is surrounded by a wall and/or gated. My neighborhood is surrounded by a wall, making walking to access services inconvenient.				

D. Walking facilities in my neighborhood

Think about sidewalks or paths provided in your neighborhood. Please put a check mark (√) corresponding to your answer.

There are sidewalks on most of the streets in my neighborhood.				
The sidewalks in my neighborhood are well connected, providing a complete pedestrian network.				
The sidewalks in my neighborhood are clean and well maintained.				
There are footpaths (worn dirt path) on most of the streets in my neighborhood.				
The sidewalks in my neighborhood are wide enough, which makes walking pleasant.				
There is on-street parking provided in my neighborhood.				
My neighborhood streets are well lit at night.				
Walkers on the streets in my neighborhood, can be easily seen by people in their homes.				
The presence of other pedestrians on the streets, makes walking a pleasant experience.				
There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood.				
There are obstructions on the path or sidewalks, that make walking a challenge (for example, trees, poles, signs, hedges, etc).				
There are many driveways along the sidewalks within local shopping/commercial area,s making walking unpleasant.				
The retail areas and stores in my neighborhood have large parking lots, making walking to the stores difficult.				

E. Neighborhood surroundings/aesthetics

Think about the landscape and buildings as well as amenities (such as benches, water fountain, etc.) provided in your neighborhood. Please put a check mark corresponding to your answer.

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
There are trees along the streets in my neighborhood.				
There are many attractive natural sights in my neighborhood (such as landscaping, views).				
There are resting spots with benches provided, along the sidewalks / paths.				
There are trash cans provided along the sidewalks / paths.				

F. SAFETY

Think about how safe your neighborhood is from traffic hazards and crime; then please respond to the following statements.

There are crosswalks in the middle of the street away from intersections, that make it safe to cross streets in my neighborhood.				
There are traffic refuge islands, or raised medians on the streets, that make me feel safer when crossing wide streets.				
There are crossing aids (for example flashing lights) to help pedestrian cross busy streets, in my neighborhood.				
There is enough separation between pedestrians on sidewalks and traffic on the street, which makes me feel safe when walking.				
The streets in my neighborhood are very wide, which makes it difficult to cross.				
There is so much traffic along nearby streets, which makes it difficult, unpleasant and/or unsafe to walk in my neighborhood.				
Most drivers exceed the posted speed limits, while driving in my neighborhood				
The posted speed limits on most nearby streets are too high, which discourages me from walking.				
If I need to cross the street and the pedestrian walk signal is flashing,  I will start and quickly cross the street.				
If I need to cross the street where there is no cross walk, and the intersection is very far from where I am, I will quickly cross the street very carefully.				
If I feel an area or route is unsafe from traffic hazards;				
- I will not walk.				
- I will be very careful/ cautious while walking in that route/area.				
- I will use an alternative route.				
If I feel an area or route is unsafe due to crime;				
- I will not walk.				
- I will use a safer alternate route.				
- I will make sure to have company while walking in that route/area.				
If I feel it is too hot, dry, dusty;				
- I will still walk but take necessary precautions.				
- I will postpone my trip.				
- I will use an alternative mode (such as car).				
I consider myself a safety-conscious pedestrian.				

Do you walk primarily to take the bus? ☐ Yes ☐ No

General comments about walkability in your neighborhood.

In a few words, please tell us what can be done to enhance the walking experience in your neighborhood?

General Information

(*Please put a check-mark in a box corresponding to your answer*)

1. How long have you lived in this neighborhood?
   - ☐ Less than 1 year
   - ☐ 1 to 5 years
   - ☐ More than 5 years
2. Do you have a vehicle available to you for your transportation?
   - ☐ Always (All the time)
   - ☐ About half the time
   - ☐ Sometimes (please specify)________________________________
   - ☐ Seldom or never
3. How often do you walk in your neighborhood (for any reason)?
   - ☐ Every day or nearly every day ☐ Rarely
   - ☐ Few times a week ☐ Never
   - ☐ Few times a month
4. Have you or anyone close to you (like a friend or family member) ever been in an accident involving a pedestrian?
   ☐ Yes ☐ No
5. If you answered Yes above, were you or the person you know the
   ☐ Pedestrian ☐ Driver ☐ Passenger
6. What is your gender? ☐ Male ☐ Female
7. Please select your age from the age brackets below.
   - ☐ 18 - 25
   - ☐ 26 - 30
   - ☐ 31 - 40
   - ☐ 41 - 55
   - ☐ 56 - 65
   - ☐ 65+
8. What is the highest level of education that you have completed?
   - ☐ High School graduate
   - ☐ Some college / 2 year college degree (associates)
   - ☐ 4 year college degree (BA, BS)
   - ☐ Masters / Doctoral / Professional degree (MD, JD)

Please put the completed questionnaire in the self-addressed stamped envelope and drop it in a post-office mailbox.

THANK YOU FOR YOUR COOPERATION.

APPENDIX II

NEIGHBORHOOD AUDIT TOOL

Category	Item / Segment Name
	Segment Length
	Street width
Landuses	No. of Landuses in neighborhood (GIS derived)
	Gated or walled community (present=1, absent=0)
	Hilly streets(flat=0, slight hill=1, steep hill=2)
Directness	Floor Area Ratio
	Int Density (GIS derived)
	No. of Obstructions
	Temporary signs
	Permanent signs
	Trees
	Utility Poles/hydrants
Continuity	Magazine racks/cabinets
	Transit shelters/benches
	Parked cars
	Sidewalk (present=1, absent=0)
	Wide-sdwalks(<5'=1,>5=2)
	Sidewalk breaks e.g dirt-paths, incomplete sidewalks etc(present=1, absent=0)
	No of driveways
	Deadends (present=1, absent=0)
	No. of Traffic Controls
Safety	Traffic Signal
	Dedicated turning arrow (protected lefts)
	Channelized right turn ln
	Exclusive right turn
	Exclusive right turn(Channelized lanes added)
	Pedestrian signals/crosswalk
	Pedestrian signs
	Pedestrian crosswalks
	Curb Ramps
	Yield, 2-Way stop sign
	4-Way Stop sign
	Traffic Circle
	Speed bumps/dips
	Chicanes or chokers
	Raised median, median alert (present=1, absent=0)
	School zones (present=1, absent=0)
	Bike lanes, share the road signs (present=1, absent=0)
	Emergency zones (present=1, absent=0)
	Buffers (present=1, absent=0)
	Trees
	Fence(temporary/flexible)
	Hedges
	Landscape(desert)
	Grass

NEIGHBORHOOD AUDIT TOOL CONTINUED....

Category	Item / Segment Name						
Safety	*Other traffic elements*						
	No. of lanes						
	Traffic Direction (1=1-way street, 2=2way-street)						
	Speed limits						
	Street parking (present=1, absent=0)						
	Lighting (yes=1, no=0)						
Aesthetic/Amenities	*Amenities (present=1, absent=0)*						
	Garbage cans						
	Benches						
	Working Water Fountain						
	Bicycle racks						
	Street vendors/vending machines						
	Covered transit shelters						
	Timetable						
	Proportion of street having shade (trees, overhead coverage, <.25, .26-.75,>.75 = 0,1,2)						
	Cleanliness/presence of physical disorders (present=1, absent=0)						
	Abandoned cars						
	Buildings with broken/boarded windows						
	Broken glass						
	Beer/liquor bottles/cans						
	Litter						
	Neighborhood watch signs						
	Umaintained compounds/ empt lots/bldgs						
	Graffiti						
	Sidewalk condition/maintenance (poor, fair, good=0, 1,2,3)						

APPENDIX III

SIGNIFICANT BOXPLOT TRENDS

Table of Significant Box plot trends

Perception Category	Variable	Mean (µ)	Std.dev	Sample size	Significance
Overall Perception	Gender-female	10.16	1.14	79	
	Gender-male	10.64	1.42	40	**1.98 > 1.66 female & male, Perception is different**
	Walking frequency - seldom	9.72	0.91	19	
	Walking frequency - moderate	9.76	1.11	28	0.13 < 1.68 seldom & moderate, Perception is not different
	Walking frequency - frequent	10.47	1.33	105	**2.6 > 1.66 moderate & frequent, Perception is different**
	Car availability - seldom	10.88	1.33	8	
	Car availability - sometimes	9.80	0.93	12	**2.15 > 1.73 seldom car availability & moderate car availability, Perception is different**
	Car availability - always	10.09	1.27	99	0.77 < 1.66 moderate car availability & frequent car availability, Perception is not different
Landuse Perception	Walking frequency - seldom	1.63	0.55	17	
	Walking frequency - moderate	1.96	0.59	22	**1.76 > 1.69 Seldom & moderate, Perception is different**
	Walking frequency - frequent	1.88	0.63	78	0.5 < 1.66 moderate & frequent, Perception is not different
	Non-transit user	2.21	0.57	103	
	Transit Users	1.73	0.69	16	**3.02 > 1.66 Non-transit user & Transit Users, Perception is different**
	Car availability - seldom	2.41	0.49	8	
	Car availability - sometimes	1.74	0.55	12	**2.78 > 1.73 caravailability always & somtime, Perception is different**
	Car availability - always	1.83	0.62	95	0.04 < 1.66 somtime & seldom/never, Perception is not different
Directness Perception	Age 18-30	2.23	0.40	8	
	Age 31-40	2.14	0.22	14	0.66 < 1.72 Age 18-30 & Age 31-40, Perception is not different
	Age 41-55	2.04	0.26	25	1.27 < 1.69 Age 31-40 & Age 41-55, Perception is not different
	Age 55-65	2.21	0.31	35	**2.28 > 1.67 Age 41-55 & Age 55-65, Perception is different**
	Age 65+	2.15	3.11	36	0.11 < 1.67 Age 55-65 & Age 65+, Perception is not different

Table of Significant Box plot trends…..continued

Perception Category	Variable	Mean (μ)	Std.dev	Sample size	Significance
Continuity Perception	Age 18-30	2.28	0.36	8	
	Age 31-40	2.00	0.28	14	**2.05 > 1.72 Age 18-30 & Age 31-40, Perception is different**
	Age 41-55	2.10	0.32	25	0.98 < 1.69 Age 31-40 & Age 41-55, Perception is not different
	Age 56-65	2.15	0.27	35	0.62 < 1.67 Age 41-55 & Age 56-65, Perception is not different
	Age 65+	2.17	0.50	37	0.2 < 1.67 Age 56-65 & Age 65+, Perception is not different
	<1 YrResidence	2.06	0.42	65	
	1-5Yrs Residence	2.19	0.27	42	**1.72 > 1.66 <1 YrResidents & 1-5Yrs Residents, Perception is different**
	5+ Yrs Residence	2.24	0.33	12	0.58 < 1.67 1-5Yrs Residents & 5+ Yrs Residents, Perception is not different
Aesthetics & Amneities Perception	Male	2.20	0.38	40	
	Female	2.05	0.40	79	**2 > 1.66 Male & Female, Perception is different**
	Age 18-30	2.04	0.65	8	
	Age 31-40	1.95	0.39	14	0.4 < 1.72 Age 18-30 & Age 31-40, Perception is not different
	Age 41-55	2.06	0.37	25	0.87 < 1.69 Age 31-40 & Age 41-55, Perception is not different
	Age 56-65	2.06	0.40	35	0.01 < 1.67 Age 41-55 & Age 56-65, Perception is not different
	Age 65+	2.24	0.34	37	**2.03 > 1.67 Age 56-65 & Age 65+, Perception is different**
	Walking frequency - seldom	1.81	0.35	17	
	Walking frequency - moderate	2.19	0.33	22	**3.47 > 1.69 Seldom & Moderate, Perception is different**
	Walking frequency - frequent	2.14	0.41	80	0.5 < 1.66 Moderate & Frequent, Perception is not different
Safety Perception	Gender-male	2.30	0.38	40	
	Gender-female	2.11	0.33	79	**2.66 > 1.66 Male & Female, Perception is different**
	Age 18-30	2.09	0.41	8	
	Age 31-40	1.88	0.34	14	1.31 < 1.72 Age 18-30 & Age 31-40, Perception is not different
	Age 41-55	2.09	0.29	25	**2.12 > 1.69 Age 31-40 & Age 41-55, Perception is different**
	Age 56-65	2.22	0.37	35	1.44 < 1.67 Age 41-55 & Age 56-65, Perception is not different
	Age 65+	2.25	0.39	37	0.28 < 1.67 Age 56-65 & Age 65+, Perception is not different

APPENDIX IV

CONTINGENCY TABLES

Contingency Tables for Walking to Specific Places & Various Land Uses

		Worship places			
		Agree	A bit of both	Disagree	Total
Walking to specific place	Walkers	11	7	9	27
		7.36	5.89	13.75	
		3.64	*1.11*	*-4.75*	
	Moderate Walkers	9	5	12	26
		7.09	5.67	13.24	
		1.91	*-0.67*	*-1.24*	
	Non-walkers	10	12	35	57
		15.55	12.44	29.02	
		-5.55	*-0.44*	*5.98*	
		30	24	56	110

		Restuarants			
		Agree	A bit of both	Disagree	Total
Walking to specific place	Walkers	17	7	6	30
		12.26	7.83	9.91	
		4.74	*-0.83*	*-3.91*	
	Moderate Walkers	14	4	9	27
		11.03	7.04	8.92	
		2.97	*-3.04*	*0.08*	
	Non-walkers	16	19	23	58
		23.70	15.13	19.17	
		-7.70	*3.87*	*3.83*	
Total		47	30	38	115

		Grocery-store			
		Agree	A bit of both	Disagree	Total
Walking to specific place	Walkers	18	6	7	31
		11.86	6.20	12.94	
		6.14	*-0.20*	*-5.94*	
	Moderate Walkers	13	4	10	27
		10.33	5.40	11.27	
		2.67	*-1.40*	*-1.27*	
	Non-walkers	13	13	31	57
		21.81	11.40	23.79	
		-8.81	*1.60*	*7.21*	
Total		44	23	48	115

		One's work place			
		Agree	A bit of both	Disagree	Total
Walking to specific place	Walkers	7	3	18	28
		2.59	2.59	22.81	
		4.41	*0.41*	*-4.81*	
	Moderate Walkers	3	2	21	26
		2.41	2.41	21.19	
		0.59	*-0.41*	*-0.19*	
	Non-walkers	0	5	49	54
		5.00	5.00	44.00	
		-5.00	*0.00*	*5.00*	
Total		10	10	88	108

		Postoffice			
		Agree	A bit of both	Disagree	Total
Walking to specific place	Walkers	9	6	14	29
		5.65	3.59	19.76	
		3.35	*2.41*	*-5.76*	
	Moderate Walkers	8	3	16	27
		5.26	3.35	18.40	
		2.74	*-0.35*	*-2.40*	
	Non-walkers	5	5	47	57
		11.10	7.06	38.84	
		-6.10	*-2.06*	*8.16*	
Total		22	14	77	113

		Bustation			
		Agree	A bit of both	Disagree	Total
Walking to specific place	Walkers	22	7	4	33
		13.54	6.77	12.69	
		8.46	*0.23*	*-8.69*	
	Moderate Walkers	12	7	8	27
		11.08	5.54	10.38	
		0.92	*1.46*	*-2.38*	
	Non-walkers	14	10	33	57
		23.38	11.69	21.92	
		-9.38	*-1.69*	*11.08*	
Total		48	24	45	117

		Retail stores			
		Agree	A bit of both	Disagree	Total
Walking to specific place	Walkers	12	9	8	29
		6.16	8.98	13.86	
		5.84	*0.02*	*-5.86*	
	Moderate Walkers	8	9	10	27
		5.73	8.36	12.90	
		2.27	*0.64*	*-2.90*	
	Non-walkers	4	17	36	57
		12.11	17.65	27.24	
		-8.11	*-0.65*	*8.76*	
Total		24	35	54	113

		Office buildings			
		Agree	A bit of both	Disagree	Total
Walking to specific place	Walkers	11	7	10	28
		6.31	7.57	14.13	
		4.69	*-0.57*	*-4.13*	
	Moderate Walkers	8	7	12	27
		6.08	7.30	13.62	
		1.92	*-0.30*	*-1.62*	
	Non-walkers	6	16	34	56
		12.61	15.14	28.25	
		-6.61	*0.86*	*5.75*	
Total		25	30	56	111

		Banks			
		Agree	A bit of both	Disagree	Total
Walking to specific place	Walkers	12	8	9	29
		7.12	8.65	13.23	
		4.88	*-0.65*	*-4.23*	
	Moderate Walkers	9	10	8	27
		6.63	8.05	12.32	
		2.37	*1.95*	*-4.32*	
	Non-walkers	7	16	35	58
		14.25	17.30	26.46	
		-7.25	*-1.30*	*8.54*	
Total		28	34	52	114

Contingency Tables for Social Walking & Various Land Uses

		Postoffice			
		Agree	A bit of both	Disagree	Total
Walk to visit friends	Walkers	10	2	7	19
		3.73	2.04	13.23	
		6.27	*-0.04*	*-6.23*	
	Moderate Walkers	8	6	47	61
		11.98	6.54	42.48	
		-3.98	*-0.54*	*4.52*	
	Non-walkers	4	4	24	32
		6.29	3.43	22.29	
		-2.29	*0.57*	*1.71*	
Total		22	12	78	112

		Clinic/pharmacy			
		Agree	A bit of both	Disagree	Total
Walk to enjoy outdoors	Walkers	20	16	51	87
		21.07	21.07	44.86	
		-1.07	*-5.07*	*6.14*	
	Moderate Walkers	10	14	15	39
		9.45	9.09	19.35	
		0.55	*4.91*	*-4.35*	
	Non-walkers	1	1	0	2
		0.48	0.48	1.03	
		0.52	*0.52*	*-1.03*	
Total		31	31	66	128

		Restuarants			
		Agree	A bit of both	Disagree	Total
Walk to get out with others	Walkers	13	8	3	24
		9.64	6.21	8.14	
		3.36	*1.79*	*-5.14*	
	Moderate Walkers	25	12	18	55
		22.10	14.24	18.66	
		2.90	*-2.24*	*-0.66*	
	Non-walkers	7	9	17	33
		13.26	8.54	11.20	
		-6.26	*0.46*	*5.80*	
Total		45	29	38	112

		Banks			
		Agree	A bit of both	Disagree	Total
Walk to visit friends	Walkers	10	5	5	20
		4.96	5.84	9.20	
		5.04	*-0.84*	*-4.20*	
	Moderate Walkers	12	19	30	61
		15.12	17.81	28.07	
		-3.12	*1.19*	*1.93*	
	Non-walkers	6	9	17	32
		7.93	9.35	14.73	
		-1.93	*-0.35*	*2.27*	
Total		28	33	52	113

		One's work place			
		Agree	A bit of both	Disagree	Total
Walk to visit friend	Walkers	6	1	9	16
		1.64	1.20	13.16	
		4.36	*-0.20*	*-4.16*	
	Moderate Walkers	4	6	50	60
		6.17	4.49	49.35	
		-2.17	*1.51*	*0.65*	
	Non-walkers	1	1	29	31
		3.19	2.32	25.50	
		-2.19	*-1.32*	*3.50*	
Total		11	8	88	107

		Postoffice			
		Agree	A bit of both	Disagree	Total
Walk to get out with others	Walkers	5	6	11	22
		3.63	2.62	15.74	
		1.37	*3.38*	*-4.74*	
	Moderate Walkers	10	5	39	54
		8.92	6.44	38.64	
		1.08	*-1.44*	*0.36*	
	Non-walkers	3	2	28	33
		5.45	3.94	23.61	
		-2.45	*-1.94*	*4.39*	
Total		18	13	78	109

Entropy

		Worship places			
		Agree	A bit of both	Disagree	Total
Walk to visit friends	Walkers	9	6	6	21
		5.64	4.67	10.69	
		3.36	*1.33*	*-4.69*	
	Moderate Walkers	17	14	23	54
		14.50	12.00	27.50	
		2.50	*2.00*	*-4.50*	
	Non-walkers	3	4	26	33
		8.86	7.33	16.81	
		-5.86	*-3.33*	*9.19*	
Total		29	24	55	108

		Banks			
		Agree	A bit of both	Disagree	Total
Walk to get out with others	Walkers	6	10	7	23
		5.18	6.84	10.98	
		0.82	*3.16*	*-3.98*	
	Moderate Walkers	15	16	24	55
		12.39	16.35	26.26	
		2.61	*-0.35*	*-2.26*	
	Non-walkers	4	7	22	33
		7.43	9.81	15.76	
		-3.43	*-2.81*	*6.24*	
Total		25	33	53	111

		Bustation			
		Agree	A bit of both	Disagree	Total
Walk to get out with others	Walkers	10	7	6	23
		8.36	5.02	9.62	
		1.64	*1.98*	*-3.62*	
	Moderate Walkers	20	14	20	54
		19.64	11.78	22.58	
		0.36	*2.22*	*-2.58*	
	Non-walkers	10	3	20	33
		12.00	7.20	13.80	
		-2.00	*-4.20*	*6.20*	
Total		40	24	46	110

APPENDIX V

TABLES OF REGRESSION MODELS' OUTPUTS

Table of Linear Regression Output for Land Use Perception Model

Land use Perception~ Gender + Meanage + log(meanincome) +
Neighborhood + WalkingFrequency + Transit + Residency + Car-Availability +
Amenities-audit + Continuity-audit + Directness-audit + Safety-audit +
CrashIndex + Infrastructure-index(FL)+ Safety-index + Landuse

Residuals:
Min 1Q Median 3Q Max
-1.33 -0.27 -0.02 0.27 1.69

Variable	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	7.39	1.49	4.96	0.00	***
Gender-Female	-0.13	0.12	-1.11	0.27	
Mean-age	-0.01	0.01	-0.92	0.36	
Log(meanincome)	-0.43	0.13	-3.35	0.00	**
Neighborhood2	-0.78	0.44	-1.76	0.08	.
Neighborhood3	-0.22	0.32	-0.67	0.51	
Neighborhood4	-0.40	0.23	-1.77	0.08	.
Neighborhood5	-0.65	0.20	-3.19	0.00	**
Neighborhood6	0.55	0.29	1.91	0.06	.
Neighborhood7	0.19	0.38	0.51	0.61	
Neighborhood8	-0.36	0.22	-1.68	0.10	.
Neighborhood9	-0.03	0.25	-0.13	0.90	
Neighborhood10	1.05	0.23	4.61	0.00	***
Neighborhood11	NA	NA	NA	NA	
Walking_frequency-Moderate	0.31	0.19	1.65	0.10	
Walking_frequency-Frequent	0.30	0.16	1.88	0.06	.
Transit-no	-0.09	0.19	-0.50	0.62	
Residency <5yrs	0.17	0.14	1.27	0.21	
Residency 5+ yrs	0.10	0.19	0.50	0.62	
Car_availability-sometime	-0.56	0.38	-1.45	0.15	
Car_availability-always	-0.54	0.37	-1.49	0.14	
Amenities-audit	NA	NA	NA	NA	
Continuity-audit	NA	NA	NA	NA	
Directness-audit	NA	NA	NA	NA	
Safety-audit	NA	NA	NA	NA	
Crash-index	NA	NA	NA	NA	
Infrastructure-index(FL)	NA	NA	NA	NA	
Safety-index(FL)	NA	NA	NA	NA	
Landuse	NA	NA	NA	NA	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.5384 on 98 degrees of freedom
Multiple R-squared: 0.4951, Adjusted R-squared: 0.3972
F-statistic: 5.058 on 19 and 98 DF, p-value: 3.718e-08

Table of Linear Regression Output for Amenities & Aesthetics Perception Model

Aesthetic-Perception~ Gender + Meanage + log(meanincome) + Neighborhood + WalkingFrequency + Transit + Residency + Car-Availability + Amenities-audit + Continuity-audit + Directness-audit + Safety-audit + CrashIndex + Infrastructure-index(FL)+ Safety-index + Landuse

Residuals:

Min	1Q	Median	3Q	Max
-0.91	-0.21	-0.01	0.18	0.98

Variable	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.15	0.94	0.16	0.87	
Gender-Female	-0.07	0.07	-0.97	0.33	
Mean-age	0.00	0.00	0.91	0.36	
Log(meanincome)	0.18	0.08	2.26	0.03	*
Neighborhood2	-0.46	0.28	-1.66	0.10	.
Neighborhood3	-0.19	0.20	-0.93	0.36	
Neighborhood4	-0.15	0.14	-1.07	0.29	
Neighborhood5	0.23	0.13	1.77	0.08	.
Neighborhood6	0.13	0.18	0.72	0.47	
Neighborhood7	0.14	0.24	0.61	0.54	
Neighborhood8	0.04	0.14	0.29	0.77	
Neighborhood9	0.05	0.16	0.33	0.74	
Neighborhood10	-0.17	0.14	-1.21	0.23	
Neighborhood11	NA	NA	NA	NA	
Walking_frequency-Moderate	0.28	0.12	2.32	0.02	*
Walking_frequency-Frequent	0.21	0.10	2.08	0.04	*
Transit-no	-0.25	0.12	-2.10	0.04	*
Residency <5yrs	0.08	0.09	0.88	0.38	
Residency 5+ yrs	0.11	0.12	0.88	0.38	
Car_availability-sometime	-0.38	0.24	-1.58	0.12	
Car_availability-always	-0.24	0.23	-1.04	0.30	
Amenities-audit	NA	NA	NA	NA	
Continuity-audit	NA	NA	NA	NA	
Directness-audit	NA	NA	NA	NA	
Safety-audit	NA	NA	NA	NA	
Crash-index	NA	NA	NA	NA	
Infrastructure-index(FL)	NA	NA	NA	NA	
Safety-index(FL)	NA	NA	NA	NA	
Landuse	NA	NA	NA	NA	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table of Linear Regression Output for Directness Perception Model

Directness-perception ~ gender + meanage + log(meanincome) +
neighborhood + wlkfreq + transit + residency + caravailability +
amenitiesaudit + continuityaudit + directnessaudit + SafetyAudit +
CrashIndex + InfrastructureIndexfuzzy + safetyfuzzyindex +
Entropy

Residuals:

Min	1Q	Median	3Q	Max
-1.81	-0.17	0.01	0.2	0.69

Variable	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	1.73	0.99	1.76	0.08	.
Gender-Female	-0.08	0.07	-1.15	0.25	
Mean-age	0.00	0.00	0.56	0.58	
Log(meanincome)	0.03	0.08	0.38	0.70	
Neighborhood2	0.09	0.33	0.27	0.78	
Neighborhood3	0.06	0.19	0.30	0.76	
Neighborhood4	0.29	0.14	1.99	0.05	*
Neighborhood5	-0.03	0.13	-0.26	0.80	
Neighborhood6	0.21	0.18	1.19	0.24	
Neighborhood7	0.07	0.24	0.29	0.77	
Neighborhood8	0.13	0.13	1.00	0.32	
Neighborhood9	0.09	0.15	0.59	0.56	
Neighborhood10	0.25	0.14	1.79	0.0771 .	
Neighborhood11	NA	NA	NA	NA	
Walking_frequency-Moderate	-0.10	0.11	-0.85	0.40	
Walking_frequency-Frequent	0.00	0.10	0.00	1.00	
Transit-no	-0.16	0.12	-1.33	0.19	
Residency <5yrs	0.12	0.08	1.45	0.15	
Residency 5+ yrs	0.08	0.12	0.71	0.48	
Car_availability-sometime	-0.16	0.29	-0.55	0.59	
Car_availability-always	-0.02	0.29	-0.07	0.95	
Amenities-audit	NA	NA	NA	NA	
Continuity-audit	NA	NA	NA	NA	
Directness-audit	NA	NA	NA	NA	
Safety-audit	NA	NA	NA	NA	
Crash-index	NA	NA	NA	NA	
Infrastructure-index(FL)	NA	NA	NA	NA	
Safety-index(FL)	NA	NA	NA	NA	
Landuse	NA	NA	NA	NA	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table of Linear Regression Output for Directness Perception Model

Continuity-perception ~ Gender + Mean-age + Meanincome +
Neighborhood + Walking-frequency + Transit + Residency + Car-availability +
Amenities-audit + Continuity-audit + Directness-audit + Safety-audit +
Crash-index + Infrastructure-index(FL) + Safety-index(FL) + landuse

Residuals:

Min	1Q	Median	3Q	Max
-0.51	-0.17	0.001	0.15	0.77

Variable	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	3.00	0.81	3.69	0.00	***
Gender-Female	-0.04	0.06	-0.60	0.55	
Mean-age	0.00	0.00	0.11	0.91	
Log(meanincome)	-0.08	0.07	-1.16	0.25	
Neighborhood2	-0.22	0.23	-0.97	0.34	
Neighborhood3	-0.13	0.17	-0.77	0.44	
Neighborhood4	-0.21	0.12	-1.73	0.09	.
Neighborhood5	0.12	0.11	1.07	0.29	
Neighborhood6	0.11	0.15	0.72	0.47	
Neighborhood7	0.00	0.20	-0.02	0.98	
Neighborhood8	0.02	0.12	0.16	0.88	
Neighborhood9	0.29	0.14	2.07	0.04	*
Neighborhood10	-0.18	0.13	-1.40	0.17	
Neighborhood11	NA	NA	NA	NA	
Walking_frequency-Moderate	0.02	0.10	0.21	0.84	
Walking_frequency-Frequent	0.08	0.08	0.96	0.34	
Transit-no	-0.08	0.10	-0.79	0.43	
Residency <5yrs	0.05	0.07	0.74	0.46	
Residency 5+ yrs	0.10	0.10	1.00	0.32	
Car_availability-sometime	-0.09	0.20	-0.45	0.65	
Car_availability-always	0.08	0.19	0.44	0.66	
Amenities-audit	NA	NA	NA	NA	
Continuity-audit	NA	NA	NA	NA	
Directness-audit	NA	NA	NA	NA	
Safety-audit	NA	NA	NA	NA	
Crash-index	NA	NA	NA	NA	
Infrastructure-index(FL)	NA	NA	NA	NA	
Safety-index(FL)	NA	NA	NA	NA	
Landuse	NA	NA	NA	NA	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

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