Modeling and Analysis of Walkability in Suburban Neighborhoods in Las Vegas

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REPORT 12-72

MODELING AND ANALYSIS OF WALKABILITY IN SUBURBAN NEIGHBORHOODS IN LAS VEGAS

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Walking has sound health benefits and can be a pleasurable experience requiring neither fuel, fare, license, nor registration. Society also benefits by the associated reduction of motorized vehicle travel. The objective of this study was to quantify the walking environment by developing a comprehensive walkability index that (1) reflects resident perceptions of their neighborhoods' walking environment; (2) reflects the suitability and adequacy of the pedestrian facilities in the neighborhood infrastructure and built environment, and (3) incorporates a pedestrian crash index, which measures the pedestrian crash experience.

Eleven neighborhoods in the Las Vegas, NV, metropolitan area were selected as a case study for this research. The study methodology involved surveying a sample of neighborhood residents to document perceptions of their walking environment, conducting field audits of the neighborhood infrastructure and land use related to walking, and collection of pedestrian crash data to develop crash indices to be incorporated into the walkability index.

Using survey results, cross-classification tables were developed to identify infrastructure, land use and other neighborhood features that influence walking. Statistical models were also calibrated to determine relationships between residents' walking frequency and some key infrastructure and neighborhood features. Furthermore, the data was used to develop comprehensive walkability indices and identify features that may need improvement in order to encourage more walking.</td></tr>
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TABLE OF CONTENTS

Executive Summary **1**

I. Introduction **3**

Background 3

Research Objectives 5

Definitions of Key Terms 5

II. Literature Review **7**

Defining Walkability 7

Methods of Evaluating Walkability 7

Summary 13

III. Study Methodology **14**

Introduction 14

Resident Survey Methodology 15

Neighborhood Audit Methodology 19

Pedestrian Crash Analysis Methodology 27

IV. Walking Characteristics from the Residential Survey Data **30**

Summary of Survey Data 30

Analysis of Walking Characteristics 30

Walking Frequency 31

Walking to Access Transit 32

Walking to Specific Places 34

Summary 35

V. Analysis of Neighborhood Walkability Features **36**

Neighborhood Summaries from Residential Surveys 36

Results of Neighborhood Audits 38

Comparison of Walking Environment Features from the Audit and Residents' Perceptions from the Survey 47

Summary 54

VI. Pedestrian Safety Analysis **55**

Introduction 55

Crash Rate Correlation with Walking Environment Features 56

Summary 58

VII. Estimation of Comprehensive Neighborhood Walkability Indices 59
Introduction 59
Infrastructure Grades 60
Walkability Index 61
Walkability Analysis 63
Summary 64

VIII. Statistical Modeling for Frequency of Walking 66
Frequency of Walking as a Function of Residents' Perceptions 66
Perception Models 69
Application of Statistical Models 75
Summary 76

IX. Conclusions and Recommendations 78
Introduction 78
Summary of Statistical Findings 79
Conclusions 79
Study Limitations and Future Research Recommendations 80

Appendix I: Neighborhood Walkability Survey Instrument 81

Appendix II: Neighborhood Audit Tool 86

Appendix III: Contingency Tables 88

Appendix IV: Tables of Regression Models' Outputs 92

Acronyms and Abbreviations 96

Endnotes 97

Bibliography 105

About the Authors 110

Peer Review 111

LIST OF FIGURES

1. Study Methodology 14
2. Methodology for the Residential Survey 16
3. Neighborhoods in Selected Census Tracts for the Residential Survey 17
4. Audit Methodology 20
5. Buffered Neighborhoods for the Audit Surveys 21
6. Pedestrian Safety Analysis Methodology 27
7. Crashes within the Buffers of Selected Neighborhoods 28
8. Comparison of the Audit vs. Residents' Perceptions Regarding Safety Features 49
9. Comparison of the Audit vs. Residents' Perceptions Regarding Land-Use 50
10. Comparison of the Audit vs. Residents' Perceptions Regarding Directness 51
11. Comparison of Audit Continuity vs. Resident Continuity Perception 52
12. Comparison of the Audit and Residents' Perceptions Regarding Aesthetics and Amenities 54
13. Audit Safety and Crash Indices 55
14. Comparison of Overall Audit Walkability Indices with and without Crash Data 56
15. Calculation of Neighborhood Walkability Grades 59
16. Comparison of Audit Results vs. Residents' Perceptions of Infrastructure 61
17. Comparison of Overall Walkability Indices for the Audit and the Survey 62
18. Probability Plot of Walking Frequency vs. Perceptions of Land-Use Mix 67
19. Walking Frequency vs. the Perception of Aesthetics and Amenities 68
20. Features to be Improved that Would Enhance the Perception of Aesthetics and Amenities in the Euclid Neighborhood 76

LIST OF TABLES

1. Income Groups 17

2. Quality Grade Thresholds for Resident Survey Scores 19

3. Compilation and Score Development for the Safety Category 24

4. Compilation and Score Development for the Categories of Land-Use, Continuity, Directness, and Aesthetics and Amenities 25

5. Quality-Grade Thresholds for Neighborhood Audit Scores 27

6. Summary of the Survey Data 30

7. Kendall Tau-b Cutoff Values 31

8. Association Measures for Walking Frequency 32

9. Association Measures for Walking to Access Transit 33

10. Association Measures for Walking to Specific Places 34

11. Association Measures for Walking for Exercise 35

12. Raw and Standardized Survey Data 37

13. Audit Land-Uses 38

14. Audit Directness Features 39

15. Audit Continuity Features 41

16. Summary of Audit Aesthetics and Amenity Features 43

17. Summary of Audit Safety Features 45

18. Neighborhood Audit Scores and Grades 48

19. Pearson's Correlation Values between Crash Indices and Safety Related Infrastructure 57

20. Rules for Assigning Infrastructure Grades 60

21. Rules for Assigning Overall Walkability Grades from Land-Use Mix, Infrastructure, and Safety Grades 62

22. Grades for All the Neighborhoods for All the Categories 63

23. Coefficients for the Walking Frequency Model 67

24. Pearson Correlation Matrix for Residents’ Perceptions 69

25. Final Model for Land-Use Perceptions 72

26. Coefficients for the Final Model for Land-Use Perceptions 72

27. Final Model of Perceptions of Aesthetics and Amenities 74

28. Coefficients for Final Model for Perceptions of Aesthetics and Amenities 75

EXECUTIVE SUMMARY

Walking has sound health benefits, and can be a pleasurable experience requiring neither fuel, fare, license, nor registration. While 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 neighborhoods and eliminate unnecessary motorized trips, various approaches have been used to evaluate an assortment of features in the walking environment. Some factors such as crash risk, however, contribute essentially to the viability of a walking environment and have yet to be considered.

The objective of this study, therefore, was to quantify the walking environment, specifically in suburban neighborhoods of Las Vegas, by developing a comprehensive walkability index that reflects the conditions of 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 both recreational and 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 residential 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, as expressed using natural language. A 'perception quality' grade for walkability, based on resident perceptions, was developed from the survey data. A trained auditor performed an audit of the neighborhoods surveyed 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. By using the various features measured on a segment, a walkability audit quality index was developed for each neighborhood. In addition, a crash index was developed as a function of population and commercial land-use within the neighborhoods surveyed.

The findings of this study are expected to enhance the evaluation of walking environments. The safety index, which incorporates crash risk and objectively measured safety elements, provides a more representative indicator of safety levels within the walking environment than an index based on only infrastructure safety features. In addition, use of crash data increases objectivity in the neighborhood audits, depending on how audit scores are estimated. With improved estimations for walkability, decision-makers would be better equipped during the planning stage to select appropriate strategies that encourage walking in a safe environment for recreational and utilitarian purposes.

A comparison of the walkability indices developed for audit quality, with and without crash data, indicated significant differences. Neighborhoods with initially high walkability indices ranked much lower after integrating the crash data. Even without statistical significance, crash data provided greater objectivity to audit quality indices, based on data collection and reduction.

The study used multinomial logit to identify parameters that influence walking frequency. Results indicate that land-use as well as 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 provide opportunities for trip chaining. As expected, better aesthetics, amenities, and infrastructure are associated with higher walking frequencies. Both aesthetics and amenities as well as land-use perceptions are correlated with perceptions of safety, directness, and continuity. This implies that improving the perception of one category is bound to have an effect on another perception category.

The study also used mixed models to identify features in the built environment that influence resident perceptions that in turn influence walking frequency. For example, the models show that neighborhoods with initial low resident land-use perception are likely to be more sensitive to the addition of new commercial premises. Furthermore, the models also show that resident perception of land-use is influenced by directness, meaning that improvement in the directness features of a neighborhood increases its residents' land-use perception which in turn increases walking frequency..

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

I. INTRODUCTION

BACKGROUND

Walking has sound health benefits, and can be a pleasurable experience that requires no fuel, fare, license, nor registration. According to the National Household Travel Survey (NHTS) of 2009,[1] approximately 10.4% out of 392 billion annual person-trips in the United States were walking trips. The report indicated that about 46% of walking trips were for recreational, health, and exercise purposes, while 43% were for school, work, personal errands, and social visits.

A great deal of focus has been directed towards physical activity by means of the President's Physical Fitness Challenge, which encourages 30 or 60 minutes a day of physical activity in adults and children, respectively.[2] For recreational purposes, the Centers for Disease Control and Prevention (CDC) recommends 150 minutes of physical activity per week for health benefits.[3]

Many research studies have evaluated the suitability of walking facilities. The studies are varied in their foci, methodology and the variables evaluated. Two basic methods of estimating the suitability of walking facilities have emerged: subjective and objective studies.

Subjective studies typically are based on data collected from surveys of pedestrians or residents on their walking experiences. Survey questionnaires are presented to respondents by means of mail, phone, or walking interviews to collect perceptions about various aspects of their walking environment and its characteristics. Subjectively evaluated elements of the built environment such as aesthetics, comfort, and a sense of security and community might be factored into the evaluation of a walking environment.

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 in order to estimate the suitability of walking facilities. Although 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 than would be expected.[4]

Objective studies, on the other hand, measure features in the built environment at both macro-scale and micro-scale levels; these measures can be replicated. The measurements are used to assess the suitability of the walking environment. Earlier walkability studies employed the Level of Service (LOS) concept, which was originally used in transportation studies to evaluate the performance of such auto-transportation facilities as highways, arterials, and major and minor roadways.[5] The LOS method evaluates such elements 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 databases of the field, geographic information systems (GIS), the U.S. Census, and local agencies, among other sources. The items measured include retail floor area ratio, land-use mix and the proximity of the land-uses to residences, the urban sprawl index, and intersection and residential densities, among others.[6]

Many tools and instruments have been developed to evaluate functional features in the walking environment, including the Pedestrian Environmental Factor (PEF), Pedestrian Environment Data Scan (PEDS), Microscale Audit of Pedestrian Streetscapes (MAPS), the Minnesota-Irvine tool, and the Neighborhood Environment Walkability Scale – Abbreviated (NEWS-A). According to Lin and Vernez, 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."[7] Objective studies, however, tend to neglect nonfunctional aspects of the walking environment, such as a sense of security and comfort.[8] While it is important to evaluate the effects of functional attributes on walking, objective measures may not reflect pedestrian perceptions accurately.

Although 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 and continuity of walking routes in order to minimize walking time, and aesthetics and amenities to make walking pleasant and comfortable. In summary, while much work has been done to advance the evaluation of walking environments, some limitations still exist, as 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 and safety-related infrastructure. None of the reviewed studies, however, considered crash risk in walkability evaluations. Safety-related infrastructure, therefore, does not completely illustrate potential crash risk in the walking environment. Cho et al. found that actual and perceived crash locations do not necessarily coincide.[9] Schneider et al. reported that even safety experts have a hard time distinguishing between crash and non-crash sites.[10] Locations that are highly reported but have a low perception of risk indicate physical problems of which pedestrians are unaware.

2. Each study method has merits; however, on their own, subjective and objective studies are limited in their suitability to evaluate the walking environment in its entirety. A decision to walk is motivated by the pedestrian's perception of the walking environment. Brown et al. recommended using a transactional evaluation approach, in which the pedestrian behavior is influenced by multiple environmental features, the pedestrian's perception of the features, and other social and cultural aspects.[11]

3. Some studies performed comparative analyses between objectively measured features and subjective evaluations.[12] There is limited guidance, however, for how to estimate the influence of measured features when walking for recreational or utilitarian purposes. A few studies quantify walkability, but with limited generalization of the procedures.[13]

RESEARCH OBJECTIVES

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

1. Analyze and model the effect of features in the built walking environment on walking for recreational or utilitarian purposes. In addition, the analyses determined whether perception of their walking facilities by residents who were surveyed was comparable to the objective audit observations in various categories.

2. Incorporate crash experiences of pedestrians in the analysis and determination of neighborhood walkability. Neighborhood crash indices were calculated based on pedestrian crash rates, and comparative analyses made between walkability indices with and without the inclusion of crash indices.

DEFINITIONS OF KEY TERMS

Walkability: Various definitions for the term walkability are discussed in Chapter 2. For this study, walkability was defined as the extent that a facility provides safe, direct connectivity to destinations while minimizing travel time and effort as well as offering a comfortable and pleasant visual environment.[14]

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

Directness: Directness describes express access between an origin and a destination. An airline distance is an example of a very direct route between an origin and destination. Any route that has to go around obstacles, either by following a street network or by avoiding obstructions, would have a lower value for directness. Residential neighborhoods – for example, gated communities and presence of cul-de-sacs – tend to have circuitous routes, and hence affect directness negatively.

Continuity: Continuity refers to the uninterrupted characteristic of a walk path or route. For example, a sidewalk that is discontinuous mid-block due to construction or some other obstructions would be considered to have lower continuity. Elements evaluated for continuity demonstrate the potential for either an unobstructed or an 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 an appreciation of the walking environment, such as articulated buildings, pleasant landscape, and cleanliness as well as the presence of physical and social disorders.

Land-use mix: This is a measure of how much diversity a neighborhood has in the different types of commercial land-uses that might attract walking trips. The value of this parameter varied from a perfect 1, if the neighborhood is within walking distance of all the major types of commercial and recreational land-uses, and zero if there are no such land-uses within walking distance of the neighborhood.

Quality walkability index: The quality index refers to the value obtained from combining category scores that measure, for example, directness, continuity, amenities, and aesthetics.

Quality walkability grade: This refers to the label assigned to the quality walkability index to infer the quality of the walking environment, in a natural language.

II. LITERATURE REVIEW

DEFINING WALKABILITY

As mentioned in Chapter 1, walkability is defined as the extent that the walking environment provides safe and direct connectivity to destinations while minimizing travel time and effort, as well as offering a comfortable and pleasant visual environment.[15] Various other definitions for walkability often depend on the scope of the measurement and estimation variables used for the study. For example, Mayne et al. defined walkability as the ability of the built environment to facilitate walking for various purposes.[16] Lwin and Murayama referred to walkability as a concept that conveys how conducive the built environment is to walking, while in her dissertation, Park defined it as the "quality of the walking environment as perceived by the walkers and as measured by micro-level urban design attributes."[17]

METHODS OF EVALUATING WALKABILITY

Two approaches have been used to measure walkability, namely, subjective and objective methods, depending on the type of data and how the data is collected. Subjective studies focus primarily on the pedestrian experience, as collected by means of surveys of respondents' opinions regarding their walking environment and its characteristics. Objective studies utilize objectively measured data from the field or databases on infrastructure, such as roadway network characteristics and land-uses in the built walking environment.

Subjective Studies

Subjective studies typically are based on the pedestrian's walking experience, as documented by means of surveys with residents. Features in the built environment are quantified by collecting subjective perceptions or opinions of the respondents regarding the infrastructure as it affects their walking environment. Data collected includes such factors as those related to street connectivity, access to and proximity of adjacent destinations and land-uses, aesthetics/amenities, and safety risks from traffic and crime. Capturing these pedestrian perceptions typically is achieved using survey questionnaires designed to elicit respondent opinions on these factors. Livi and Clifton stated that using "perception questions is a convenient way to sketch actual walkability conditions."[18] The surveys are implemented by mailing questionnaires to respondents, making phones calls, or interviewing pedestrians in their walking environments. The following are some typical studies that have used subjective methods to evaluate walkability.

Kelly et al. conducted three surveys in Leeds, UK, designed to increase an understanding of factors that influence levels of walking and pedestrian route choice.[19] The surveys were used to assess the pedestrian environment from a pedestrian's perspective. The first survey was a stated preference survey, in which respondents were requested to select their preferred routes based on various pedestrian attributes and associated levels of Council Tax rebates. Relative weights were assigned to the attributes and were aggregated to obtain a "utility" score. Higher scores indicated a more suitable environment for walking. The second survey was a route-based on-street survey designed to investigate various attributes of the walking environment. Interviewers waited at the end of a route and asked respondents to rate the walkability of the route, using 21 factors on a five-point scale ranging from very good (5) to very bad (1). The third survey was a walking interview designed to capture actual pedestrian experiences while the respondents were walking. Results of the stated preference survey indicated that pavements disorders and heavy traffic were restrictive factors for walking. The on-street survey and walking interviews suggested a need for improvements in traffic safety.

Shriver, in 2003, used the Walkable Places Survey (WPS) to evaluate a 10-block length of Baltimore Avenue in West Philadelphia, PA.[20] The study area comprises some of the earliest developments in West Philadelphia, dating 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 an orientation, while walking in assigned areas, survey participants evaluated 30 environmental design characteristics associated with walkable places. Quantitative results were averaged across a 3-point Likert scale (poor, fair, and good) for each of the areas evaluated. 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 segments earned higher scores due to ongoing activities that enhance street livability, such as eating and biking. Conversely, survey participants poorly rated cracked and dirty sidewalks, vacant lots, abandoned buildings, chaotic signage that provided negative visual effects, noise from cars and trolleys, inadequate public seating, and inadequately marked crosswalks.

Pikora et al. identified potential environmental influences on pedestrian activity from published evidence, policy literature and a Delphi study.[21] The Delphi technique, mainly developed at the Rand Corporation in the 1950s, is a widely used and accepted method for achieving censuses on real-world issues based on knowledge and opinions solicited from experts within the topic of interest.[22] Included in the findings from their study was a list of environmental factors that have significant influence on the walking environment and pedestrian experience. These factors were grouped into four categories: functional, safety, aesthetic and destination. Factors in the functional category included the type of walking surface, geometric characteristics of streets and traffic conditions. Factors under safety included availability of lighting on pedestrian facilities and pedestrian street crossing aids. Under aesthetics, factors included street maintenance and cleanliness, presence of trees, and parks and architectural features with pleasing views. Finally, the destination category included destination facilities such as shops and parks.

Since these studies are based on respondents' subjective opinions, they tend to have low reliability when predicting walking behavior.[23] In studies correlating pedestrian activity with perceptions of the walking environment, there were instances of confounding results. For example, several authors showed that the residents' perceptions of safety risk conflicted with the locations of actual risks.[24] Brown et al. cited cases of increased walking despite walking barriers, such as heavy traffic and limited mixed land-use.[25] Methods of administration surveys can often be challenging. For example, although recent reports indicate mail surveys have higher response rates than phone interviews, they are sometimes limited in having the respondents recall walking conditions of large areas.[26] This can introduce inaccuracies to the collected data.

As can be seen from the reviewed studies, various approaches are available when developing walkability indices from data collected from surveys. Shriver averaged Likert scores to obtain her walkability index, while Pikora et al. calculated inter-quartile ranges.[27] This process of developing walkability indices – in which various factors, weighted or un-weighted, are aggregated – tends to be very subjective. In addition, there are limitations in replicating perceptions from one area to another, which can present challenges when attempting to compare different studies.

Objective Studies

Objective studies involve the collection and analysis of field data on built environment features that have an effect on walkability. Built environmental variables often are obtained from field audits and/or GIS databases. For example, land-use types, retail floor area, and assessor acreage can be obtained from GIS databases of local planning agencies. Social demographic information, such as household income or total population, can be obtained from the Topologically Integrated Geographic Encoding and Referencing (TIGER) files in the U.S. Census Bureau database. In addition, roadway geometry, pedestrian and traffic volumes can be measured from the field or obtained from agency databases. The level of detail of information stored in agency databases influences how objective studies quantify walkability.

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.

Examples of audit tools in objective studies include PEDS, *NEWS-A* and MAPS. Variations of these tools 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.[28] The SPACES tool was later adapted to the U.S. environment and employed to assess street-level features in the pedestrian environment using integrated handheld technology.[29] The instrument is designed to objectively and subjectively assess the overall quality of the built environments for cycling and walking by evaluating features related to these activities. These include road geometry, walking and cycling facilities, and land-use characteristics. Several studies including this one have used variants of PEDS to conduct neighborhood audits.[30]

Other audit instruments for objective studies include NEWS-A, the abbreviated version of *NEWS* and 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.[31] The MAPS tool measures such built-environment features as street-crossing amenities, sidewalk qualities, transit stops, street design, social features, and aesthetics.[32] Millstein et al. used MAPS to examine the relationship of physical activity patterns across age groups in different locations with street-level attributes of the walking environment.[33] The authors conducted regression analyses to determine the effects of MAPS scores that were obtained regarding physical activity. Results indicated strong relationships between utilitarian walking/biking and land-uses, streetscape, and segment and intersection variables. Physical activity for recreational purposes was related to the aesthetic variables. The overall summary score was related to total moderate and vigorous physical activity (MVPA) in children and adults.

Another audit tool used for objective studies is the Pedestrian Environmental Factor (PEF), which was designed to determine a composite measure of pedestrian friendliness in the built environment. The PEF developed in 1993 by planners in Oregon aggregates ease of street crossings, sidewalk continuity, street geometry, and topography. Used in the analysis for Oregon's Land-use, Transportation and Air Quality Connection (LUTRAQ) project, households in neighborhoods with high PEF values showed less vehicle-related travel compared to households with low PEF values.[34] A variety of other tools and instruments for objective studies can be found on an active online website, Active Living Research.[35]

Additional specific studies have used various objective methods to evaluate walkability. Peiravan, et. al. developed a Pedestrian Environment Index (PEI), which is zone-based and suitable for metropolitan planning organizations (MPOs).[36] PEI is defined as a product of four sub-indices that capture characteristics relevant to walking, namely:

$$PEI_i = \frac{1}{16}\,(1+LDI_i) * (1+PDI_i) * (1+CDI_i) * (1+IDI_i) \qquad 2\text{-}1$$

where:

LDI_i = Land-Use Diversity Index

PDI_i = Population Density Index

CDI_i = Commercial Density Index

IDI_i = Intersection Density Index.

The index is a product rather than a typical sum, based on the rationale that factors affecting the pedestrian walking environment, according to Peiravan, et. al. "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."

Another study by Allan developed a Walking Permeability Index (WPDI) as a principal form of analysis to evaluate how the City of Adelaide and other cities in Australia catered to utilitarian walking.[37] WPDI was developed on the rationale that pedestrians do not have the time or endurance to walk unnecessarily, and is expressed as:

$$WPDI = \frac{AD}{DD} \qquad 2\text{-}2$$

where:

AD = Actual distance by most practical route

DD = Direct distance between origin and destination

A WPDI value of ‘1’ indicated sufficient permeability and ‘1.5’ was set as the limit of accessibility. Study results showed that 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 values.

Kuzmyak et al. in collaboration with the Baltimore Metropolitan Council (BMC), undertook an effort to advance incorporation of land-use considerations in the regional transportation planning process.[38] In their study, walking opportunities were explored based on the influence of local and regional accessibility on the rates of vehicle ownership and vehicle miles traveled (VMT). The data used for analyses included parcel land-use data, U.S. Census data for the year 2000, one-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 was calculated as:

$$\text{Walkability} = \sum_{i=1}^{n} I_i \qquad \text{2-3}$$

where:

I_i = ‘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; and

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

Although not originally planned, determination of origins and destinations for walking trips was incorporated into the study, resulting in the “Walking Opportunities Index.” Using GIS, the distance of walking opportunities within the 0.25-mi buffer was calculated as:

$$\text{Walk opportunity} = \sum_{O_i}^{O_n} \frac{W_i * S_i}{D_i} \qquad \text{2-4}$$

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; and large = 3; and

D_i = Distance from household to opportunity

Study results indicated more walking at households that were adjacent to neighborhoods having a more varied land-use mix and better accessibility. In addition, the results suggested that mixing commercial and residential parcels as well as providing good regional transit connections would serve to manage travel growth and reduce demand for new capacity.

In urban studies, Frank et al. developed a walkability index as a function of residential density, intersection density, retail Floor Area Ratio (FAR) and land-use or entropy score.[39] 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, as expressed as:

$$\text{Walkability} = 2(\text{z-intersection density}) + (\text{z-residential density}) + (\text{z-retail FAR}) + (\text{z-land-use}). \tag{2-5}$$

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. Results showed that higher densities resulted in more non-auto trips and were also synonymous with more interesting street life and security for pedestrians. A higher intersection density was indicative of a variety of route options.

Major limitations of objective studies include the fact that they ignore resident or pedestrian walking experience and perceptions. As such they may not be able to model walking characteristics accurately. Secondly, aggregating the various features and parameters in order to determine walkability indices still involves a lot of subjective judgement on the importance or impact of various features on neighborhood walkability. Some researchers therefore opted to combine both studies in order to determine more representative walkability indices or models.

Combined Studies

Due to the limitation of individual objective and subjective studies, several walkability studies have combined the use of both studies in order to obtain more representative comprehensive walkability indices. The following are examples of such studies.

In an effort to validate their survey tool, the Neighborhood Environment Walkability Scale (NEWS), Adams et al. compared their survey results to objectively measured GIS-based results. Survey questions were categorized into four groups: accessibility to land-uses, diversity of land-uses, aesthetics, and safety from traffic and crime. Correlation tests were performed between NEWS survey measures and corresponding GIS measures. For most measures, significant weak-to-moderate concordance was seen, indicating agreement between subjectively obtained measures and corresponding objectively obtained measures.

In their walkability study, Hajna et al. compared a GIS-based study on site neighborhood audits, using a modified PEDS instrument, and a pedestrian survey using self-administered questionnaires. The relationships among the calculated audit, GIS, and survey indices were analyzed using Spearman correlation coefficients. Their findings determined that there was no correlation between pedestrian perceptions and objectively measured audit and GIS indices. Conversely, there was a correlation between audit and GIS-derived walkability indices, which implied that it was reasonable to use GIS-derived measures in place of more labor-intensive audits.

Park conducted two surveys as well as developed an audit instrument used to audit street segments at the study sites (transit stations). Walkability indicators from the audit were aggregated and summarized into path walkability indicators. In the survey of station users, mail-back self-administered questionnaires were distributed to transit users, collecting information on “access mode choices, trip origins, and socioeconomic data.” The survey regarding onboard perceptions requested that the transit users score their walking routes. Using factor analysis and multiple regression models, a composite walkability index was obtained by correlating perceptions of the survey participants with objectively measured street attributes of reported routes to the station. The reported importance of walkability items was used proportionately to weigh the given walkability items in the overall model.

SUMMARY

Lin and Vernez[6] reported that objective measures of the built environment were more strongly associated with walking compared to subjective measures. As evidenced in the literature, however, each method on its own was limited when quantifying walkability as a whole. The choice to walk is based on a pedestrian’s perceptions of the walking environment. Pikora et al.[21] adopted “a social ecological model” to understand how this choice is made. In contrast, Brown et al. used a “transactional approach” by which pedestrian behavior was influenced by multiple factors in the physical environment as well as psychological experiences of the pedestrian. When both subjective and objective approaches are combined, there is a greater likelihood of accurately estimating the suitability of the walking environment.

III. STUDY METHODOLOGY

INTRODUCTION

Figure 1 summarizes the methodology adopted for this study. Subjective walkability studies (i.e., resident surveys) and objective walkability studies (i.e., neighborhood audits) were integrated and neighborhood pedestrian crash rates were incorporated in order to determine walkability indices. The study was conducted in selected residential neighborhoods in the Las Vegas area. Results were calculated for three walkability indices for each neighborhood, one based on the subjective study results, one based on the objective study results, and one that integrated both.

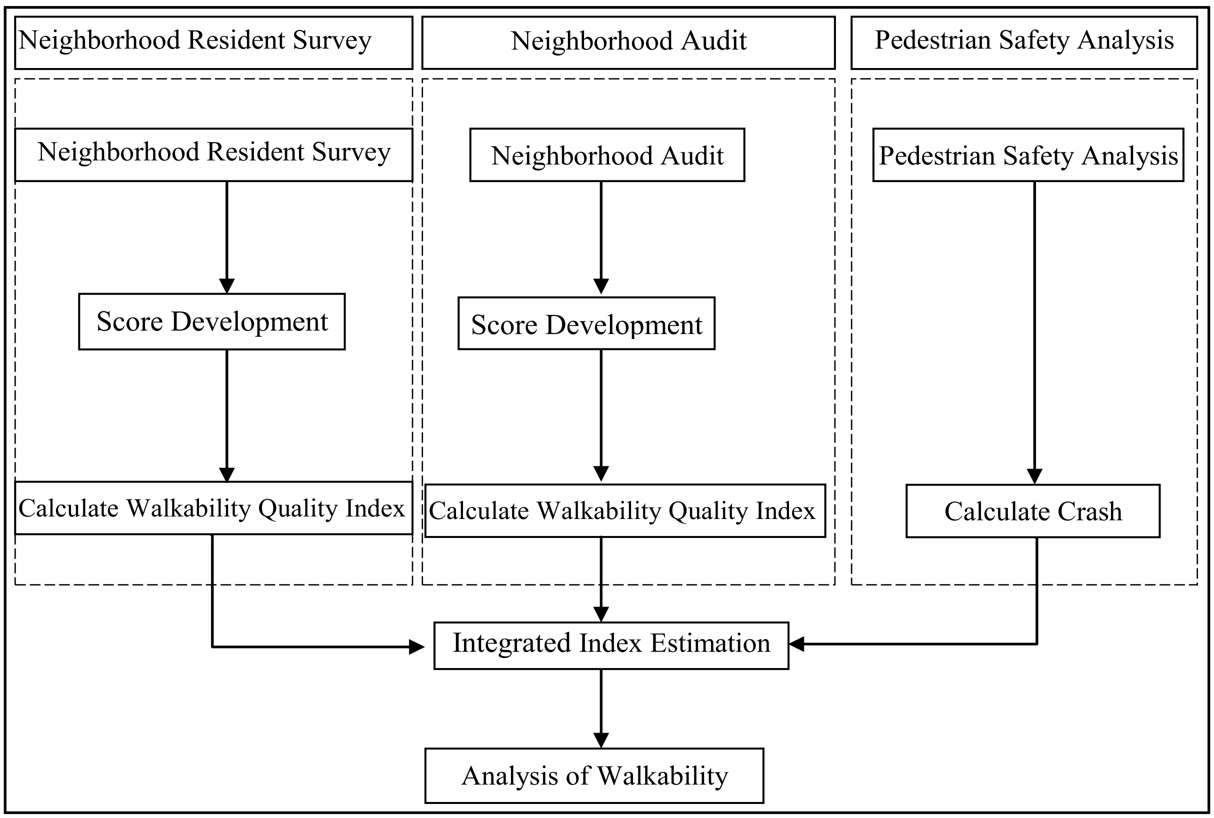

Figure 1. Study Methodology

The objective of conducting residential surveys was to document the perceptions, experiences and concerns of residents regarding various aspects of their walking environments, including safety, access, land-use, and convenience. Written questionnaires were distributed to residents of randomly selected neighborhoods asking them to respond to questions regarding the various aspects of the walkability environment in their neighborhoods. Their responses were compiled, summarized, and used to calculate a ‘walkability quality index’ for each neighborhood, a parameter designed to reflect the residents’ perceptions of their walking environment.

Neighborhood audits involved collecting field data on objectively measured features of the neighborhood built environment, including the roadways, land-use, and other features that affect on neighborhood walkability. Research personnel collected the audit data. As with the resident surveys, the audit data was compiled, summarized, and used to calculate an audit-based 'walkability quality index' for each neighborhood in the study.

The third aspect of the methodology related to pedestrian safety analysis for each neighborhood. Pedestrian crash data was collected and used to calculate a pedestrian crash index for each neighborhood. There have not been many previous studies that have incorporated crash experiences when determining walkability indices.

Finally, the three indices were integrated to determine the overall walkability indices for each neighborhood. Below is a detailed description of each of these three major phases of the research.

RESIDENT SURVEY METHODOLOGY

Methodology

The methodology included designing the survey instrument, the sampling procedure, implementation of the survey, data compilation, and score development (see Figure 2).

Survey Design

The survey questionnaire (see Appendix I) was organized into seven sections:

1. Reasons for walking,
2. Land-uses within a 15-minute walk of the residence,
3. Directness of the walking infrastructure,
4. Continuity of the walking infrastructure,
5. Aesthetics/Amenities of the walking environment,
6. Safety of the walking environment, and
7. Sociodemographic characteristics of the respondents.

Questions used in the survey tool were based on two instruments, the Microscale Audit of Pedestrian Streetscapes (MAPS) and the Neighborhood Environment Walkability Scale - Abbreviated (NEWS-A).[40] A complete survey is attached in Appendix I.

A four-point Likert response scale indicated a level of agreement from Strongly Agree, Somewhat Agree, Somewhat Disagree, and Strongly Disagree. A neutral or midpoint category was not offered because studies have shown that a neutral option might introduce unreliability when respondents are trying to be overly helpful or otherwise.[41] In another study, Ducharme noted that neutral options added no value for the respondent when assessing individual preferences or attitudes.[42] Further, he showed that a Likert 'forced choice' was warranted if it was reasonable to assume that respondents should have an opinion about and be familiar with the topic. In this study, respondents were surveyed where they resided, so it was safe to assume that residents were familiar with their neighborhoods and had an opinion regardless of whether or not they walked.

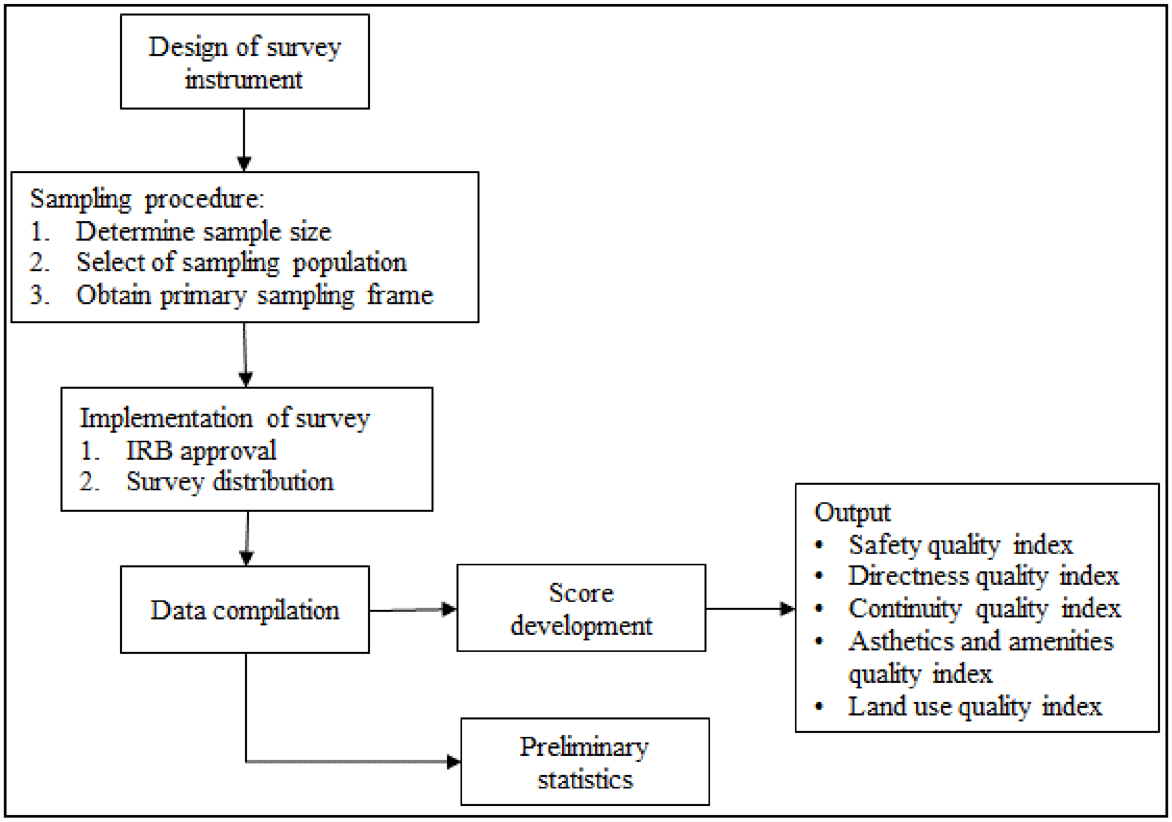

Figure 2. Methodology for the Residential Survey

Survey Sampling

Based on the available budget to conduct the survey, a sample size of 2,000 households was selected. The sampling population was limited to the Las Vegas Valley – encompassing the cities of Las Vegas, North Las Vegas, and Henderson – from which a representative cross section of neighborhoods was selected. The primary sampling frame was derived from the United States Census Bureau TIGER/Line® data, consisting of five-year estimates of the American Community Survey (ACS) and 2010 Census shape files.[43] For confidentiality purposes, the shape files consisted of demographic and economic data aggregated over census tracts and block groups. Census tracts and block groups are units of analysis designed by the Census Bureau, and consist of 1,500-8,000 and 600-3,000 people, respectively. These tracts represent neighborhoods that are relatively homogeneous with respect to population characteristics, economic status, and living conditions.

Within the Las Vegas Valley are 501 census tracts, sorted into four jurisdictions: Henderson, Clark County, the City of Las Vegas, and the City of North Las Vegas. Income data obtained from the Census Bureau was used to stratify the census tracts into five income groups according to the Census Bureau estimates, as shown in Table 2.[44]

For this study, 11 census tracts, two tracts representing a each stratum (income group), were selected randomly from the four jurisdictions in the Las Vegas Valley (Figure 3). Statistically, larger sample sizes result in smaller sampling errors. Similarly, homogenous clusters generate smaller sampling errors compared to heterogeneous populations.[45] A stratified sampling design was adopted.

Table 1. Income Groups

Income Class	Income Bracket (Annual Household Income)
Poverty	≤ $20,592
Lower-middle class	$20,593 to $39,735
Middle class	$39,736 to $64,553
Upper-middle class	$64,554 to $104,086
Upper class	≥ $104,087

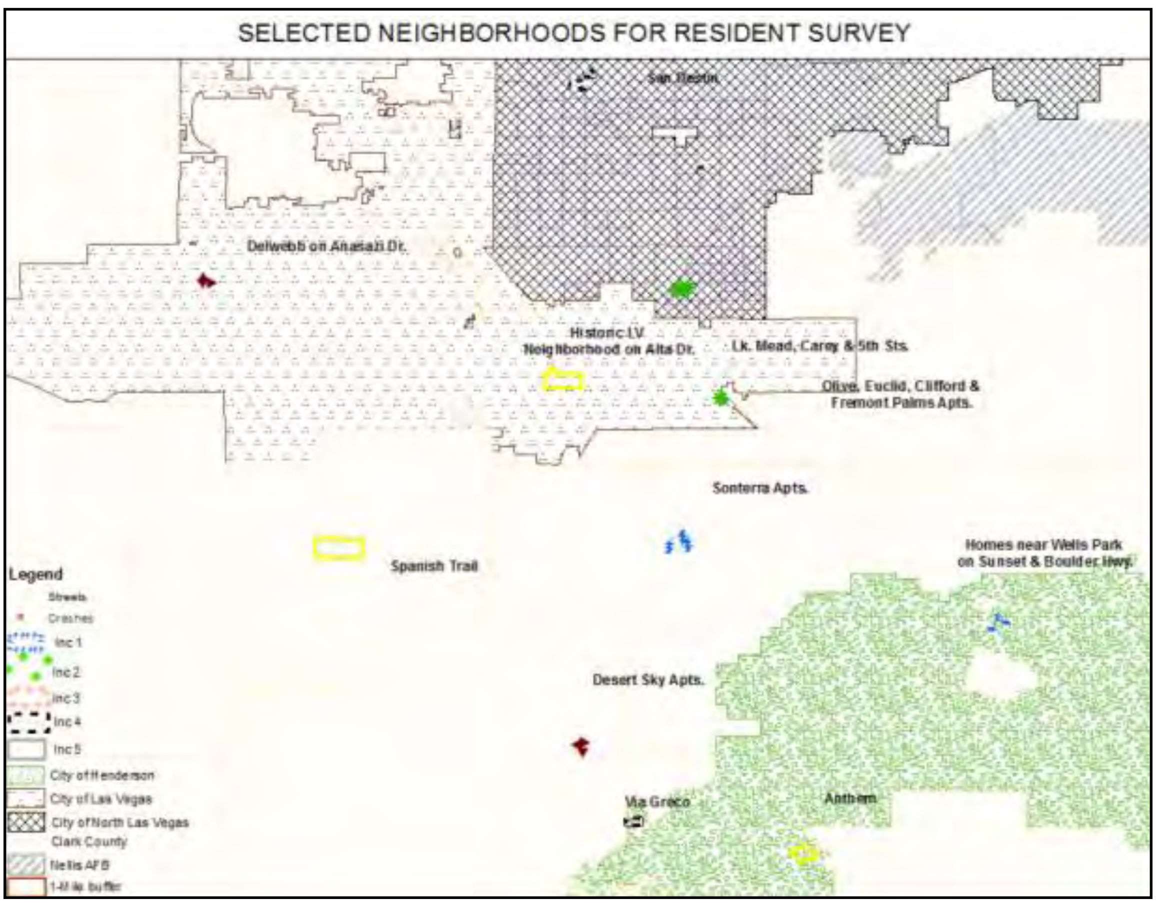

Figure 3. Neighborhoods in Selected Census Tracts for the Residential Survey

Survey Implementation

The survey fell under social behavioral research involving human research subjects; it 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 obtaining better responses or have been deemed more successful than others. For this study, a self-administered survey was selected as the method to collect perceptions and opinions of residents about their walking environment. The surveys were sent to residents in mail-back questionnaire packets. In addition, the questionnaire was posted and could be completed online in a version hosted by Qualtrics.[46]

The survey questionnaires, distributed in self-addressed stamped envelopes, were written in English and Spanish. Survey packets were distributed by hand in selected neighborhoods, except for two high-income neighborhoods; those packets had to be mailed since the survey team was not allowed access into these neighborhoods. In total, 2,014 survey packets were distributed to selected households; 1,740 were hand-distributed to each household, and 274 were mailed due to limited access to the neighborhoods.

Data Compilation and Score Development

A total of 154 completed surveys were received. For ease of analysis, the data was collapsed from four Likert responses to three responses. The “Somewhat Agree” and “Somewhat Disagree” categories, which both contained elements of agreement and disagreement, were combined into a new category called “Uncertain.”

The three categories – Strongly Agree, Uncertain, and Strongly Disagree – were assigned the weights “3”, “2”, and “1” in order of declining agreement, respectively. The perception for each category was taken as the average of the residents’ agreement for each neighborhood.

Upper and lower thresholds threshold scales were developed from the best-case and worst-case scenarios, against which a category score was measured. The best case was obtained when respondents strongly agreed to having all favorable elements in a category that promoted walking. The worst case was when residents reported the presence of elements in a category that detracted from walking. There were five categories of responses, namely:

- Land-use accessibility (Group A in the questionnaire – Appendix I),
- Directivity (Group B questions),
- Continuity (Group C questions),
- Amenities and aesthetics (Group D questions), and
- Safety (Group E questions).

For each of these categories, a simple average of the scores was calculated for each neighborhood from the responses of the respondents from those neighborhoods. This resulted in scores between 1 and 3, with higher scores indicating a positive contribution to walkability. The category scores were standardized to values between 0 and 1, and were assigned quality grades using labels on a four-point scale, A to D, to indicate the suitability of the walking environment in each neighborhood, namely,

Quality grade A - Walking facilities are very good.

Quality grade B - Walking facilities are reasonably good.

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

Quality grade D - Walking facilities need immediate attention.

The cut-off threshold values for these different grades were different for the various categories of the walkability environment. These values were selected rather subjectively, based on a consensus of the research team. These thresholds are summarized in Table 3.

Table 2. Quality Grade Thresholds for Resident Survey Scores

Grade		Land-Use	Directness	Continuity	Amenities	Safety
A	≥	0.750	0.850	0.750	0.800	0.750
B	≥	0.500	0.600	0.650	0.525	0.625
C	≥	0.300	0.400	0.525	0.400	0.375
D	≥	0.000	0.000	0.000	0.000	0.000

NEIGHBORHOOD AUDIT METHODOLOGY

Background

Neighborhood audits were performed using selected walkability audit instruments to estimate walkability as functions of land-use characteristics, infrastructure, and street design and traffic operational parameters. The audits were performed in the same neighborhoods selected in resident surveys. The same procedure used to calculate indices in the survey was used to obtain indices for safety, land-use, directness, continuity, amenities and aesthetics. The methodology involved design of audit instrument, 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 illustrates the procedure followed.

Design of the Audit Instrument

In a manner similar to the resident survey, the audit instrument was designed based on questions from the MAPS and the Pedestrian Environment Data Scan (PEDS).[47] In order to enable comparable analyses, the features were grouped into five categories that closely resembled the survey categories. The built environment features that were measured are:

1. Land-use mix
2. Directness
3. Continuity
4. Safety
5. Aesthetics/amenities

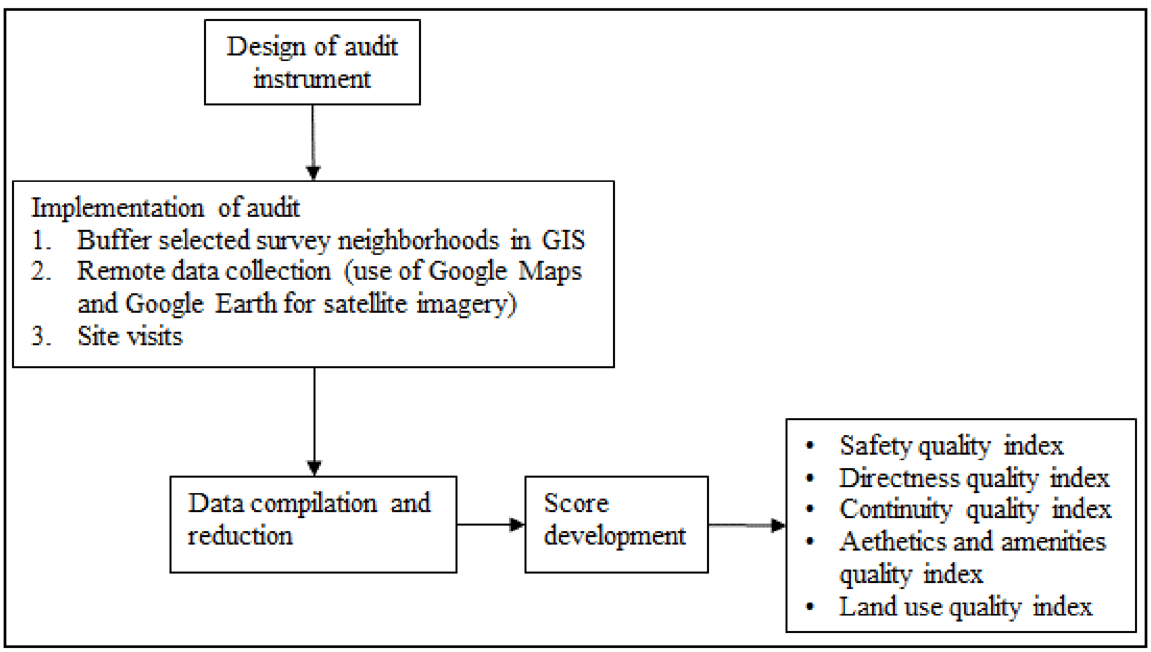

Figure 4. Audit Methodology

Audit Sampling

The audit was performed in the same randomly selected neighborhoods as the residential survey. Since studies have shown that pedestrians typically are willing to walk 10 to 15 minutes to access transit,[48] a 15-min buffer – which translated to a 0.682 mi buffer in radius, using a walking speed of four feet per second – was used for this study. The buffer was rounded up to a 0.75-mi buffer around the neighborhood. Buffer areas were not allowed to intersect freeways, as pedestrians typically are discouraged from crossing freeways. Figure 5 illustrates the buffered selected neighborhoods used for the audit.

Audit Implementation

The audit was conducted remotely, using the latest Google Earth satellite imagery and street views that were available at the time of the study. This was due to limited access to two of the neighborhoods, which were gated and did not allow access for the researchers to conduct the audits inside their neighborhoods. All neighborhoods were thus audited in a comparable manner. Site visits to confirm the audit parameters were performed where necessary. Audit data was collected by roadway segments, and varied in length from about 0.1 mi to 0.75 mi. Street segment data was catalogued according to the built environment features, and are described in the following sections. A spreadsheet of the audit instrument is attached in Appendix II.

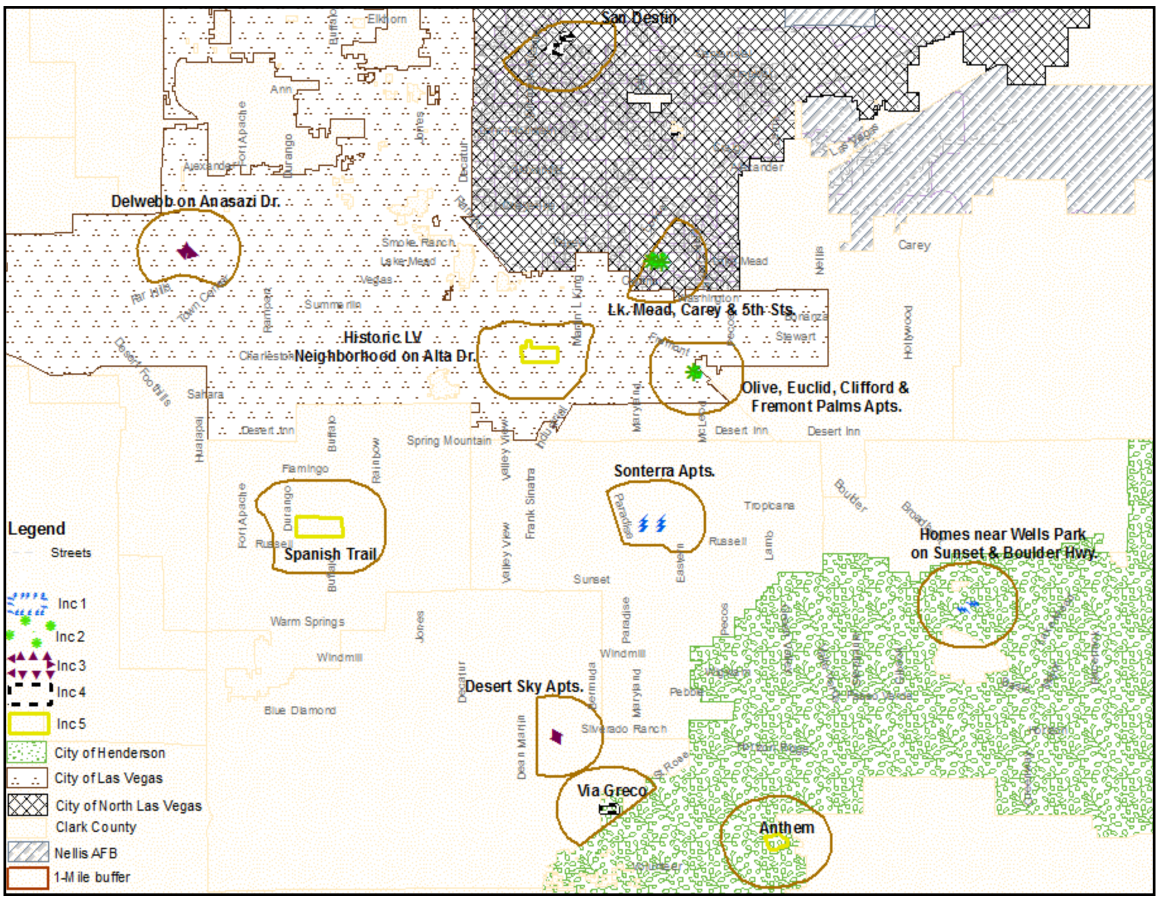

Figure 5. Buffered Neighborhoods for the Audit Surveys

Land-Use Mix

Land-use mix was estimated as a proportion of the types of land-uses. A score of “1” indicated that the neighborhood was within walking distance of all major types of land-uses that might generate walking trips, including retail stores, recreational facilities, office buildings, bus stops, health facilities and clinics, post offices, and banks. Parcel area data from the Clark County Assessor was used to identify the available land-uses that were within a 0.75-mi buffer of selected neighborhoods.

Directness

Regarding directness, infrastructure elements were evaluated to determine the presence or absence of circuitous routes that affect pedestrian travel times. Such features as the presence and numbers of gated or walled communities, street gradients, and commercial Floor Area Ratio (FAR) were some of the measures for directness. The presence of gated communities resulted in the need for circuitous walk routes, which ended up increasing the distances that pedestrians had to walk in order to reach their intended destinations. Street gradient, or steepness, of the sidewalks tend to make walking more difficult; therefore, the steeper the gradients, the worse was the directness score. Steepness was coded as “0,” “1,” and “2” for flat sidewalks, slightly hilly sidewalks, and hilly sidewalks, respectively. A sidewalk was considered flat if there was no noticeable gradient. A slightly hilly segment had a discernibly gentle slope; however, pedestrians still could walk with ease. Hilly segments had steep gradients that made walking difficult.

Distance travelled between origin and destination on commercial parcels was estimated in terms of FAR. Data for commercial parcels from the Clark County Assessor parcel database was used to determine the distance between parcel limits and an actual building’s footprint. A larger ratio between a parcel area and the actual building square footage indicated a shorter distance a pedestrian needed to travel in order to gain access to the premises. A smaller ratio implied large parking lots on the premises, hindering quick access to the buildings.

Continuity

Elements evaluated in the continuity category demonstrated the potential for an unobstructed or obstructed trip. The intersection density indicated that the distance walked to cross streets was catalogued by counting the number of intersections within the buffer. Obstructions indicated the ease or lack of facility access for all pedestrians.

The 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 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 dead ends were coded as zero. The number of driveways on a segment was counted and catalogued as well.

Safety

In the Safety category, infrastructure was catalogued that facilitated safe interactions between pedestrians and traffic in the walking environment. Intersection geometry catalogued on each segment included the existence of curb ramps and channelized and/or exclusive right-turn lanes at intersections. 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” for segments with these elements and “1” for those segments without the elements. In Las Vegas, bike lanes can share the right of way with vehicles with a three-foot separation and also can have a dedicated lane as part of the right of way. Bike lanes and street parking tend to lower the speed limit by reducing street capacity as well as providing separation between traffic and pedestrians. In addition, street segments were distinguished between those with or without medians. The medians can be 1) reserved lanes serving as two-way left-turn lanes or 2) raised medians with inset trees, which can serve as refuge islands that allow pedestrians to cross one direction of traffic at a time.

The posted speed limit and the number of lanes on a segment were catalogued. The speed limits for residential streets were assumed to be 25 mph whether posted or not.[49] The direction of traffic movement was coded as one-way and two-way. Though both one- and two-way streets had merits, pedestrians’ exposure to traffic on two-way streets was higher compared to one-way streets. Higher speeds are considered unfavorable for pedestrian activity. Regarding safety features, segments with street lighting were coded as “1” and those without were coded as “0.”

Aesthetics and Amenities

Aesthetics and Amenities include attractiveness of the streetscape, which engenders diverse and articulate viewpoints that tend to be rather subjective. Segments evaluated for Aesthetics and Amenities were catalogued by coding “1” for segments having the indicated amenities and “0” if none were present. In addition, the segments were coded “1” if there was evidence of indicated physical and social disorders and “0” if none were present. Segments considered to have 25% to 75% of the street shaded either by trees or building abutments were coded as “1,” those with 75% or more being shaded were coded as “2,” and those with less than 25% shaded were coded as “0.” The sidewalk condition was graded between “1,” “2,” and “3,” representing poor, fair, and good sidewalk conditions, respectively.

Data Compilation and Reduction and Score Development

The collected data was summarized by estimating the proportions within each neighborhood for each feature. Multiple aggregation and weighting was performed on the data in a framework developed for this study. The weights had positive or negative valences depending on the influence of the item to pedestrian walkability. The resulting score for each category of walkability was obtained as a weighted sum of the individual elements of the category as expressed by:

$$D_i = \Sigma W_{ij} X_{ij} \tag{3-1}$$

where:

W_{ij} is a subjectively assigned weight that controls the influence of element *j* of category *i*

X_{ij} is the value of element *j* of walkability category *i*

The units for the values of *Xij* mostly were in terms of number per mile. For example, such factors as traffic signals and mid-block pedestrian crossings were measured by the number per mile. Others, such as speed limits and traffic volumes, were measured as weighted averages over all the street segments. These various measures and units made it more challenging when integrating the measure to obtain a single score for a category. Hence, weights were assigned to bring the values of the different elements to comparable values that could be integrated to determine a single category score.

Tables 4 and 5 provide illustrations of the data collection and procedure used to develop category scores for the three segments in a neighborhood. The upper and lower thresholds for the scales were developed from the best-case and worst-case scenarios against which a category score was evaluated. The best case was obtained when a neighborhood had all the category features that promote excellent conditions for walking. The worst case was when elements that detract from walking were prevalent in a category.

Table 3. Compilation and Score Development for the Safety Category

		Segment name					
Category	**Item**	**Seg 1**	**Seg 2**	**Seg 3**	**Proportion**	**Weights**	**Score**
	Segment length (miles)	0.48	0.39	0.43	1.3		
	Total segments				3		
	Number of traffic controls						
Safety	Traffic signals	3	2	2	5.4	2	
	Dedicated turning arrows (protected lefts)	6	4	4	10.8	1	
	Exclusive right turns		1		0.8	-1	
	Exclusive right turns (channelized lanes added)	0	1	1	1.5	-1	
	Pedestrian signals/crosswalks	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 signs	1			0.8	0.25	
	4-Way stop signs		2		1.5	0.25	
	Traffic circles				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	1		1	0.7	1.5	
	School zones	1			0.3	1.5	

Category	Item	Segment name Seg 1	Seg 2	Seg 3	Proportion	Weights	Score
	Bike lanes, share the road signs			1	0.3	1.5	
	Emergency zones				0	1.5	
	Traffic sub-score					**0.4**	**48.3**
	Buffers (present =1, absent=0)						
	Trees	1		1	0.67	2	
	Fences (temporary/flexible)				0	1	
	Hedges				0	1	
	Landscape (desert)	1		1	0.67	2	
	Grass				0	1	
	Buffer sub-score					**0.25**	**2.67**
	Other safety elements						
	Average number of lanes	1	5	2	2.67	-1.5	
	Traffic direction (1-way street = 1, 2-way street = 2)	2	2	2	1	-1.5	
	Speed limit	25	35	25	0.33	-2.00	
	Street parking	1	1	1	1	2	
	Lighting	1	1	1	1	2	
	Other safety sub-score					**0.35**	**-2.17**
	Overall Safety Subscore						**19.20**

Table 4. Compilation and Score Development for the Categories of Land-Use, Continuity, Directness, and Aesthetics and Amenities

Category	Item	Segment name Seg 1	Seg 2	Seg 3	Proportion	Weights	Score
	Segment length (miles)	0.48	0.39	0.43	1.3		
	Total segments				3		
Land uses	Number of land uses in the neighborhood			10	1.00	1	
	Land use sub-score					1	**1.00**
Directness	Gated , walled communities (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 subscore						**0.27**
Continuity	Intersection density per mile (GIS derived)				57.34	0.05	
	Number of obstructions						
	Temporary signs				0	-0.05	
	Permanent signs		3	1	1.33	-0.8	
	Trees				0	-0.05	
	Utility poles/hydrants		3	3	2.00	-0.5	
	Magazine racks/cabinets				0	-0.05	
	Transit shelters/benches				0	-0.5	

Category	Item	Segment name Seg 1	Seg 2	Seg 3	Proportion	Weights	Score
	Parked cars				0	-0.05	
	Sidewalk (present=1, absent=0)	1	1	1	1.00	2.5	
	Average sidewalk width (≤ 5ft =1, > 5 ft =2)	1	2	2	1.67	1	
	Sidewalk breaks e.g incomplete sidewalks (present=1, absent=0)	0	1	0	0.33	-3.5	
	Number of driveways	7	48	12	51.54	-0.09	
	Deadend sidewalks (present=1, absent=0)				0	-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 fountains				0	1	
	Bicycle racks				0	1	
	Street vendors/vending machines				0	1	
	Covered transit shelters	1			0.33	2	
	Transit timetables	1			0.33	2	
	Prop. of street having overhead shade (<.25, .26 -.75, >.75 = 0,1,2)	1	2		0.67	2	
	Amenities sub-score					**0.3**	**5.33**
	Cleanliness/presence of physical disorders (present=1, absent=0)						
	Abandoned cars				0	-1	
	Buildings with broken/boarded windows				0	-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/ empty lots/bldgs				0	-3	
	Graffiti		1	1	0.67	-3	
	Physical disorder sub-score					**0.3**	**-5.67**
	Sidewalk condition/mainenance (poor, fair, good= 1,2,3)	2	2	3	5.38	2.35	
	Other amenities/aethetics sub-score					**0.4**	**12.7**
	Overall amenities/aesthetics sub-score						**4.96**

Audit category scores and scales were standardized to values between “0” and “1.” Audit quality grades were assigned in a similar manner to the resident survey scores. However, since the units of measurements were different, the thresholds were different, and were determined subjectively by the research team (see Table 6).

Table 5. Quality-Grade Thresholds for Neighborhood Audit Scores

Grade		Land-Use	Directness	Continuity	Amenities	Safety
A	≥	0.95	0.62	0.85	0.70	0.75
B	≥	0.75	0.35	0.80	0.60	0.50
C	≥	0.25	0.20	0.65	0.55	0.33
D	≥	0.00	0.00	0.00	0.00	0.00

PEDESTRIAN CRASH ANALYSIS METHODOLOGY

Introduction

One of the objectives of this study was to determine a pedestrian crash index for each neighborhood based on pedestrian crash experience in each neighborhood. The methodology followed is outlined in Figure 6. A crash index was developed in the same neighborhoods as were selected for the survey/audit, using five-year pedestrian crash data from the Nevada Department of Transportation (NDOT).

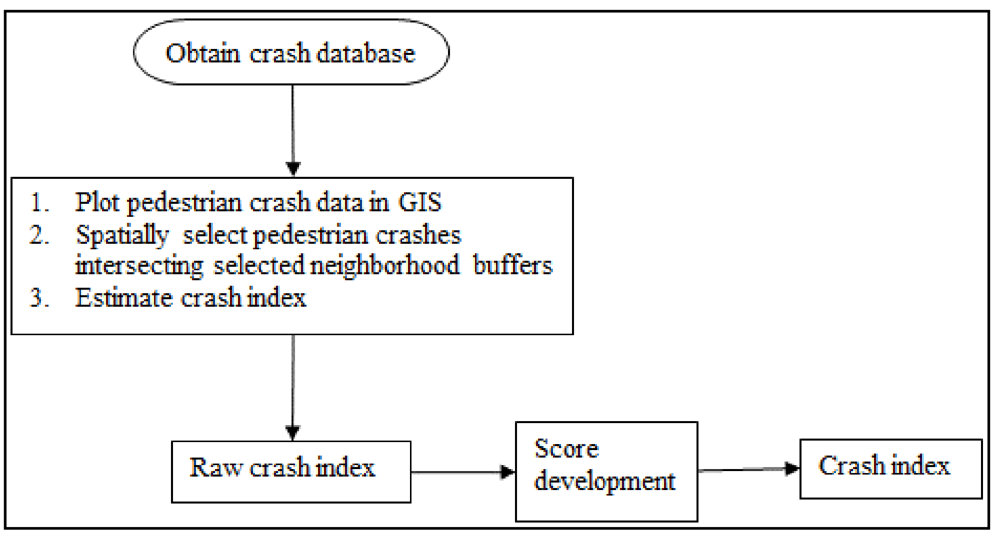

Figure 6. Pedestrian Safety Analysis Methodology

Sampling and Crash Data Collection

For audit purposes, 0.75-mile buffers used for audit purposes were the same ones used for pedestrian safety analysis. Figure 7 shows the crashes within neighborhood buffers that were used for the analysis. Pedestrian crash data over a five-year period (2007-2012) was obtained from NDOT. The crashes were overlaid onto the Las Vegas arterial network (street centerline database) in GIS (Figure 7). Crashes falling within and intersecting the study neighborhood buffers were spatially selected.

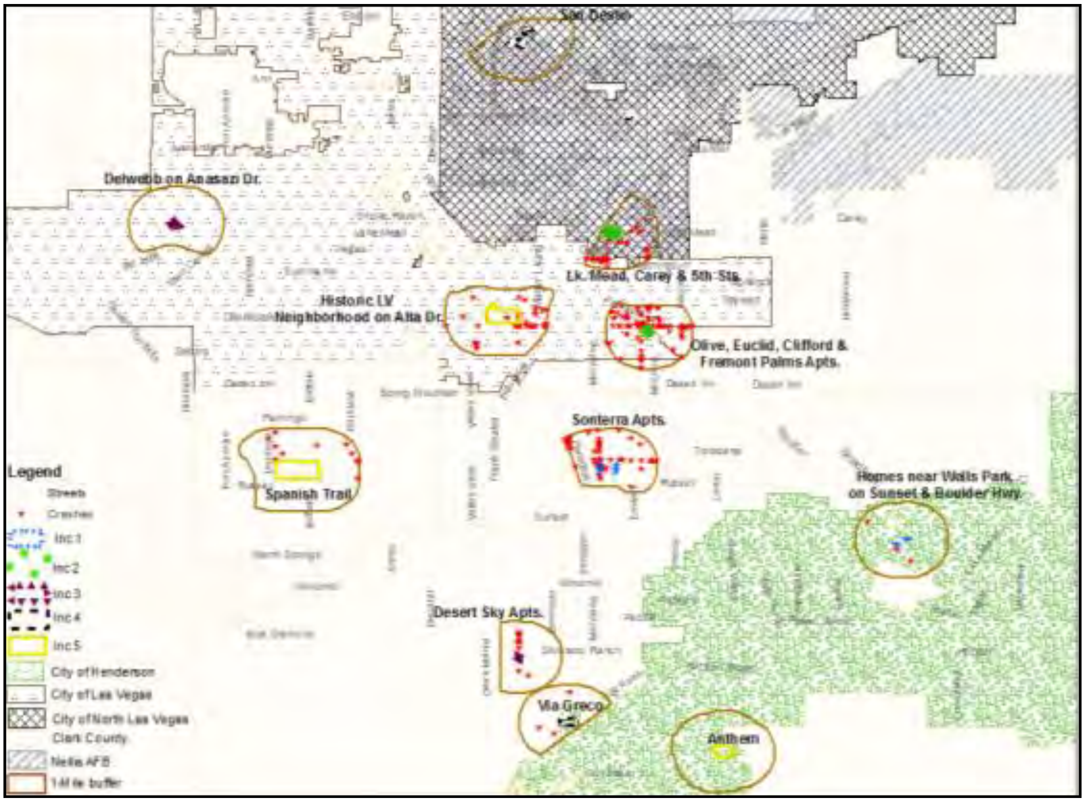

Figure 7. Crashes within the Buffers of Selected Neighborhoods

Ideally, to calculate pedestrian crash rates, pedestrian volumes should be used to obtain the crash rates in terms of the number of crashes per pedestrian. In this study, however, pedestrian volumes were not readily available, and the project did not have funds and resources to collect this information. Crash rates therefore were estimated based on the residential population and commercial land-use characteristics. The assumption here is that pedestrian volumes will be related to the resident population as well as the existence of commercial land-uses that would attract walk trips. For neighborhoods with commercial land-uses, the commercial footprint area was used as a proxy for pedestrian traffic volume attracted by commercial sites. The ACS five-year population estimates from the U.S. Census Bureau TIGER/Line data and parcel data from the Clark County Assessor were used to estimate the crash index. The pedestrian crash index was estimated as a function of the total population and commercial footprint area with a modification factor *x*, expressed as:

$$\frac{CF_i}{Pop_i}(1 - x_i) + \frac{CF_i}{CA_i} * x_i \qquad \text{3-2}$$

where:

x_i is the ratio of commercial building parcel area and building footprint within buffer *i*, i.e.:

$$x_i = \frac{CA_i}{BA_i}$$

CF_i is crash frequency in buffer i (i.e., the number of pedestrian crashes)

Pop_i is the total population within buffer *i*

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

BA_i is the total area of buffer *i*

For a neighborhood with no commercial land-uses within the buffer, $x_i = 0$; in addition, the index only will be a factor of the resident population, i.e., $CI_i = CF_i/Pop_i$.

IV. WALKING CHARACTERISTICS FROM THE RESIDENTIAL SURVEY DATA

SUMMARY OF SURVEY DATA

In total, 154 survey responses were received, 145 that were mailed back and nine online responses. Out of 2027 survey packages distributed, the response rate was approximately 7.6%. Table 7 provides a summary breakdown of the survey respondents. Most of the survey participants reported that they walked frequently, either every day 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 6. Summary of the Survey Data

Category	Group	Count
Walking Frequency	Frequent	105
	Moderate	28
	Seldom	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 for each neighborhood by the five categories, namely, land-use mix, directness, continuity, amenities and aesthetics, and safety features of the walking environment. The average raw scores from surveyed residents of each neighborhood were then standardized between zero and one and assigned quality indices.

ANALYSIS OF WALKING CHARACTERISTICS

Statistical analyses were conducted from the 154 survey respondents to determine or explore the relationships between various walking characteristics and the built walking environment as perceived by the residents. Using contingency tables, also referred to as cross-tabulations, significant measures of association between walking characteristics and parameters representing the walking environment were determined based on chi-square (χ^2) statistics, Kendall's tau values, and p-values. While χ^2 and p-values indicate the existence of a significant statistical association between variables, the Kendall's tau values indicate strength and directionality of the relationship. Kendall's tau-b and c were estimated as:

$$\tau = \frac{N_C - N_D}{\frac{1}{2}N(N-1)} \qquad \text{4-1}$$

where NC and ND are the number of concordant pairs and discordant pairs respectively. Typical threshold Kendall's values are given in Table 8.

Table 7. Kendall Tau-b Cutoff Values

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

The following walking parameters were analyzed:

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

The corresponding raw contingency tables used in the analysis are all in Appendix III.

WALKING FREQUENCY

The Table 8 summarizes features of the walking environment that were found to have statistically significant associations with the walking frequency, as indicated by the corresponding χ^2 and Kendall's tau (τ) values as well as the p-values. Three parameters – namely, the existence of large parking lots at the retail facilities, recreational facilities in the neighborhood, and the presence of other pedestrians in the walking environment – were found to have an influence on walking frequency (Table 8).

Table 8. Association Measures for Walking Frequency

		Chi-Square (χ^2)			Kendall's Tau (τ)		
Category	**Walking Environment Features**	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

The results show that there is a negative association (negative Kendall's tau value) – even though it is weak, based on the value of Kendall's tau – between the walking frequency and the perceived existence of large parking lots at retail stores. In other words, people who walked less frequently also tended to report the existence of large parking lots. Therefore, one may infer that the existence of large parking lots discourages walking. On the other hand, recreation facilities show a positive association, although weak, with walking frequency. Frequent walkers in the study appear more likely to acknowledge the existence of recreational facilities than do less frequent walkers or non-walkers; this implies that the existence of recreational facilities encourages or generates walking trips. Last, the presence of other pedestrians in the walking environment has a positive association with walking frequency, implying that busy pedestrian corridors tend to attract more walkers.

One may conclude that corridors that have high pedestrian activity should be maintained in order to attract more walkers. Similar findings were reported by Shriver, who observed higher ratings for segments with pedestrian activities that enhance street livability.[50] In addition, Ewing reported that the presence of other pedestrians was reported to enhance a sense of safety and community.[51]

WALKING TO ACCESS TRANSIT

Walking to access transit was found to have a statistically significant association with several features in the categories of safety, directness, land-use mix, and Aesthetics and Amenities (Table 9). The following is a discussion of each individual feature and the nature and strength of association with walking to access transit.

Table 9. Association Measures for Walking to Access Transit

		Chi-Square (χ^2)			Kendall's Tau-b (τ)		
Category	**Measure**	**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
	Mid-block 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 and 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

Safety Features that Influence Walking to Access Transit

The safety features that appear to influence walking to access transit include high posted speed limits, high traffic volumes, and the presence of crossing aids and mid-block crosswalks. There is a negative association between walking to access transit and high posted speed limits as well as to high traffic volumes. As would be expected, this implies that these two features (i.e., high posted speeds and high traffic volumes) tend to discourage those walking to access transit. On the other hand, the existence of crossing aids and mid-block crosswalks appear to have a positive association with walking to access transit.

Directness Features that Influence Walking to Access Transit

In the directness category, cul-de-sacs showed a weak negative association with walking to access transit. This implies a reduced likelihood of walking to access transit when cul-de-sacs are present. This does make sense, since cul-de-sacs inhibit directness and the continuity of routes. A similar finding was reported by Allan.[52]

Aesthetics and Amenities Features that Influence Walking to Access Transit

There was a significant but weak negative association between resident perceptions of the presence of trees and attractive landscaping with walking to access transit. This result was unexpected by the authors, who expected to see a positive association with these parameters, implying that the existence of trees for shade and pleasing landscaping would encourage walking. An alternative interpretation could be that transit riders are the ones who notice the lack of trees and pleasing landscaping in their neighborhoods.

Land-Use Mix Associated with Walking to Access Transit

Land-uses that had an influence on walking frequency included retail stores, grocery stores, post office, and restaurants (Table 10). More transit users than other pedestrians reported walking to such services as retail stores, grocery stores, post office, and restaurants within walking distance of their residences. For respondents who used transit, more access to services would positively affect walking to access transit.

WALKING TO SPECIFIC PLACES

Walking to specific places included trips for utilitarian purposes, such as going to work, going to the grocery store, or going to a restaurant. This walking characteristic was influenced by various walking environment features under the categories of safety, directness, continuity, aesthetic and amenities, and land-use mix (Table 10).

Similar trends were observed as before, except for on-street parking. Existence of on-street parking appears to have a negative effect on walking. A possible explanation for this is that on-street parked vehicles make crossing a street more difficult or less safe. However, a counter-argument is that on-street parking provides an extra layer of buffer between moving street traffic and sidewalks, making it safer to walk. Indeed, in other categories, associations between on-street parking and walking were observed to be positive.

Table 10. Association Measures for Walking to Specific Places

		Chi Sq (χ^2)			Kendall's Tau-b (τ)		
Category	**Measure**	**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 exceeding speed limits	8.30	4	0.08	-0.20	0.09	0.02
	On-street parking	7.71	4	0.10	-0.20	0.09	0.02
	Availability of crosswalks and 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 and 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
	Banks	14.11	4	0.01	0.30	0.08	0.00

Walking for Exercise

Contrary to what was previously observed, on-street parking had a positive association with walking for exercise, although the association was not very statistically significant, having a p-value of 0.09 which is slightly higher than the typical threshold of 0.05 for statistical significance (Table 11). As discussed earlier, this could imply that those who walk for exercise see on-street parking as an additional buffer between pedestrians and traffic as well as calming down traffic due to narrow lanes. Hence, on-street parking is perceived to provide a safer walking environment.

Attractive landscaping, a feature of Aesthetics and Amenities, has a positive association with walking for exercise; this is different from what was observed in the previous section. The positive association implies that neighborhoods with attractive Aesthetics and Amenities are bound to attract recreational walking. Moreover, the provision of trash cans for discarding trash instead of carrying it around or trashing the sidewalks and paths offers an additional convenience 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.

As expected, the presence of recreational facilities and other pedestrians in the walking environment had a positive association with walking for exercise.

Table 11. Association Measures for Walking for Exercise

		Chi Sq χ^2			Kendall's Tau-b (τ)		
Category	**Measure**	χ^2	**df**	**p-value**	(τ)	**Std. Error**	**p-value**
Safety	On-street parking	8.15	4	0.09	0.17	0.08	0.04
Aesthetics and Amenities	Presence of trash cans	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	Recreation facilities (indoors/outdoors)	13.33	4	0.01	0.25	0.08	0.01
	Grocery stores	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

SUMMARY

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

V. ANALYSIS OF NEIGHBORHOOD WALKABILITY FEATURES

This chapter presents and compares walkability scores from the residential surveys. Survey responses were assigned indices and aggregated for each neighborhood according to five categories of the walking environment: land-use mix, directness, continuity, amenities and aesthetics, and safety features. The average raw scores from residents surveyed in each neighborhood were standardized between “0” and “1” and assigned quality indices.

NEIGHBORHOOD SUMMARIES FROM RESIDENTIAL SURVEYS

Table 13 presents a summary of the category scores for each neighborhood, based on the responses from residential surveys. Both the raw and standardized scores and their corresponding grades are presented for each category for each neighborhood. It can be seen that most of the scores fell in the “B” and “C” grades. A more detailed discussion of the implications of these scores or grades appears in the following sections along with the audits results.

Table 12. Raw and Standardized Survey Data

	Land-Use			Directness			Continuity			Amenities			Safety		
	Raw score	Stand. Score	Quality grade	Raw score	Stand. Score	Quality grade	Raw score	Stand. Score	Quality grade	Raw score	Stand. Score	Quality grade	Raw score	Stand. Score	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	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
Del Webb	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
Desert Sky	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
Via Greco	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
Spanish Trail	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

Note: Stand. score – Standardized score.

RESULTS OF NEIGHBORHOOD AUDITS

Introduction

Neighborhood audits were conducted on 497 segments in the 11 neighborhoods studied. This section summarizes the audit scores for each category for each surveyed neighborhood.

As discussed earlier, when aggregate category scores were computed, weights were applied to the raw audit scores for each measured element in order to make the data values more comparable numerically so that they could reflect their appropriate levels of influence on the overall category score. This was a subjective process that was achieved after several iterations of trial-and-error based on intuitive expectations of the effects of each measure, using the experience of the research team members. Although different researchers would arrive at different weights and therefore different results, the expectation is that the general trends of the effects can be replicated. Note that the factors could either be positive or negative, depending on whether they affected walkability negatively or positively.

Land-Use Mix

Table 14 summarizes land-use scores for each of the neighborhoods studied. The table shows that neighborhoods in Income Groups 1 and 2 had a more varied land-use mix compared to higher-income neighborhoods. Neighborhoods with the least number of land-uses were DelWebb and Via Greco, which were predominantly residential. The 5th & Carey neighborhood had an ideal mix of land-uses, which had a higher likelihood of attracting walking trips. The Historic Alta neighborhood had the highest number transit stops, while DelWebb, Via Greco, and Anthem neighborhoods had none.

Table 13. Audit Land-Uses

	Neighborhood										
Audit land-use	**5th/Carey**	**Euclid**	**Sonterra**	**Sunset/Boulder**	**Del Webb**	**Desert Sky**	**San Destin**	**Via Greco**	**Anthem**	**Historic Alta**	**Spanish Trail**
Income group	1	1	2	2	3	3	4	4	5	5	5
Number of transit stops	9	16	13	10	0	6	2	0	0	25	9
Land use sub-score	1.00	0.82	0.91	0.73	0.27	0.64	0.64	0.27	0.64	0.82	0.91

Directness

A summary of audited directness features is presented in Table 15. The proportion of gated communities along a segment represented circuitous routes that pedestrians had to use to get to their destinations. Sidewalk gradients represented the ease of getting from origin to destination. The lower the value, the gentler was the sidewalk. The average FAR was used to express walking impedance due to the presence of large parking lots in front commercial premises. A larger ratio represented shorter distances or smaller parking lots in front of the commercial premises.

The DelWebb neighborhood ranked lowest in terms of directness, given that it was a gated community and also was in a neighborhood that had many other gated communities, as indicated by the proportion of segments with gated communities in the neighborhood. This neighborhood was in a hilly area with relatively steep sidewalk gradients. In addition, it had a relatively low FAR score for its neighborhood commercial land-uses, which had negative effect on walkability.

Table 14. Audit Directness Features

	Neighborhood											
Audit directness	**5th/Carey**	**Euclid**	**Sonterra**	**Sunset/Boulder**	**Del Webb**	**Desert Sky**	**San Destin**	**Via Greco**	**Anthem**	**Historic Alta**	**Spanish Trail**	**Weights**
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	-0.03
Gated neighborhood (yes=1, no=0)	0	0	1	0	1	1	1	1	1	0	1	-0.13
Average sidewalk gradients (flat=0, slight hill=1, steep hill=2)	0.10	0.19	0.28	0.02	1.29	0.21	0.45	0.24	0.90	0.13	0.19	-0.03
Average floor area ratio (FAR)	0.13	0.17	0.20	0.06	0.01	0.11	0.07	0.03	0.07	0.22	0.20	2.24
Overall directness subscore	0.43	0.54	0.46	0.29	0.01	0.25	0.15	0.08	0.15	0.64	0.46	

The Via Greco neighborhood had similar circumstances, except that it had one ingress and egress point. The 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, and Alta had the highest FAR.

Continuity

Intersection density had the highest values in the continuity category, between 36 and 145 intersections per mile; this included intersections with and without signals that mainly were in a grid-like pattern. A high intersection density represented higher route continuity. However, as Table 16 shows, there were segments that had broken and incomplete sidewalks as well as dead ends. For example, the Alta neighborhood, which had the highest intersection density, also had a high proportion of segments with incomplete sidewalks.

The most prevalent obstructions per mile were street infrastructures, such as utility poles and hydrants, permanent signs, and driveways. The Euclid neighborhood had the highest number of driveways, at 62.52 driveways per segment mile. This neighborhood largely consists of homes that have been converted to offices, hence the high density of driveways. In addition, it had a large number of street furnishings which were obstructing the sidewalks. The average sidewalk width on most segments that had sidewalks was at least five feet, which is compliant with Clark County standards.

Table 15. Audit Continuity Features

Audit continuity	Neighborhood											
	5th/Carey	**Euclid**	**Sonterra**	**Sunset/Boulder**	**Del Webb**	**Desert Sky**	**San Destin**	**Via Greco**	**Anthem**	**Historic Alta**	**Spanish Trail**	**Weights**
Income group	1	1	2	2	3	3	4	4	5	5	5	
Intersection density (in GIS) per sq mile	57.3	61.7	94.1	44.5	102.3	44.5	104.3	77.3	36.1	145.4	120.5	
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	-0.05
Permanent signs	0.01	0.02	0.06	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	-0.80
Tree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	-0.05
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	-0.50
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	-0.05
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	-0.50
Parked cars	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.05
Driveways	38.82	62.52	36.32	29.47	32.52	14.12	10.46	8.45	16.36	52.52	11.15	-0.09
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	2.50
Proportion of segments with sidewalk breaks e.g dirt-paths, incomplete sidewalksetc	0.16	0.19	0.25	0.77	0.38	0.45	0.18	0.76	0.57	0.41	0.59	-3.50
Average sidewalk width (<5'=1, >5'=2)	1.92	1.73	2.00	1.77	2.00	1.76	1.94	1.54	1.62	1.73	1.96	1.00
Proportion of segments with deadend sidewalks	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.13	0.04	-2.25
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**	

Aesthetics and Amenities

More pedestrian activity can be found where the physical environment meets the comfort and convenience of the user. From Table 17 below, the neighborhood with the highest average score for Aesthetics and Amenities was Anthem, while Euclid scored the lowest. The Anthem and DelWebb neighborhoods predominantly had well-maintained sidewalks. In addition, trash cans and resting spots that were found mainly at transit stops in most neighborhoods were scattered along sidewalks in the Anthem and DelWebb neighborhoods, whether transit stops were available or not. Most of the segments audited in the DelWebb neighborhood had trees that provided shade along the sidewalks. Conversely, even though the Euclid neighborhood had shading on most of the sidewalks, most of the audited segments exhibited physical and social disorders, such as trash, graffiti, and unmaintained lots and buildings. Previous studies reported that some of the features that influence walking and cycling are low pollution levels, presence of trees, sidewalk maintenance, landscape attractiveness and diversity, and the presence of recreational facilities.[53]

Table 16. Summary of Audit Aesthetics and Amenity Features

Audit aethetics and amenities	5th/Carey	Euclid	Sonterra	Sunset/Boulder	Del Webb	Desert Sky	San Destin	Via Greco	Anthem	Historic Alta	Spanish Trail	Weights
	Neighborhood											
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	0.90
Benches	0.12	0.21	0.13	0.07	0.02	0.00	0.00	0.11	0.05	0.18	0.00	0.30
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	0.30
Bicycle racks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
Street 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	0.30
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	0.60
Transit timetable	0.08	0.01	0.03	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60
Shading (trees, overhead coverage)	0.29	0.75	1.00	0.05	0.74	0.15	0.73	0.04	0.38	0.79	0.20	0.60
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	-0.30
Buildings with broken/boarded windows	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.30
Broken glass	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.30
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	-0.90
Litter	0.57	0.63	0.70	0.27	0.00	0.12	0.03	0.11	0.00	0.41	0.28	-0.90
Neighborhood watch signs	0.14	0.13	0.00	0.04	0.00	0.09	0.45	0.02	0.05	0.00	0.13	-0.30
Unmaintained compounds/ empty lots/bldgs	0.63	0.61	0.13	0.70	0.00	0.82	0.18	0.78	0.19	0.20	0.50	-0.90
Graffiti	0.35	0.27	0.23	0.16	0.00	0.06	0.06	0.04	0.00	0.11	0.06	-0.90
Average sidewalk conditions (poor, fair, good= 1,2,3)	2.29	1.67	2.20	2.32	3.00	2.61	2.88	2.15	3.00	1.93	2.93	0.94
Amenities/aesthetics sub-score	**1.41**	**1.22**	**2.28**	**1.53**	**3.27**	**1.72**	**2.93**	**1.33**	**2.96**	**2.24**	**2.27**	

Safety Features

For the Safety category, Table 18 presents a summary of raw scores for each element and the aggregate score. Higher aggregate scores indicate the existence of more safety features, hence a safer walking environment. Pedestrian signals and crosswalks were catalogued as infrastructures that facilitate safe interactions between pedestrians and vehicles. Several studies, however, reported more pedestrian crashes at marked crosswalks than due to jaywalking.[54]

Other safety elements were related to the provision of buffers between the walking facilities and other traffic. They provided separation between traffic and pedestrians on sidewalks. Buffers could be in the form of trees, landscaping between the sidewalk and the street, and such permanent barriers as fences and poles.

Table 17. Summary of Audit Safety Features

Audit safety	5th/Carey	Euclid	Sonterra	Sunset/Boulder	Del Webb	Desert Sky	San Destin	Via Greco	Anthem	Historic Alta	Spanish Trail	Weights
	Neighborhood											
Income group	1	1	2	2	3	3	4	4	5	5	5	
Traffic controls per mile												
Traffic signals	3.28	2.79	4.01	0.76	0.86	1.58	2.17	0.29	0.48	3.73	1.83	0.80
Dedicated turning arrows (protected lefts)	5.21	5.43	7.13	1.31	1.57	3.16	4.18	0.57	0.61	6.30	3.43	0.40
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	-0.40
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	-0.40
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	-0.40
Pedestrian signals	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.48
Pedestrian signs	4.98	3.46	1.43	0.49	3.07	0.75	3.22	1.72	3.03	2.57	1.29	0.48
Pedestrian crosswalks	1.64	1.06	0.34	0.11	1.07	0.17	0.32	0.57	0.36	0.73	0.35	0.48
Curb ramps	20.06	18.32	12.97	11.01	14.62	9.43	10.78	7.80	8.73	15.58	8.44	0.20
Yield, 2-Way stop signs	1.64	1.85	0.75	2.45	0.64	2.16	0.64	1.50	0.36	1.21	0.82	0.10
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	0.10
Traffic circles	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
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	0.40
Chicanes or chokers (proportion of segments)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.26	0.00	0.60
Raised medians (proportion of segments with..)	0.43	0.27	0.20	0.32	0.48	0.15	0.45	0.13	0.52	0.45	0.11	0.60
School zones (proportion of segments)	0.31	0.27	0.05	0.04	0.05	0.03	0.36	0.15	0.10	0.13	0.09	0.60
Bike lanes (proportion of segments)	0.04	0.13	0.00	0.30	0.21	0.12	0.03	0.20	0.24	0.14	0.20	0.60
Emergency zones (proportion of segments)	0.00	0.06	0.00	0.00	0.00	0.00	0.03	0.04	0.10	0.04	0.09	0.60
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	0.50
Fence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.02	0.00	0.25
Landscape(desert)	0.00	0.01	0.03	0.05	0.07	0.00	0.21	0.15	0.00	0.05	0.04	0.25

	Neighborhood											
Audit safety	**5th/Carey**	**Euclid**	**Sonterra**	**Sunset/Boulder**	**Del Webb**	**Desert Sky**	**San Destin**	**Via Greco**	**Anthem**	**Historic Alta**	**Spanish Trail**	**Weights**
Permanent hedges	0.12	0.19	0.10	0.13	0.50	0.18	0.48	0.43	0.52	0.16	0.26	0.50
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	0.25
Other safety elements												
Average number of lanes	3.92	3.57	1.73	2.88	3.40	3.18	4.52	2.96	2.24	3.79	4.50	-0.70
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	0.18
Proportion of >25mph speed limit segments	0.49	0.52	0.73	0.43	0.52	0.45	0.73	0.33	0.24	0.57	0.70	-0.70
Proportion of segments with on-street parking	0.47	0.46	0.35	0.50	0.36	0.18	0.09	0.15	0.00	0.38	0.07	0.70
Proportion of segments with street lights	0.96	0.97	1.00	0.93	1.00	0.73	1.00	0.63	1.00	0.88	1.00	0.70
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	

COMPARISON OF WALKING ENVIRONMENT FEATURES FROM THE AUDIT AND RESIDENTS' PERCEPTIONS FROM THE SURVEY

Table 19 presents a summary of the audit scores and grades for all the categories and neighborhoods. This data will be compared with the scores and grades based on resident perceptions (Table 13).

Table 18. Neighborhood Audit Scores and Grades

	Land-Use			Directness			Continuity			Amenities			Safety		
	Raw score	Stand. Score	Quality grade	Raw score	Stand. Score	Quality grade	Raw score	Stand. Score	Quality grade	Raw score	Stand. Score	Quality grade	Raw score	Stand. Score	Quality grade
5th/Carey	1.00	1.00	A	0.43	0.25	C	3.02	0.65	C	1.41	0.64	C	9.13	0.67	B
Euclid	0.82	0.82	B	0.54	0.30	B	0.73	0.54	D	1.22	0.70	C	6.70	0.54	C
Sonterra	0.91	0.91	B	0.46	0.27	C	4.92	0.75	C	2.28	0.77	B	7.14	0.56	C
Sunset/Boulder	0.73	0.73	B	0.29	0.18	C	0.69	0.53	D	1.53	0.66	C	2.25	0.29	D
Del Webb	0.27	0.27	D	0.01	0.05	D	5.35	0.77	C	3.27	0.75	B	5.52	0.47	C
Desert Sky	0.64	0.64	C	0.25	0.17	C	3.39	0.67	C	1.72	0.61	C	2.40	0.30	D
San Destin	0.64	0.64	C	0.15	0.12	C	7.98	0.90	B	2.93	0.70	C	5.04	0.45	C
Via Greco	0.27	0.27	D	0.08	0.08	D	3.96	0.70	C	1.33	0.55	D	1.18	0.23	D
Anthem	0.64	0.64	C	0.15	0.12	C	2.45	0.62	C	2.96	0.71	C	3.62	0.37	C
Historic Alta	0.82	0.82	B	0.64	0.35	B	4.55	0.73	C	2.24	0.84	B	8.61	0.65	B
Spanish Trail	0.91	0.91	B	0.46	0.27	C	7.27	0.86	B	2.27	0.77	B	2.20	0.29	D

Note: Stand. score = Standardized score.

Comparison of the Audit and Residents' Perceptions of Safety Features

Figure 8 is a plot of the grades for safety from the audit against grades given by residents in the survey. Regarding safety, there was no distinct correlation between audit observations and residents' perceptions. Further, there was little variance between observations and residents' perceptions.

In Via Greco, the audit data and residents' perceptions mainly differed with regard to the street width and the proportion of two-way streets. Audit observations indicated that the average number of lanes was 2.96; however, respondents disagreed on whether the streets were wide. The highest number of lanes was 4.57, which implies higher traffic volumes. Audit observations indicated a low traffic-signal density of 0.29/mi, which was confirmed by the residents' perception of safety with regard to the availability of crossing aids and mid-block crosswalks. Both audit observations and residents' perceptions coincided regarding a high proportion of segments that had lighting and the availability of buffer areas along the sidewalks.

In San Destin neighborhood, the audit data and resident perception mainly differed with regard to street width. This neighborhood had the highest average number of lanes (4.5). Audit observation showed a traffic signal density of 2.17, confirmed by residents who agreed that crossing aids as well as mid-block crosswalks were available. In addition to the consensus of residents' perceptions and audit observations, the availability of buffers, street parking, and raised medians served as traffic calming measures and also provided refuge islands on wide streets.

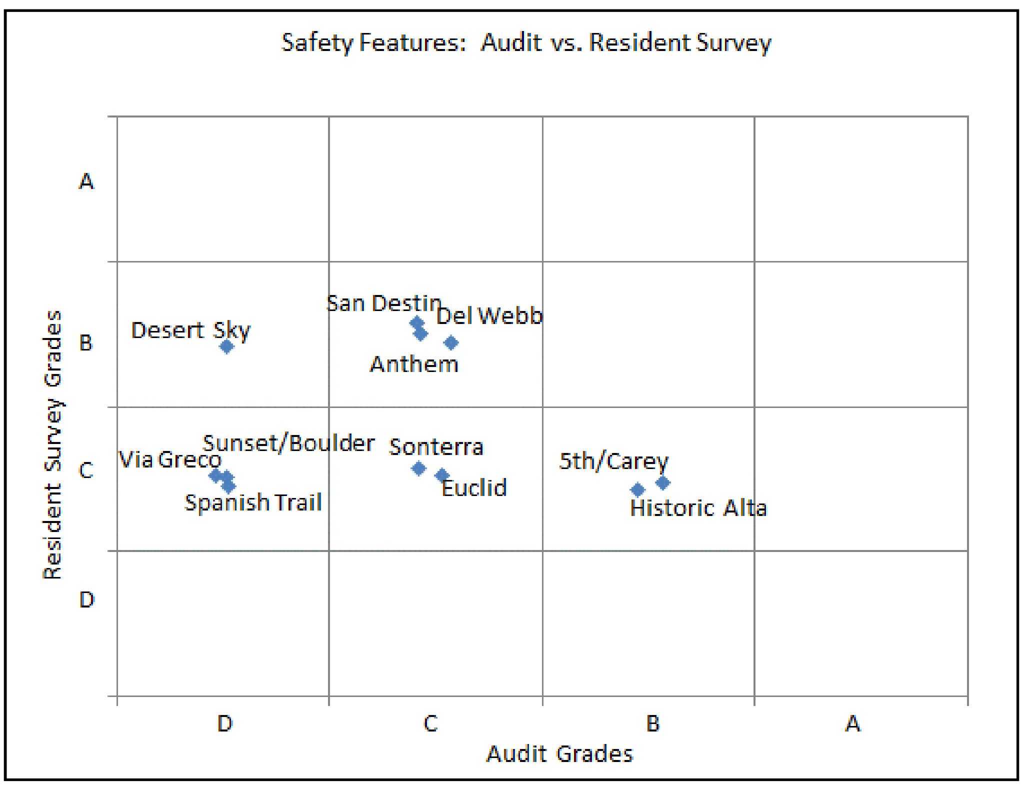

Figure 8. Comparison of the Audit vs. Residents' Perceptions Regarding Safety Features

The perceptions of residents of the 5th & Carey neighborhood slightly 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. Most residents strongly disagreed, however, regarding the availability of crossing aids and crosswalks. In addition, the respondents felt that the refuge islands were inadequate. Audit observations indicated that the proportion of segments with refuge islands was 43%. Residents' perceptions and audit observations were similar regarding the availability of street parking, street width, availability of street lighting and buffers.

Comparison of the Audit and Residents' Perceptions of Land-Use

There was no consistent trend of grades from residents regarding land-use compared to audit results for land-use mix; even so, each pair was within one letter grade, except for Desert Sky and Spanish Trail (Figure 9). In the Spanish Trail neighborhood, residents had a low perception of land-uses compared to results of the audit from the parcel data. As it was a planned gated community, such recreational facilities as gyms were located within the gates. To access retail premises on Rainbow Boulevard and Durango Drive, however, residents had to walk or drive circuitous routes for utilitarian trips.

On the other hand, in the Desert Sky neighborhood, the residents' perceptions of the land-uses were much higher than results of the audit. Some of the commercial land-uses reported in the resident responses, such as a bank, places of worship, a post office, and medical facilities were not in the Assessors' parcel data that was used in the audit survey. Similarly, in the San Destin neighborhood, residents had a high perception of land-uses within walking distance of their residence compared to results of the audit.

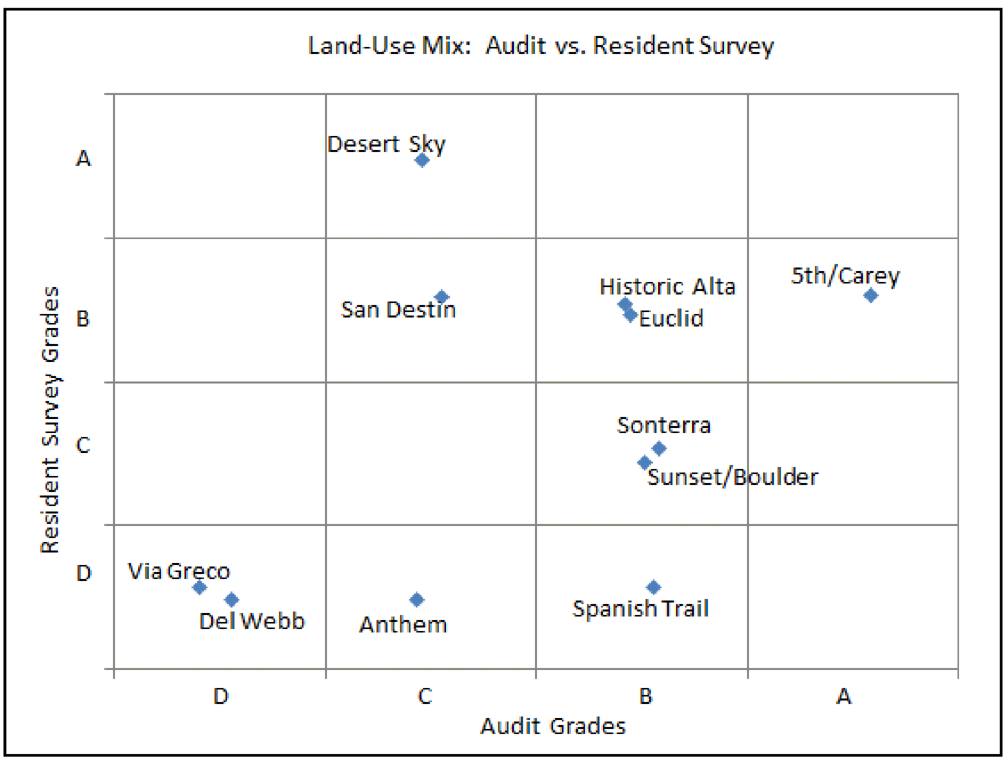

Figure 9. Comparison of the Audit vs. Residents' Perceptions Regarding Land-Use

Comparison of the Audit vs. Residents' Perceptions of Directness

Resident perceptions of directness within their neighborhoods were all within one letter grade of each other. There was no distinct pattern, as illustrated in Figure 10, nor much variance between observations. This could imply that there are other parameters not identified in the study that influence the perception of directness.

The Del Webb neighborhood is a retirement community that has hilly sidewalks and is walled; it has several egress and access points. In addition, commercial properties are few and located towards the boundary, making walking access a challenge mainly for utilitarian trips. Most respondents in Del Webb reported a lack of mid-block crosswalks to facilitate safe and quick access to the few commercial land-uses within the neighborhood. There was general consensus about the presence of sidewalks with steep gradients from both the audit observations and perceptions by residents.

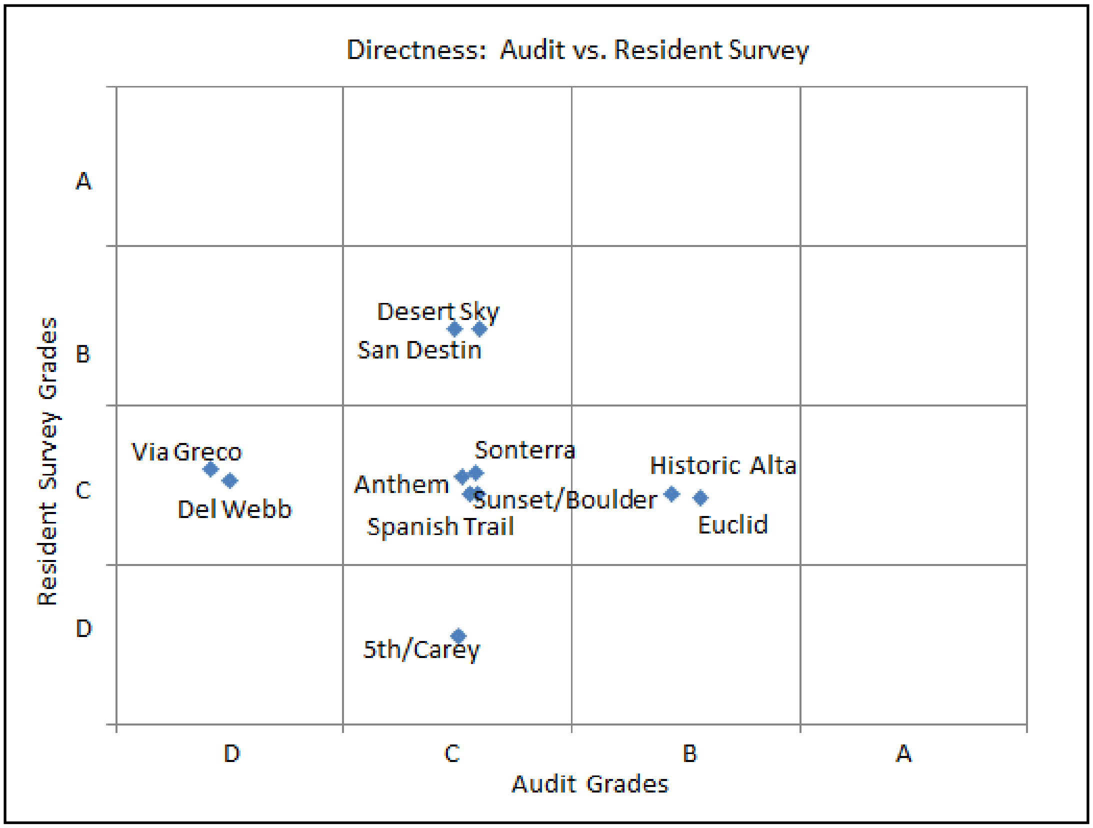

Figure 10. Comparison of the Audit vs. Residents' Perceptions Regarding Directness

The San Destin neighborhood audit showed a low grade for directness compared to the high perception of directness by residents. The neighborhood was walled, with relatively flat sidewalks, and had a small FAR value. The convenience store located right next to the neighborhood had very little parking space in front, and so presented no challenges to walkers 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 mid-block crosswalks within the neighborhood, which was confirmed during site visits.

Residents in Via Greco, a gated neighborhood with a single access/egress point, reported limited mid-block crosswalks and pedestrian signs. The FAR for this neighborhood was 0.03, implying that large parking lots were located in front of the commercial premises. Respondents did not report, however, any large parking lots that made walking to the stores difficult. The low FAR value resulted from only two commercial land-uses whose building footprints on the parcel were small, implying that large parking lots were located in front of these two buildings. Audit observations matched residents' perceptions with regard to restricted routes due to many enclosed communities as well as to the gradient of the sidewalks, which was relatively flat.

Comparison of the Audit and Residents' Perceptions of Continuity

The residents' perceptions of continuity compared reasonably well with audit observations, as shown in Figure 11. As mentioned earlier, restricted access to the Anthem neighborhood limited the accuracy of the audit with regard to the walking environment. Alta, an older neighborhood (in the Clark County jurisdiction) than the other neighborhoods, had segments that lacked standard sidewalks. Some segments had utility poles right in the middle of the sidewalks. In addition, some of the audited segments were narrower than the standard five-foot width.

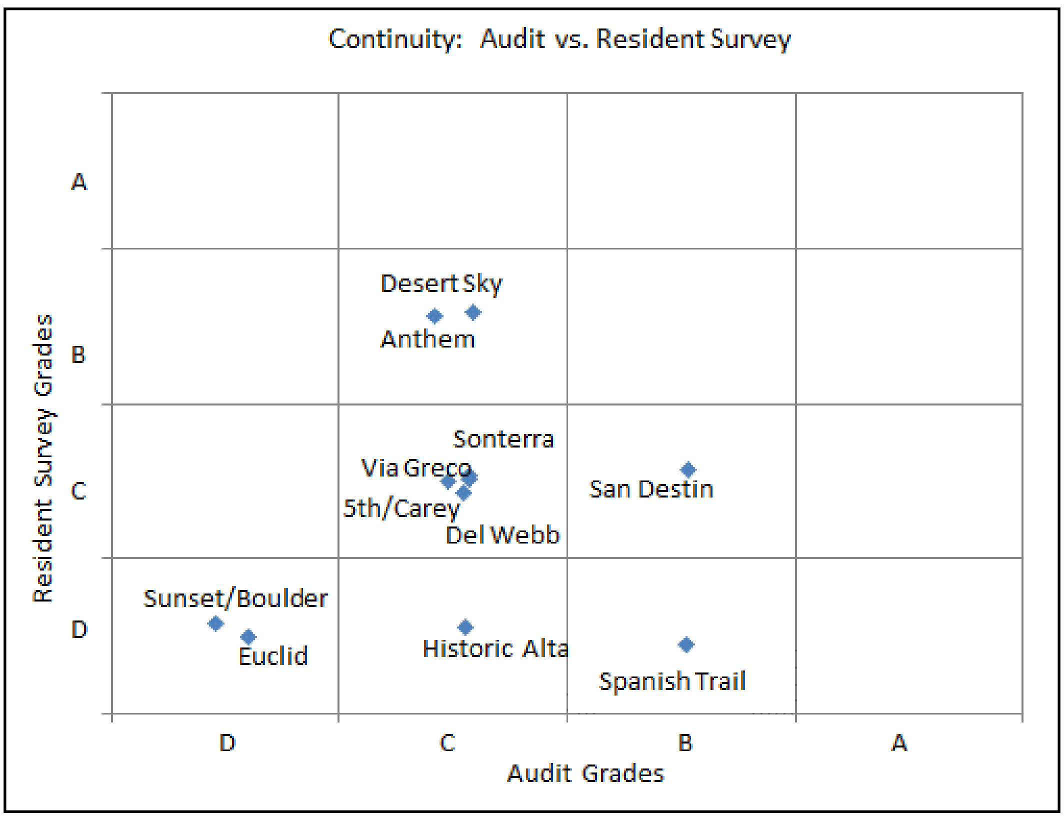

Figure 11. Comparison of Audit Continuity vs. Resident Continuity Perception

The residents' opinions differed from audit observation regarding sidewalk width and the presence of obstructions. Their perceptions coincided with incomplete sidewalks due to the presence of footpaths, cul-de-sacs, and high driveway densities that inhibited the continuity of routes. The surrounding neighborhood had a grid-pattern street network, resulting in the highest intersection density in the study; this was confirmed by residents' perceptions.

In the Spanish Trail neighborhood, the main difference between audit observations and respondents' perceptions was in regard to the distance between intersections. Spanish Trail is a gated master-planned community. Therefore, even though it had the second highest intersection density (approximately 121 intersections/mile), the residents were subjected to circuitous routes to access the numerous intersections. Both audit observations and residents' perceptions in this neighborhood confirmed the presence of footpaths that inhibited the continuity of trips. Conversely, there were wide sidewalks, low driveway density, a small proportion of dead-end streets, and few obstructions on pedestrian paths; this was confirmed by residents' perceptions regarding continuity.

Comparison of the Audit and Residents' Perceptions of Aesthetics and Amenities

From Figure 12, there was little variation between audit observations and residents' perceptions, implying generally similar conditions. Out of the 11 neighborhoods, four had differing perceptions regarding the visual interest and amenities of the neighborhood, compared to audit observations. Most walking environments had a quality grade of B and C with regard to amenities and aesthetics.

In Sonterra neighborhood, the perception regarding Aesthetics and Amenities differed from audit observations mainly about landscaping. Some of the audited segments had empty lots, which are unsightly, and had empty buildings with graffiti. Within the enclosed community, the neighborhood generally was appealing compared to the surrounding area, which was primarily commercial. Similarly to the historic Alta neighborhood, randomly selected neighborhoods were considered to be appealing; however, as a whole, there were segments with empty lots that had trash, segments with litter, and unshaded areas.

In the Via Greco neighborhood, audit observations and residents' perceptions differed with regard to 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, even though the audit showed that at least 50% of the audited segments had unmaintained or empty lots. Most of the segments were under construction or had unmaintained lots. Audit observations and residents' perceptions concurred on the availability of transit stops, which had benches and therefore provided rest spots as well as trash cans. The respondents confirmed that the sidewalks and rest stops were clean and well maintained.

Similarly, in Desert Sky neighborhood, respondents reported shading and landscaping; this result was the opposite of what was observed in the audit. The neighborhood had many segments with unmaintained or empty lots. Asphalt-pavement sidewalks, however, were provided on some segments that were not developed. Audit observations and residents' perceptions concurred on the availability of transit stops, which came with benches, therefore providing rest spots as well as trash cans. Residents reported clean sidewalks for the walking environment; the audit, however, showed segments that were littered (Figure 12). It is possible that areas where respondents walked were cleaner when compared to audit segments or that street cleaning and trash collection had not been done when the images were recorded.

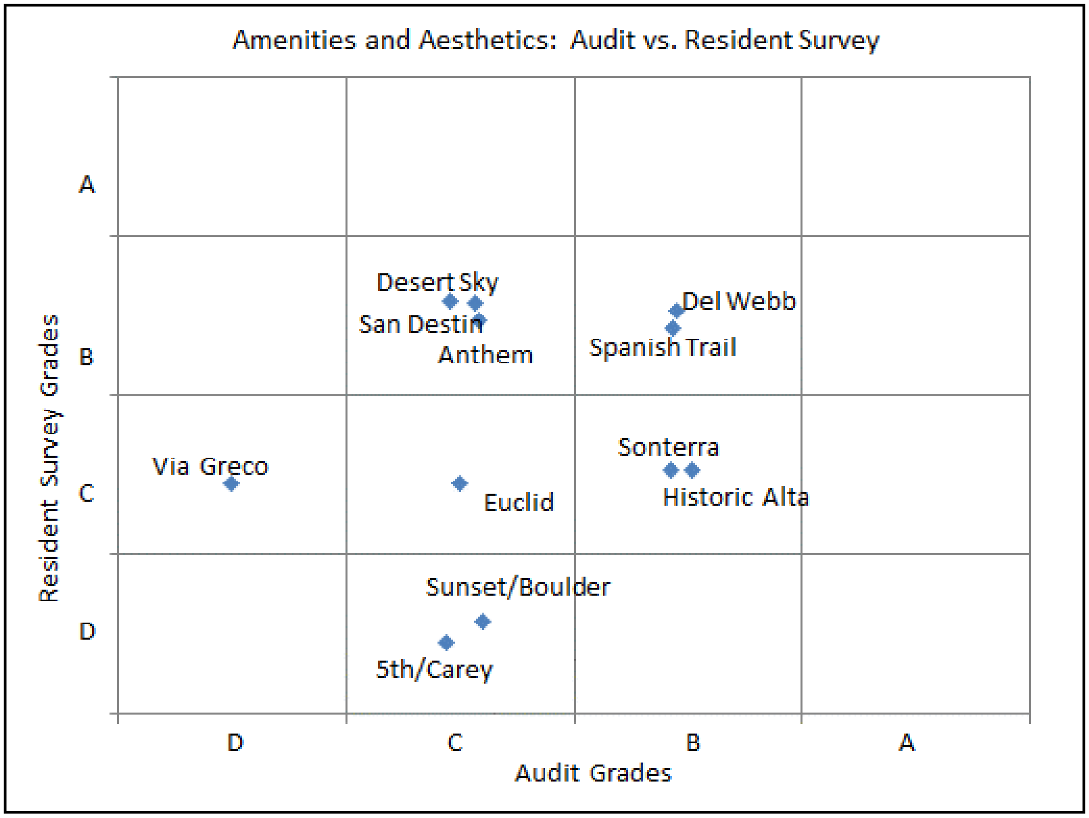

Figure 12. Comparison of the Audit and Residents' Perceptions Regarding Aesthetics and Amenities

SUMMARY

Overall, there was little variance when comparing the audit observations for safety, continuity, directness, and aesthetics and amenities and the corresponding categories for residents' perceptions from the survey. Intuitively, an increase of category features might result in an increase in variance, particularly regarding residents' perceptions. The lack of trend suggests that other factors have an influence on residents' perceptions for various categories.

There was an evident trend in the perception of land-use and an increase in land-use mix for most of the neighborhoods, which was expected. Lower-income neighborhoods in Groups 1 and 2 had a more varied land-use mix compared to higher-income neighborhoods. The audit observations tended to coincide with residents' perceptions regarding various categories in some neighborhoods. However, in every category, there were neighborhoods that differed somewhat on some features, which was expected.

Audit accuracy was limited in the Anthem neighborhood due to restricted access even for satellite imagery. The perceptions of residents in the San Destin and Via Greco neighborhoods differed in several categories. It was expected that their overall perceptions and audit indices would differ when the categories were combined.

VI. PEDESTRIAN SAFETY ANALYSIS

INTRODUCTION

This chapter presents the analysis and results of pedestrian crash data and their effects on neighborhood walkability indices. Figure 13 shows, side by side, the standardized crash scores and audit safety scores for each neighborhood. It should be noted that a high safety score indicates the presence of many pedestrian safety features in the infrastructure. Similarly, a high score based on the crash index is an indication of low crash rates, meaning less risk of pedestrian crashes.

Comparing the two safety scores in Figure 13, it is evident that in several of these neighborhoods, these two scores were contradictory. For example, three of the neighborhoods with high safety scores based on the crash indices (i.e., no crashes reported over the study period) had low audit safety scores. This meant that they did not have sufficient safety features in the infrastructure. Therefore, safety levels based on the safety infrastructure alone may not be able to provide a complete picture of the pedestrian safety issues in a neighborhood. This implies that there is a need to include crash data into the determination of the walkability index.

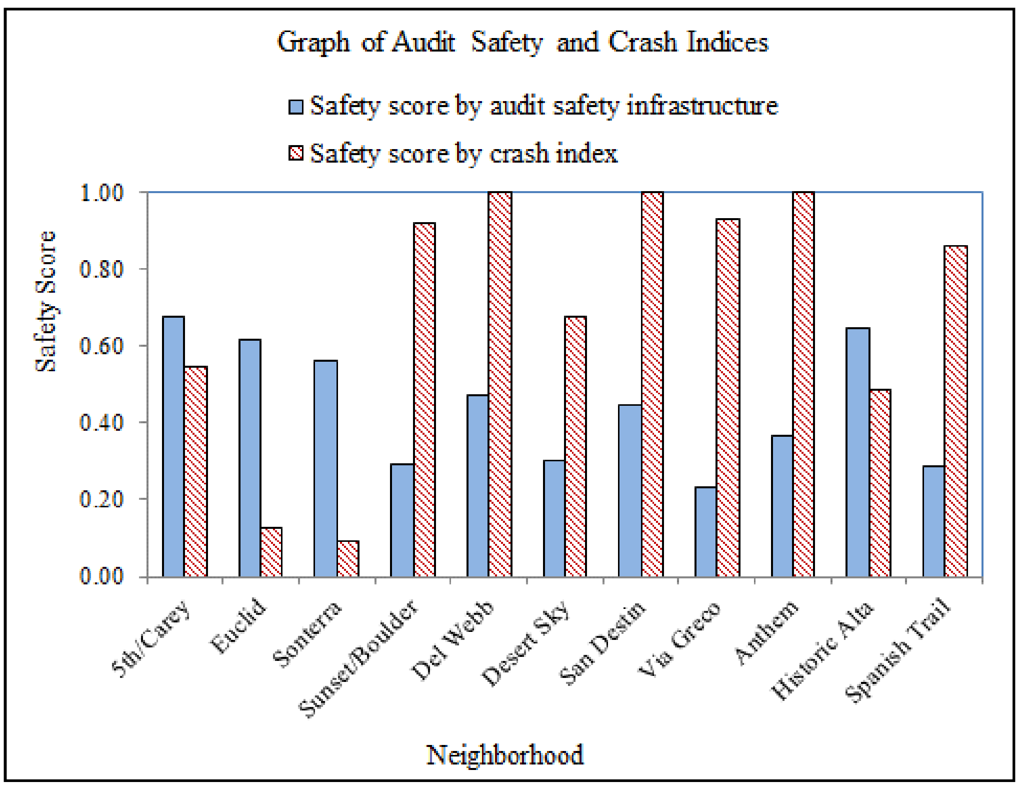

Figure 13. Audit Safety and Crash Indices

Figure 14 compares walkability indices with and without the inclusion of the crash index. For example, it was observed that in the absence of crash data, the 5th and Carey neighborhood had the highest audit walkability index, followed by Sonterra, with DelWebb ranking last. When crash data were included in the index, the DelWebb neighborhood ranked among the neighborhoods with the highest walkability index, while the 5th & Carey neighborhood dropped to fourth position. Using a paired sample, the difference between walkability indices without the crash data was significantly higher than those with crash data (p = 0.07, α = 0.1, one-tailed test).

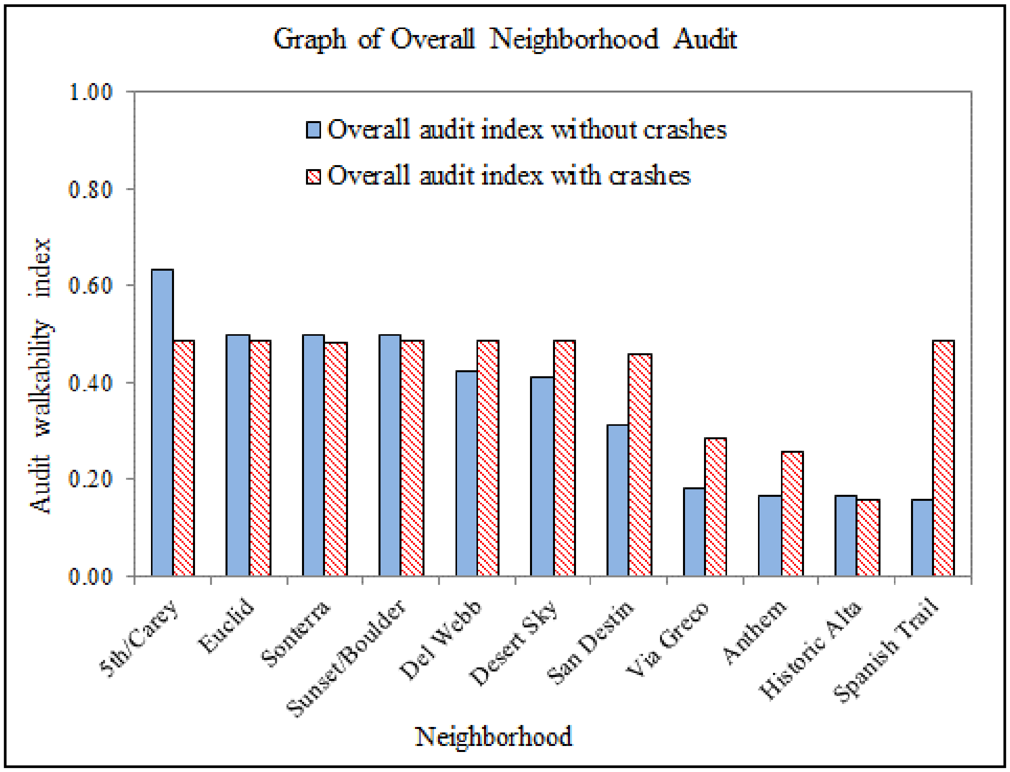

Figure 14. Comparison of Overall Audit Walkability Indices with and without Crash Data

CRASH RATE CORRELATION WITH WALKING ENVIRONMENT FEATURES

Previous studies involving crash data focused mostly on roadway geometry and its associations to crash risk.[55] For this study, the association between walking environment features in the study neighborhoods and related crash indices was estimated using Pearson's *r* correlation coefficient in Software Package for the Social Sciences (SPSS) (Version 22). Results are summarized in Table 20 and discussed as follows.

It was observed that there was a strong positive and statistically significant relationship between bus stops and crash rates. This manifested itself with several instances of vehicles hitting pedestrians at bus stops and on sidewalks in Las Vegas.[56] To separate transit users and pedestrians on sidewalks from traffic, buffers such as crash barriers can be installed as treatments to reduce crash risk.

In addition, the data appeared to show a negative correlation between the presence of two-way traffic and pedestrian crashes. This meant that there was a lower risk of pedestrian crashes on two-way streets than on one-way streets. Conflicting opinions exist on this observation. For example, Cunneen and O'Toole reported a considerable 38% decrease in accidents when two way streets were converted to one-way streets.[57] Conversely, in their review, Walker et al. reported that 30-40% more vehicle/pedestrian conflicts typically occurred on one-way networks.[58] On the other hand, Lum and Soe reasoned that crossing one-way streets presented greater challenges due to increased points of conflict for pedestrians and vehicles.[59]

Table 19. 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 mid-block crosswalks	0.279	0.41
Presence of un-signalized 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

Intersection infrastructures, such as right-turn lanes and 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.[60] Channelized right turns that 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 on pedestrians, resulting right-turn crashes.

Pedestrian signals and mid-block crosswalks have positive relationships with crash risk, although the mid-block crosswalk association are not statistically significant. Dultz et al. found that 44% of reported street injuries occurred at signalized crosswalks compared to 32% of involving jaywalkers.[61] Researchers have reasoned that when in high-perceived risk areas, pedestrians could be exercising increased caution and alertness, while at marked signalized crosswalks increased crashes could be a result of risky pedestrian and driver behavior near marked crosswalks, weak crosswalk design, or other factors.[62]

Bike-lane features and safety features have a negative relationship with the crash risk, implying that an increase in these features lowers crash risk. Un-signalized intersections typically are located at intersections with low traffic volumes. Intuitively, stop-and-go operations help reduce traffic speeds and lower crash risk; even so, this association is not statistically significant. Bike lanes reduce lane width as well as provide an additional buffer between pedestrians and vehicular traffic.

As expected, driveways that typically interrupt pedestrian trips have a positive association with crash risk by 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.

SUMMARY

Results indicated that there was no correlation between audit safety scores and crash rates, meaning that neighborhoods with high audit scores for safety did not necessarily have lower crash rates. Therefore, safety levels based on safety infrastructure alone could result in masking potential safety problems within the walking environment. Inclusion of crash data, therefore, is recommended for an improved representation of walking environment safety.

Correlation with the safety infrastructure showed a negative relationship between crash risk and such features as buffers, medians, traffic calming measures, and two-way traffic. Features that had a positive relationship with crash risk included land-use mix, FAR, the presence of transit stops, traffic signals, exclusive and channelized right turns, mid-block crosswalks, and driveways.

VII. ESTIMATION OF COMPREHENSIVE NEIGHBORHOOD WALKABILITY INDICES

INTRODUCTION

This chapter presents the development of a comprehensive walkability index for each neighborhood that integrates residents' perceptions of their walking environment with neighborhood audits of walking environment features. This task was done in stages, as shown in Figure 15. First, directness, continuity, and aesthetics and amenities were combined, using the look-up table (Table 20) to obtain estimated infrastructure grades for each neighborhood. The rules were developed based on the researchers' judgement and were designed to give more weight to directness and continuity relative to aesthetics and amenities. As an example of how to use this table, if a neighborhood has a grade "A" for directness, a "B" for continuity and a "C" for aesthetics and amenities, the overall infrastructure grade based on this table will be a "B."

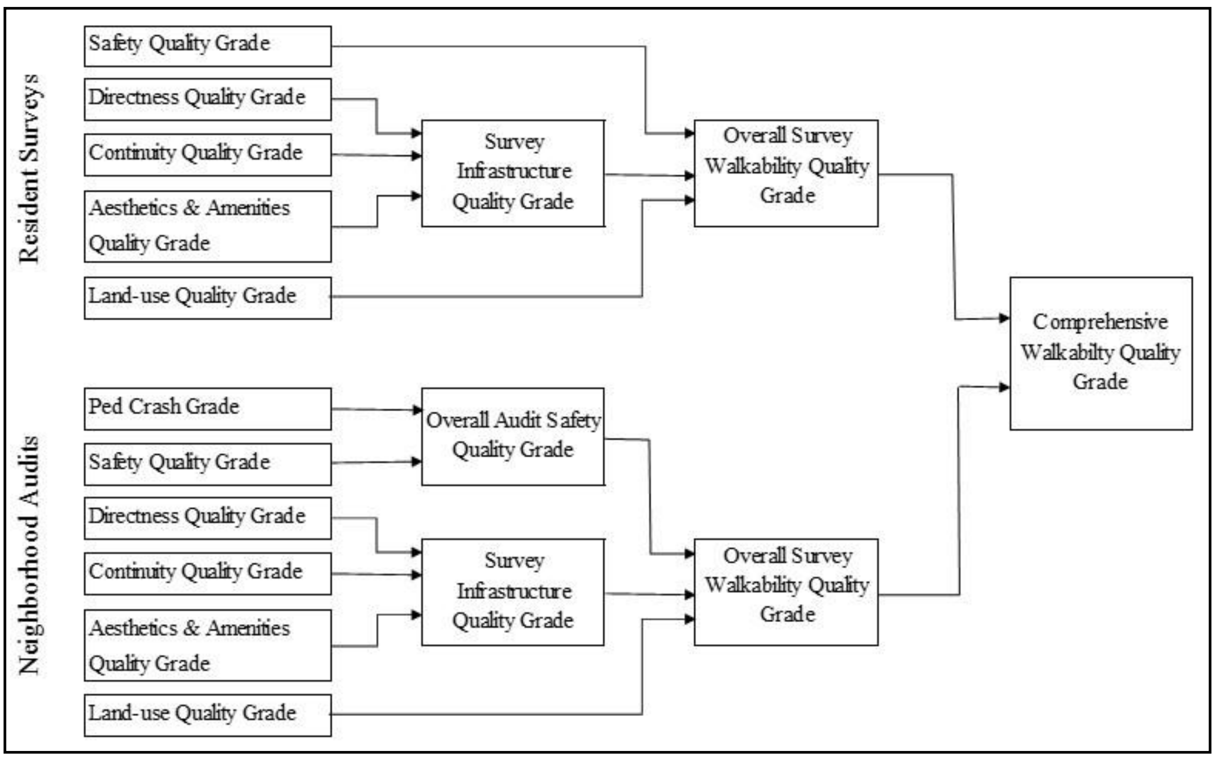

Figure 15. Calculation of Neighborhood Walkability Grades

Table 20. Rules for Assigning Infrastructure Grades

		Aesthetics and Amenities			
Directivity	**Continuity**	**A**	**B**	**C**	**D**
A	A	A	A	B	B
	B	B	B	B	B
	C	B	B	C	C
	D	C	C	C	C
B	A	B	B	B	B
	B	B	B	B	B
	C	C	C	C	C
	D	C	D	D	D
C	A	B	B	B	B
	B	B	B	C	C
	C	C	C	C	C
	D	D	D	D	D
D	A	B	B	B	B
	B	C	C	C	C
	C	C	D	D	D
	D	D	D	D	D

INFRASTRUCTURE GRADES

The infrastructure category integrated the three walkability categories: directness, continuity, and amenities and aesthetics. Infrastructure grades were assigned using the look-up table rules as summarized in Table 21. For example, if directness had an “A” grade, continuity had a “D,” and amenities and aesthetics had a “B,” then the infrastructure grade was “C.” These rules were developed subjectively; greater weighting, however, was applied to directness and continuity than for amenities and aesthetics. The resulting grades for infrastructure quality, based on audits and resident survey, are plotted in Figure 16. Generally, the grade for infrastructure was between “B” and “D” for both the audit and survey data.

Grades from resident surveys were compared with those from audits. Figure 16 shows that for six of the 11 neighborhoods surveyed, the resulting infrastructure grades were the same. For another four neighborhoods, grades were within one letter grade of each other. Only one neighborhood, Spanish Trail, had a difference of two letter grades, a “B” from the audit and a “D” from respondents of the residential survey. This meant that the residents had a much worse perception of their walking environment than what was observed from the audits. Overall, this process produced fairly comparable indices (or grades) from the two methods used to determine the infrastructure index/grade.

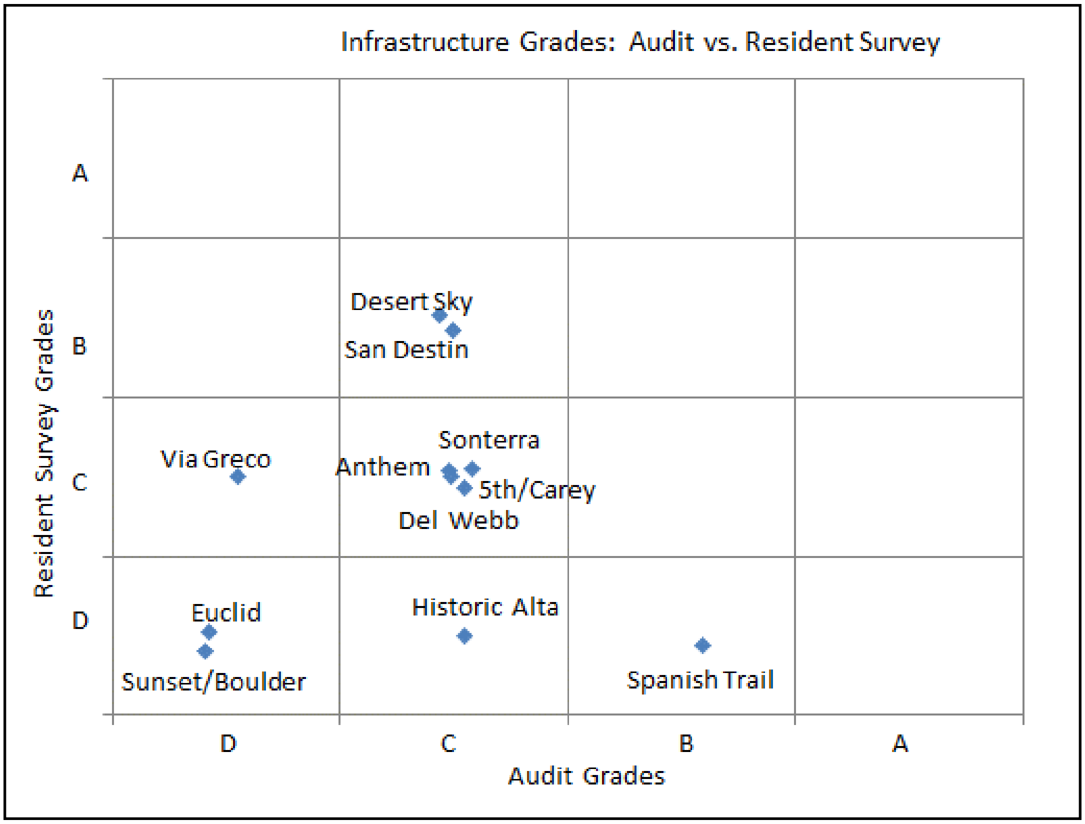

Figure 16. Comparison of Audit Results vs. Residents' Perceptions of Infrastructure

WALKABILITY INDEX

In this section, the overall walkability grade or index was estimated by combining the grades for land-use mix, infrastructure, and safety. Table 21 shows the look-up table of the rules used to obtain the overall grade from those three categories. The rules reflect an almost equal weight of importance among the three categories.

Figure 17 illustrates the overall walkability indices for various neighborhoods. Audit observations generally were similar to residents' perceptions, implying that 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 also have reported no correlation between pedestrian perceptions and objectively measured audit and GIS indices.[63]

There was little variation among neighborhoods that were similar in median income. For example, Euclid (in Income Group 1) and the Sunset and Boulder neighborhoods ranked closer together. Income Group 5 – Spanish Trail and Historic Alta – also ranked closer together. In the Alta neighborhood, residents had a poorer perception of safety features in the walking environment compared to audit observations in the safety category. In addition, Alta residents had a poorer perception of the elements for continuity and aesthetics and amenities that were present in their walking environment.

Table 21. Rules for Assigning Overall Walkability Grades from Land-Use Mix, Infrastructure, and Safety Grades

		Safety			
Land-Use	**Infrastructure**	**A**	**B**	**C**	**D**
A	A	A	A	B	B
	B	B	B	B	B
	C	B	B	C	C
	D	C	C	C	C
B	A	B	B	B	B
	B	B	B	C	C
	C	C	C	C	C
	D	C	C	C	D
C	A	B	B	C	C
	B	C	C	C	C
	C	C	C	C	D
	D	C	D	D	D
D	A	C	C	C	C
	B	C	C	C	D
	C	C	D	D	D
	D	D	D	D	D

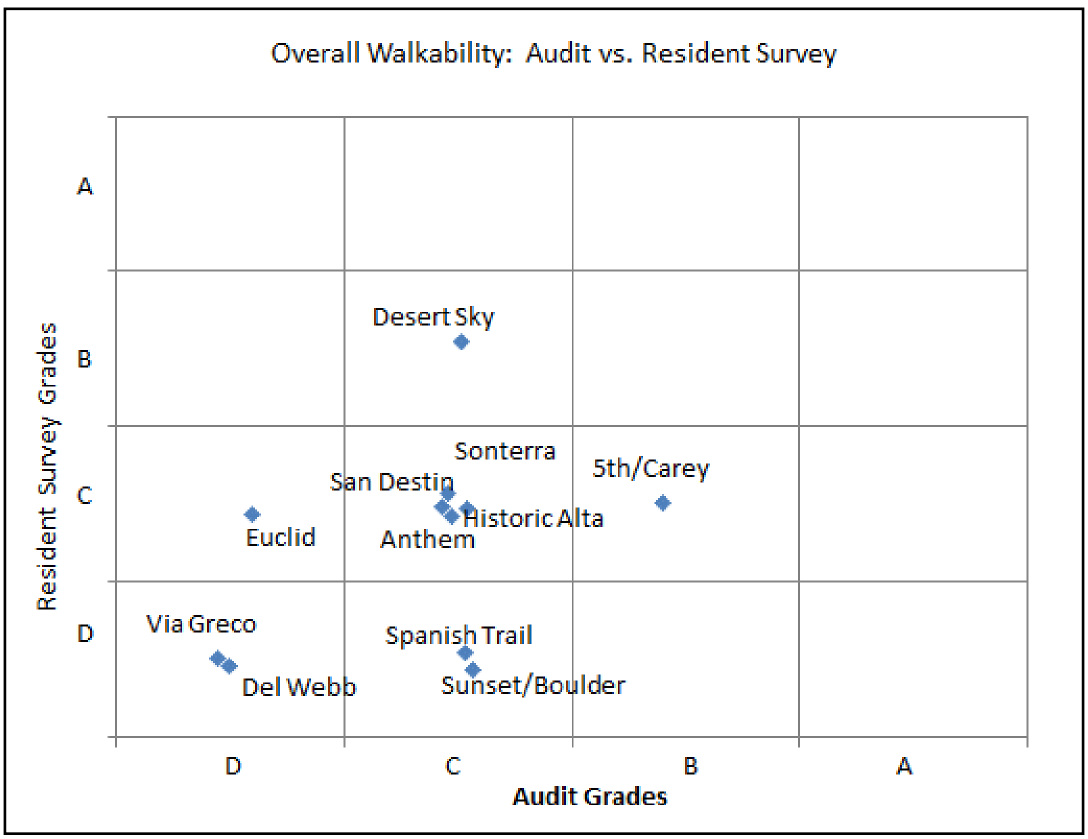

Figure 17. Comparison of Overall Walkability Indices for the Audit and the Survey

WALKABILITY ANALYSIS

Table 22 summarizes grades for both the audit and the residential survey for all the neighborhoods. In the category of land-use, neighborhoods with the lowest grades each had two types of commercial land-uses within the study boundary. Neighborhoods with the highest grade for land-use had at least nine commercial land-uses. Differences in audit observations for land-uses and residents' perceptions could stem from the fact that land-uses were within a 0.75-mi buffer of a neighborhood which, with regard to residents' perceptions, might not be as close as a 15-min walk. A higher land-use mix was associated with more walking opportunities.

For the directness category, quality indices varied between a “B” and “D” for both the audit and the survey. Directness was estimated from FAR, the sidewalk gradient, and the proportion of segments with walled or gated communities. A large proportion of the segments audited had walled or gated communities. According to the audit, only one neighborhood (DelWebb) had steep sidewalks; this was confirmed by the residents.

Table 22. Grades for All the Neighborhoods for All the Categories

	Neighborhood Audits							Resident Surveys							
	Directness	Continuity	Amenities & Aesthetics	Infrastructure	Land use	Safety	Overall Walkability	Directness	Continuity	Amenities & Aesthetics	Infrastructure	Land use	Safety	Overall Walkability	Comprehensive Walkability
5th/Carey	C	C	C	C	A	B	B	D	C	D	C	B	C	C	C
Euclid	B	D	C	D	B	D	D	C	D	C	D	B	C	D	D
Sonterra	C	C	B	C	B	D	C	C	C	C	C	C	C	C	C
Sunset/Boulder	C	D	C	D	B	C	C	C	D	D	D	C	C	D	D
Del Webb	D	C	B	D	D	B	D	C	C	B	C	D	B	C	D
Desert Sky	C	C	C	C	C	C	C	B	B	B	B	A	B	B	C
San Destin	C	B	C	C	C	B	C	B	C	B	B	B	B	B	C
Via Greco	D	C	D	D	D	C	D	C	C	C	C	D	C	D	D
Anthem	C	C	C	C	C	B	C	C	B	B	C	D	B	C	C
Historic Alta	B	C	B	C	B	C	C	C	D	C	D	B	C	D	D
SpanishTrail	C	B	B	B	B	C	C	C	D	B	D	D	C	D	D

Features evaluated for the category of continuity measured the potential for an obstruction-free trip. The strength of audit evaluations were the audit tools that enabled the evaluation of the presence of obstructions, such as driveways and street furniture as well as the presence and condition of sidewalks. Although useful, driveways hinder walkability and increase pedestrian-vehicular conflict points; meanwhile, obstructions pose threats, especially for pedestrians with disabilities. Neighborhoods having lower grades for continuity had a prevalence of driveways, street furnishings that were obstructing, and sidewalks that were either missing or in poor condition.

In the category of aesthetics and amenities, the presence of physical and social disorders as well as transit stops and associated furnishings were evaluated. The grade varied between “B” and “D” for audit observations and resident perceptions. Articulated buildings, attractive landscaping, and 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 residents’ perceptions and audit observations, weighted the perception higher than audit observations. Intuitively, the residents are the ones who make the decision to walk based on their perception of the walking environment; hence, a higher weight was given for their perceptions in the final comprehensive index. The comprehensive walkability grade was between “C” and “D.” Neighborhoods with the lowest index included Sunset & Boulder, Euclid, Via Greco, Historic Alta, and Spanish Trails.

The final comprehensive audit index and grade was not the goal, necessarily, but does ease the path to goal achievement, which is to provide walkable environments. Having both audit and survey data as points of view, practitioners would be able to backtrack and identify which particular categories needed interventions. For example, in the Sunset & Boulder neighborhood – which had a comprehensive grade of “D” – both audit observations and residents’ perceptions indicated a grade of “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 from this neighborhood also reported the presence of physical disorders, such as litter and drug paraphernalia. An additional cleaning schedule for such neighborhoods could planned in an effort to address the respondents’ comments, subject to funding availability.

SUMMARY

The comprehensive walkability index was obtained by combining overall grades for both the audit and the survey. Survey and audit indices each were obtained by combining the indices for infrastructure, safety, and land-use. The infrastructure category was comprised of amenities and aesthetics, directness and continuity categories. Neighborhoods whose respondents’ perceptions on infrastructure differed from the audit observations exhibited a little variation. Generally, the grade for infrastructure varied between “B” and “D” for both the audit and survey data.

The safety index for the audit 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 the population and commercial land-use in a buffer. Even without significant results, the inclusion of crash data into the walkability analyses brought a certain amount of objectivity. When crash data was introduced into the analyses, neighborhoods with high walkability indices dropped in walkability ranking. Using a paired sample, the difference between walkability indices without crash data was significantly higher than those with crash data ($p=0.07$, $\alpha=0.1$, one tailed test).

Overall, the audit walkability index was similar to residents' perceptions, implying that either approach to evaluating walkability could be optimized to estimate the other. There was little variance among neighborhoods that were similar in median income. The comprehensive walkability grade varied between grades "C" and "D."

The final comprehensive index for the audit was not necessarily the goal, but eases the path to goal achievement, which is to provide walkable environments. Using both an audit and a survey, practitioners would be able to backtrack and identify which particular categories needed interventions. Some of the features in which audit observations and respondents' perceptions coincided that need addressing include access to land-uses, the presence and condition of sidewalks, the presence of obstructions, and the presence of buffers as well as shading and appealing aesthetics.

VIII. STATISTICAL MODELING FOR FREQUENCY OF WALKING

Statistical models for the frequency of walking as the dependent variable were calibrated using the software R. The modeling was conducted at two levels. Level 1 models were used to assess the frequency of walking as a function of the individual resident's perceptions of the walking environment. Level 2 models included both the user's perceptions as well as characteristics of the neighborhood walking environment, based on the audit surveys.

FREQUENCY OF WALKING AS A FUNCTION OF RESIDENTS' PERCEPTIONS

Individual responses with regard to the frequency of walking were grouped into three categories, namely, *frequent* walkers (those who walked every day or almost every day), *moderate* walkers (those who walked a few times a month), and *seldom* walkers (those who never or rarely 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, and is expressed as:

$$P(Y_i = s) = \frac{e^{\eta_{is}}}{\sum_{t=1}^{g} e^{\eta_{it}}} \tag{8-1}$$

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*, and

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

All five perception categories were included in the model. Results for the multinomial logit model are summarized in Table 23. The table shows that the two statistically significant variables were the perceptions of 1) the land-use mix and 2) amenities and aesthetics. The results included the odds as well as the probabilities of respondents' walking frequency for a unit increase in the scores of both the land-use mix and aesthetics and amenities.

Table 23. Coefficients for the Walking Frequency Model

	Walking frequency: Moderate				Walking frequency: Frequent			
Parameter	**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
Land-Use 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**

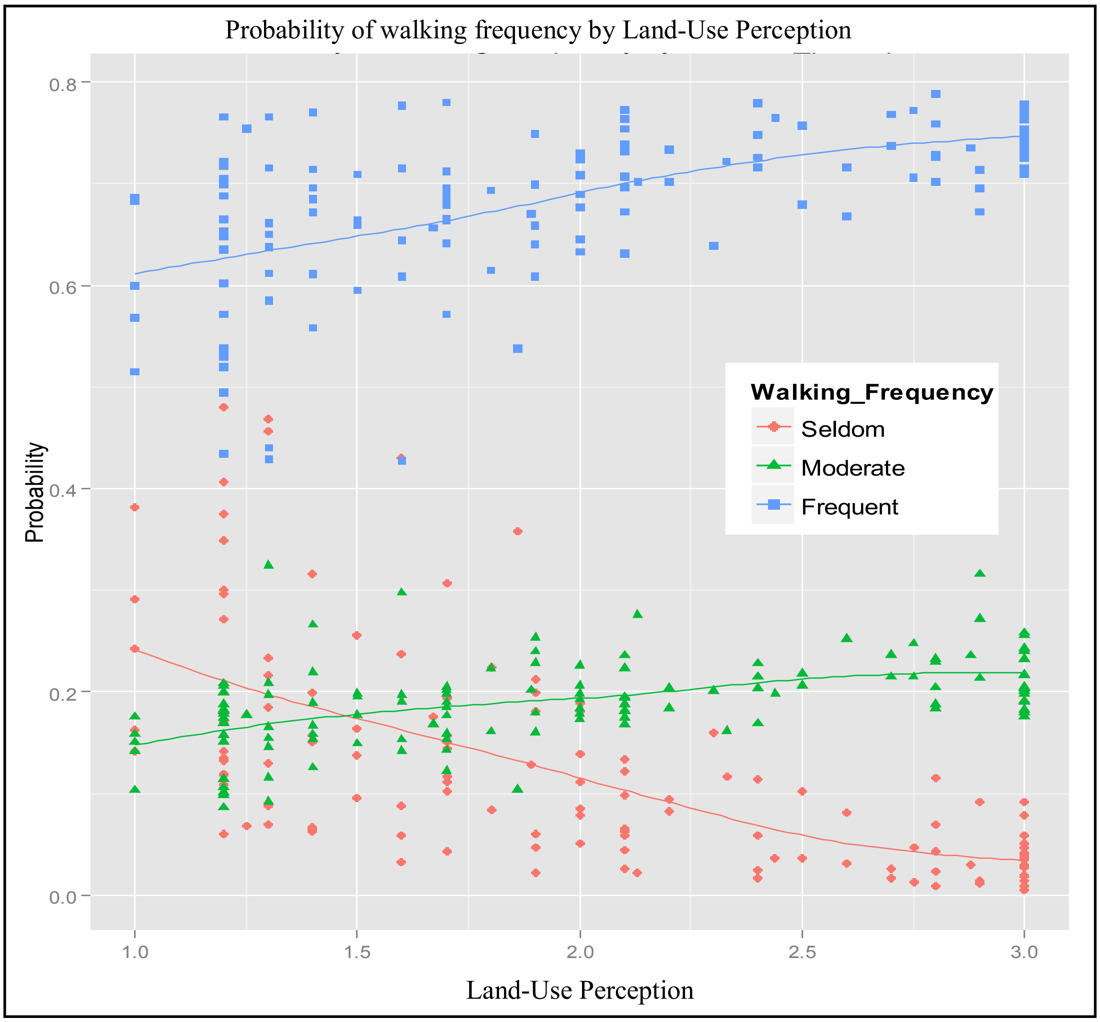

Figure 18. Probability Plot of Walking Frequency vs. Perceptions of Land-Use Mix

Walking Frequency versus the Perceptions of Land-Use Mix

Table 23 summarizes the results of the model, showing the odds as well as the probabilities of the respondents' walking frequency due to a unit increase in land-use. All other things being equal, the probability of a respondent's walking frequency being "moderate" due to a unit increase in the perception of land-use was 20%. The unit increase ranged from "Strongly Agree" to "Uncertain," a relationship that was statistically significant (α = 0.1). Figure 18 illustrates the odds ratio of walking frequencies transformed into predicted probabilities. An upward trend was observed for "frequent" and "moderate" walking as the perception of land-use increased.

Walking Frequency versus the Perceptions of Aesthetics and Amenities

Table 23 shows a statistically significant relationship (α = 0.05) between walking frequency and the perception of aesthetics and amenities. Similar to perceptions regarding land-use, due to a unit increase in the perception of aesthetics and amenities, the probability of respondents being in the "moderate walking" category was 20%. There was a higher probability (69%) of respondents being in the "frequent walking" category due to a unit increase in the perception of aesthetics and amenities.

Predicted probabilities were plotted for illustration in Figure 19. An upward trend is evident for frequent and moderate walking with an increase in the perception of aesthetics and amenities. This implies the probability that enhanced aesthetics and amenities increase the frequency of walking to the "moderate" and "frequent" categories; this, in turn, reduces the probability of residents "seldom walking."

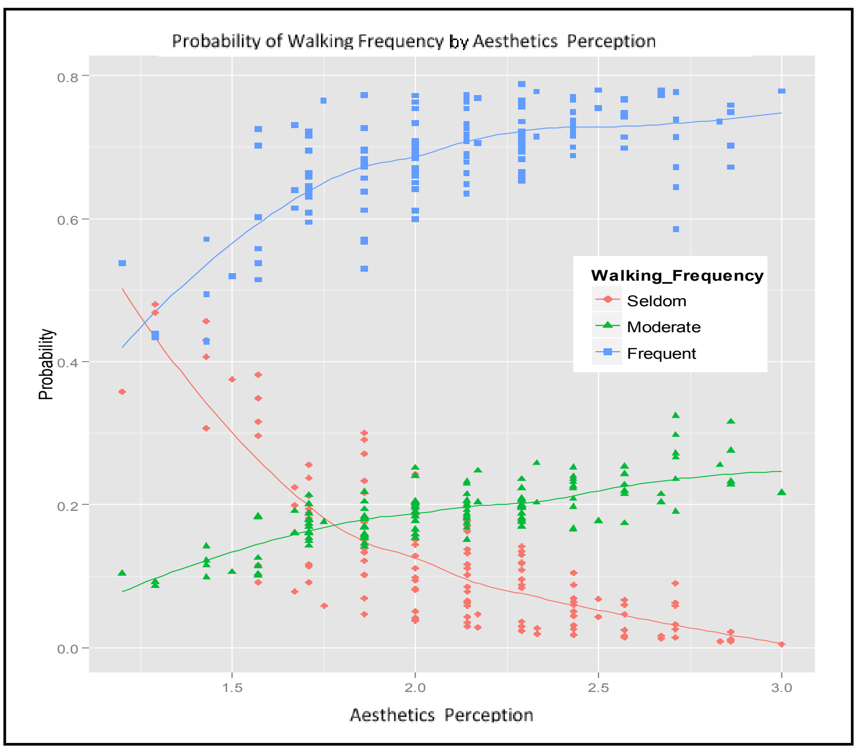

Figure 19. Walking Frequency vs. the Perception of Aesthetics and Amenities

Table 24. Pearson Correlation Matrix for Residents' Perceptions

		Land-use perception	Directness perception	Continuity perception	Aesthetics perception	Safety perception
Land-use perception	Correlation Sig. (2-tailed)	1				
Directness perception	Correlation Sig. (2-tailed)	0.28** 0.00	1			
Continuity perception	Correlation Sig. (2-tailed)	0.02 0.77	0.21** 0.01	1		
Aesthetics perception	Correlation Sig. (2-tailed)	0.19* 0.02	0.30** 0.00	0.49** 0.00	1	
Safety perception	Correlation Sig. (2-tailed)	0.07 0.41	0.51** 0.00	0.42** 0.00	0.42** 0.00	1

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

The perceptions regarding aesthetics and amenities 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 the aesthetics of this walking environment. The relationship between directness and safety perception, however, which is moderately strong and significant, differed from expectations. Intuitively, cul-de-sacs and enclosed communities restrict direct access to land-uses. Conversely, for enclosed communities, restricted traffic access results in low traffic flows as well as speed limits, which is conducive to pedestrian activity. In addition, the walls surrounding communities serve as buffers between residences and vehicles that veer off the road.

PERCEPTION MODELS

Introduction

A walking-frequency model was calibrated as a function of the residents' perceptions of their walking environment. The variables that were significant in the model were the perceptions of land-use mix and of amenities and aesthetics. These two variables were modeled as functions of audit characteristics of the socioeconomic variables as well as the walking environment of the neighborhood.

The study was designed as a "repeated measures" study, during which the respondents were drawn from selected income groups and neighborhoods. Multiple measurements per neighborhood generally resulted in correlated errors that violated the statistical independence of an assumption of consecutive errors. To correct the violation of a within-subject correlation, each respondent ideally should have individual intercepts and or slope.[64] Typically, this would result in uncorrelated errors around each respondent's regression line, modeled conditionally on each random effect. Treating each respondent as a fixed effect with their own intercept, however, consumes substantial degrees of freedom.

In addition, a comparison of residents' perceptions and audit observations exhibited little variance except in the perception of land-use. Therefore, a single variance parameter was estimated that represented the spread of random intercepts around which the common intercept of each group was estimated. The analysis was conducted using a mixed-model approach consisting of fixed and random parameters, expressed as:

$$y_i|\gamma_i = X_i\beta + Z_i\gamma_i + \varepsilon \tag{8-2}$$

where:

β is the estimated intercept for each fixed parameter X_i

Z_i is the intercept for each random effect

Y_i is the random effect

ε is the error term

Fixed-effect parameters describe variability of the population means between any set of treatments, while random-effect parameters represent general variability among subjects. In addition to Level 1 data, Level 2 data aggregated at the neighborhood level was used in the analysis. For respondents coming from the same neighborhood, a singular variable was used for the audit observations.

Model Calibration

The modeling procedure was as follows. The first step was to identify the various perceptions that influenced walking frequency. Using the following steps, perception models were calibrated to identify influences of these various perceptions that might result in increasing the walking frequencies.

Step 1. The data was organized in a wide format such that each row corresponded to a respondent or observation.

Step 2. A stepwise regression model was fitted to identify predictor variables that could be included in a final perception model.

Step 3. Initially, neighborhood differences were modeled that assumed 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 the total variance is the explained variance (by the random effect) plus the residual variance explained by the fixed effects. ICC is 1.0 only when there is no variance due to the random effect and there is no residual variance to explain.[65]

Step 4. If the random effects warranted a mixed-effects model, a random-slopes model was tested. The random-slopes model allowed neighborhoods to have different intercepts as well as differing slopes. This model proved to be rather expensive in light of limited data, especially for low-income neighborhoods with fewer than

10 responses. From the perception box plots, the difference could be reasonably modeled using a single variance value that represents the spread of perception. However, due to significant difference in neighborhood design, 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 effects of various features of the walking environment elicit varying perception responses. For example, for neighborhoods that were gated/walled, adding more entrances/exits around the community probably would result in more walking to nearby stores compared to neighborhoods that were already accustomed to uninhibited access.

Step 5. Initially, all audit categories were modeled using a combination of fixed intercepts and random slopes. This was to determine variables that had enough variability between neighborhoods for the mixed-effects model. Finally, the most practical and useful combination of variables was selected as fixed and random effects. The analysis of variance (ANOVA) test was used to compare among the predictor variables to determine the best combination of variables.

Step 6. After significant and or practically useful variables were selected, the final model was tested to determine goodness of fit, using such diagnostics as residual and normality plots. Cook's distances were plotted to determine the presence of influential outliers.

Results of the Land-Use Perception Models

A random intercept model was fitted to confirm the need for a mixed model. Table 25 illustrates a substantial amount of variance between neighborhoods accounting for land-use perception. Each audit category was fitted as a random effect in order to determine those categories whose neighborhood variations accounted for a substantial variation in the perceptions of land-use. The final model was selected, and resulting output was expressed as:

$$Land - use\ perception_{ij} = \gamma_j^0 + \gamma_j^1 Land\ use_i + \beta_1 Walking_{frequency} + \beta_2 Directness\_audit + \varepsilon_{ij} \quad \text{8-3}$$

where:

Land-use perception$_{ij}$ = the land-use perception of the i^{th} respondent in the j^{th} neighborhood.

In Table 25, holding all other fixed effects constant, the land-use perceptions of respondents who walked moderately was 0.27 units higher than those who seldom walked. The land-use perception of respondents who walked frequently was much higher (0.3 units) than respondents who seldom walked. Intuitively, more frequent walking provides more opportunities for statistically significant familiarity of land-use (α = 0.05). Easy and quick access to the land-uses enhanced land-use perceptions as well. A strong and statistically significant direct relationship between directness and land-use perceptions indicates that better accessibility to land-use is likely to improve resident perception regarding land-use.

Table 25. Final Model for Land-Use Perceptions

Land-use perception ~ Walking _frequency + (0 + Landuse | Neighborhood) + Directness-audit

REML criterion at convergence: 208

Scaled residuals:

Min	IQ	Median	3Q	Max
-2.5	-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	**

Note: Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

Regarding random effects, variation of land-uses by neighborhood explains almost half the variances in the perceptions of land-use. From audit observations, neighborhoods with the highest land-uses had 11 land-uses, and those with the lowest had two land-uses. It is reasonable to expect different responses from residents in neighborhoods with more land-uses and those with only a few. For example, if the 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 the use of vehicles – e.g., Wal-Mart tends to have large parking lots – thus influencing transportation modes. Convenient stores between transit stops and residential neighborhoods provide walking opportunities to the stores, and allow patrons to link work and shopping trips on foot during their return trips home. A fixed intercept was used to represent the spread of various land-uses, and random slopes were used to model the effect of land-uses on residents' perceptions. Table 26 shows the different coefficients for the land-use perception model.

Table 26. Coefficients for the Final Model for Land-Use Perceptions

			Land-Use		Directness-
Neighborhood	Intercept	Land-Use	Moderate	Frequent	Audit
5th/Carey	1.11	0.19	0.27	0.30	1.81
Euclid	1.11	-0.11	0.27	0.30	1.81
Sonterra	1.11	-0.08	0.27	0.30	1.81
Sunset/Boulder	1.11	-0.02	0.27	0.30	1.81
Del Webb	1.11	-0.24	0.27	0.30	1.81
Desert Sky	1.11	0.80	0.27	0.30	1.81

Neighborhood	Intercept	Land-Use	Land-Use Moderate	Land-Use Frequent	Directness-Audit
San Destin	1.11	0.59	0.27	0.30	1.81
Via Greco	1.11	0.08	0.27	0.30	1.81
Anthem	1.11	-0.32	0.27	0.30	1.81
Historic Alta	1.11	-0.10	0.27	0.30	1.81
Spanish Trail	1.11	-0.73	0.27	0.30	1.81

Intuitively, neighborhoods with a low land-use mix likely are more sensitive to land-use changes within their neighborhood. The negative coefficients in Table 26 indicate that perceptions of low land-use are significantly associated with more sensitivity to small changes in land-use.

The perceptions of high land-use in such neighborhoods as 5th & Carey, Desert Sky Apartments, and San Destin coincided with audit observations. In such neighborhoods, small changes might be unnoticeable, so the direct relationship was indicated by positive coefficients.

Neighborhoods such as Sonterra, Euclid, Sunset & Boulder Anthem, Spanish Trail and Historic Alta indicated improved perceptions in land-use with small changes in land-uses. Of these neighborhoods, Spanish Trail, Sonterra, and Anthem are gated; land-uses, therefore, might be further than a 15-minute walk from residences. In Historic Alta and Sunset & Boulder neighborhoods, land-uses generally were located on one side of the neighborhood, also requiring a little further than a 15-minute walk.

In the Via Greco neighborhood, respondents had perceptions of low land-use, which coincided with the relatively low land-use observed in the audit. To improve perceptions in this particular neighborhood, whose land-uses mainly consisted of small cafes, cocktail lounges, and club houses, much larger changes in land-use would be required.

Results of the Model for Perception of Amenities and Aesthetics

After a series of steps that included a stepwise regression analysis and a random-effects model, a final fixed-effect model was calibrated (Table 27). The model had the following functional form:

$$\begin{aligned} &Amenities\ \&\ Aesthetics\ Perception_{ij} \\ &\quad = \gamma_j^0 + \gamma_j^1 + Walking\ frequency + Transit + Land\ use \\ &\quad + \beta_3 Infrastructure + \ \varepsilon_{ij} \end{aligned} \tag{8-4}$$

where:

Amenities & Aesthetics Perception$_{ij}$ = the perception of amenities and aesthetics of the i^{th} respondent in the j^{th} neighborhood.

Table 27. Final Model of Perceptions of Aesthetics and Amenities

Aesthetics-perception ~ Walking _frequency + transit + (0 + Safety-index(FL) | Neighborhood) + Landuse + Infrastructure-index(FL)

REML criterion at convergence: 93.2

Scaled residuals:

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

Random effects:

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

Fixed effects:

	Estimate	Std. Error	df	t-value	Pr(>|t|)	
(Intercept)	1.8	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	0.1	111.01	2.44	0.02	*
Transit - no	-0.18	0.1	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	**

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

All things held constant, a unit increase in land-uses reduced the perception of aesthetics and amenities by 0.65. In some cases, the type of business, such as a service garage or a flea market, influences how pleasant the surroundings are. Intuitively, commercial properties that are associated with significant traffic more likely attract such physical disorders as trash. A unit increase in infrastructure resulted in a 1.36-unit increase in the perception of aesthetics and amenities.

From the audit, overall safety was modeled as a random effect by neighborhood, and explained approximately 14% of the variances in the perception of aesthetics and amenities (Table 27). The remaining variance was explained by the fixed effects discussed in the previous paragraph. Table 28 presents the final coefficients for the aesthetics and amenities model.

From Table 28, the negative coefficients indicate that neighborhoods with initially low perceptions of aesthetics and amenities likely are more sensitive to small changes in the infrastructure that enhance safety and reduce crash risk to a statistically significant relationship. Except for the DelWebb neighborhood, in Income Group 3, neighborhoods in Income Groups 1 and 2 had low perceptions of aesthetics and amenities. Having a better perception of aesthetics and amenities compared to the other neighborhoods, DelWebb residents likely are more sensitive to greater changes in the safety infrastructure.

Table 28. Coefficients for Final Model for Perceptions of Aesthetics and Amenities

Neighborhood	Intercept	Safety-index(FL)	Walking Frequency - Moderate	Walking Frequency - Frequent	Transit - no	Land-Use	Infrastructure-index(FL)
5th/Carey	1.80	-0.03	0.26	0.23	-0.18	-0.64	1.36
Euclid	1.80	-0.01	0.26	0.23	-0.18	-0.64	1.36
Sonterra	1.80	-0.03	0.26	0.23	-0.18	-0.64	1.36
Sunset/Boulder	1.80	-0.02	0.26	0.23	-0.18	-0.64	1.36
Del Webb	1.80	-0.14	0.26	0.23	-0.18	-0.64	1.36
Desert Sky	1.80	0.05	0.26	0.23	-0.18	-0.64	1.36
San Destin	1.80	0.05	0.26	0.23	-0.18	-0.64	1.36
Via Greco	1.80	0.04	0.26	0.23	-0.18	-0.64	1.36
Anthem	1.80	0.10	0.26	0.23	-0.18	-0.64	1.36
Historic Alta	1.80	0.02	0.26	0.23	-0.18	-0.64	1.36
Spanish Trail	1.80	0.02	0.26	0.23	-0.18	-0.64	1.36

In addition, the coefficient illustrating the magnitude of change was much smaller for this neighborhood – which reported no pedestrian crashes – compared to other neighborhoods that might be sensitive to small changes in the safety infrastructure. Among the neighborhoods likely to be less sensitive to small changes in the infrastructure, the Anthem neighborhood had the largest coefficient. In this neighborhood, no pedestrian crashes were reported; in addition, there were safety features that could double for aesthetics, such as landscaped buffers. For safety infrastructures, such as landscaped buffers, the intersection geometry intrinsic to sidewalks, ramps, and lighting could enhance the visual acuity of the walking environment.

APPLICATION OF STATISTICAL MODELS

This section illustrates the application of calibrated perception models, using the Euclid neighborhood as an example. Euclid had a low comprehensive grade for the quality of walkability. From the perception indices in Table 22, perceptions of continuity as well as amenities and aesthetics had the lowest indices in the neighborhood. From the walking-frequency model, continuity was not statistically significant. However, the perception of aesthetics and amenities as well as safety was significantly correlated with the perception of continuity. Therefore, features that improve the perception of aesthetics and amenities likely will improve the perception of continuity as well as increase walking frequency.

The model for perceptions of aesthetics and amenities consisted of safety, infrastructure (i.e., the audit categories for continuity, directness, and amenities and aesthetic), and the land-use mix obtained from audit observations and transit use. Features that are likely to improve the perception of aesthetics and amenities in the Euclid neighborhood are illustrated in Figure 20.

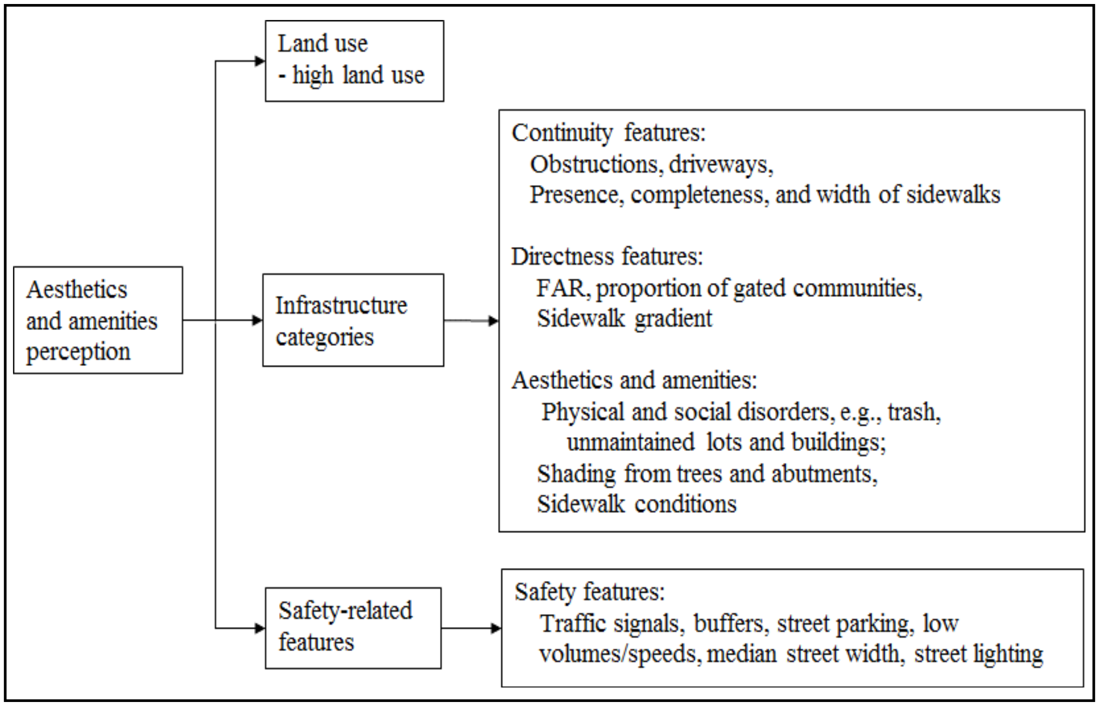

Figure 20. Features to be Improved that Would Enhance the Perception of Aesthetics and Amenities in the Euclid Neighborhood

SUMMARY

The results of statistical modeling for walking frequency as well as the perceptions of land-uses and amenities and aesthetics are summarized as follows. The study design used was "repeated measures," in which multiple measurements were taken from each neighborhood. To address the violation of the independence of the assumption of consecutive errors, mixed models were adopted to model 1) resident perceptions as a function of socio-demographic variables and 2) audit observations. The modeling procedure involved identifying perceptions that could influence walking frequency. Although not all perception categories were statistically significant, mixed models were calibrated for each perception category. The following is a summary of the observations.

1. The walking frequency model showed that perception about land-uses and amenities and aesthetics were the significant variables influencing the frequency of walking. These factors were modeled further to see how they relate to individual socioeconomic characteristics as well as neighborhood walking environment, as measured by the audit surveys.

2. The final model for land-use perceptions consisted of walking frequency, variable for directness in the audit, and land-uses observed in the audit as a random effect. Walking frequency and directness (from the audit) were positively associated with land-use perceptions. Neighborhoods with a low land-use mix were likely more sensitive to land-use changes within their neighborhood.

3. The final model for perceptions of aesthetics and amenities consisted of walking frequency, transit use, land-uses observed in the audit, infrastructure, and overall safety from the audit. The infrastructure category consisted of features for directness, continuity, and aesthetics and amenities. Overall safety consisted of crash risk and safety-related infrastructure observed in the audit. There was a direct relationship between walking frequency and infrastructure variables; transit and land-use variables, however, exhibited an inverse relationship. The random-effect relationship showed that neighborhoods with initially low perceptions of aesthetics and amenities were likely to be more sensitive to small changes in the infrastructure that enhanced safety and reduced crash risk.

IX. CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The main objective of the study was to develop a comprehensive walkability index that quantified the walking environment of the Las Vegas Valley in its entirety. This index reflects the condition of the walking environment as well as residents' perceptions of it. In quantifying walkability, the following sub-objectives of the study addressed limitations of 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. Provide frameworks for estimating the influence of perceptions 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 that have high safety scores for safety-related infrastructures. The results indicated, however, that some neighborhoods with high safety scores also had high crash indices. Safety levels based on safety infrastructure alone could mask potential safety problems within the walking environment. In addition, when crash data was introduced into the analyses, neighborhoods with high walkability indices dropped in ranking. Inclusion of crash data into walkability analyses not only reflected safety risks, but brought objectivity to the safety evaluations.

Audit and perception grades for the quality of various features of the walking environment were within one letter grade of each other, except in very few cases. In these cases, the residents' perceptions were either lower or higher than the audit observations. This report presented the comprehensive walkability index obtained by the overall indices, combining audit observations and residents' perceptions regarding walkability.

The study calibrated parameters of the perception models by using audit observations collected from 11 neighborhoods. The study used a "repeated measures" design, in which multiple measurements were taken from each neighborhood. To address the violation of the independence of consecutive errors assumptions, hierarchical linear mixed models, implemented in R, were adopted to model residents' perceptions as a function of socio-demographic variables as well as from audit observations. In addition, a multinomial logit model was calibrated to estimate perceptions that influence walking frequency.

SUMMARY OF STATISTICAL FINDINGS

A comparison of crash and safety-related infrastructure indices show that these two safety-level indicators conveyed different information. Safety-related infrastructure does not completely reflect potential risk for pedestrian crashes in the walking environment. The study compared walkability indices from the audit surveys, with and without crash data, and found statistically significant differences in the walkability indices. Neighborhoods with high walkability indices based on only audit-based safety features eventually ranked much lower after integration of the crash data. This indicates the need for inclusion of crash data in the evaluation of the safety index related to walkability.

In the study by Pikora et al., the most important issues related to walking were ranked in decreasing orders of personal safety, aesthetics, and destinations.[66] In Park's study, coefficients with the highest values were in order of a sense of security and safety, appealing aesthetics, and easy access to land-use.[67] Results from the current study indicate that perceptions regarding aesthetics and amenities and land-use had a significant relationship with walking frequency.

Perceptions of aesthetics and amenities as well as land-use were correlated with perceptions regarding safety, directness, and continuity; this implied that improving the perception of one category was bound to have an impact on another category. The parameter for directness in the audit served as both a disincentive and an incentive to walking. Regarding the perceptions for land-use, increasing features that contributed to directness resulted in uninhibited access to land-uses; this, in turn, increased walking frequency. Conversely, an increase in uninhibited access resulted in lower perceptions regarding safety. Intuitively, enclosed communities had lower traffic flows as well as speed limits, which are conducive to pedestrian activity and also provide buffers from errant traffic.

CONCLUSIONS

Generally, results indicated the need for a transactional evaluation approach, which recognizes that pedestrian behavior is influenced by many environmental features and by the perceptions regarding the walking environment as well as by social and cultural aspects. Conclusions for this study were made based on the following observations.

1. Perception categories that significantly influenced walking frequency were land-use as well as aesthetics and amenities. The perceptions of safety, directness, and continuity were not significant, but had weak-to-moderately significant associations with the perceptions of land-use and aesthetics and amenities. This implies that improving the perception of one category is bound to improve or negatively affect the perception of a correlated category. For example, land-use perceptions were correlated with perceptions of directness; this is intuitive, given that directness is measured in terms of quick and easy access to land-uses. Conversely, directness was moderately correlated with safety. Considering the interaction among the perception categories, therefore, the models were calibrated for each perception category.

2. A higher land-use mix was determined to improve land-use perceptions. In addition, features that enabled quick and easy access to a variety of land-uses were likely to improve perceptions regarding directness and land-use. This result would recommend flatter sidewalk gradients, smaller parking lots in front of commercial premises, and better access at and inside enclosed communities.

3. The perception of aesthetics and amenities was influenced by infrastructure of the walking environment, and included directness, continuity, and perceptions of an appealing environment. A complete and well-maintained facility not only is visually appealing, but also enhances quicker access between the origin and destinations for utilitarian trips. In addition, completeness of the walking environment is synonymous with safety, such that pedestrians do not have to maneuver around obstructions that put them at risk from traffic.

STUDY LIMITATIONS AND FUTURE RESEARCH RECOMMENDATIONS

The walking frequency and perception models developed in this study address some of the limitations of 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 of crashes is exposure, derived from vehicle and pedestrian volumes that were not readily available during 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 generalizations based on a very small sample become questionable. Owing to lack of resources, mail-back surveys with reminders might have had a better response rate than employing an online survey and dropping survey packages at residences.

3. A larger sample size study is recommended for future studies for more statistically valid results.

APPENDIX I: NEIGHBORHOOD WALKABILITY SURVEY INSTRUMENT

REGIONAL TRANSPORTATION COMMISSION
RTC
OF SOUTHERN NEVADA

UNLV
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				
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 areas 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.

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
There are crosswalks in the middle of the street away from intersections that make it safe to cross streets in my neighborhood.				
The streets in my neighborhood are very wide which makes it difficult to cross.				
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.				
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? _______ years _______ months
   - ☐ 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 fold and 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 (miles)
	Street width
Land uses	Number of land uses in the neighborhood (GIS derived)
Directness	Gated , walled communities (present=1, absent=0)
	Hilly streets (flat=0, slight hill=1, steep hill=2)
	Floor area ratio (GIS derived)
Continuity	Intersection density (GIS derived)
	Number of obstructions
	Temporary signs
	Permanent signs
	Trees
	Utility poles/hydrants
	Magazine racks/cabinets
	Transit shelters/benches
	Parked cars
	Sidewalk (present=1, absent=0)
	Average sidewalk width (≤ 5ft =1, > 5 ft =2)
	Sidewalk breaks e.g dirt paths, incomplete sidewalks (present=1, absent=0)
	Number of driveways
	Deadend sidewalks (present=1, absent=0)
Safety	Number of traffic controls
	Traffic signals
	Dedicated turning arrows (protected lefts)
	Exclusive right turn lanes
	Exclusive right turns (channelized lanes added)
	Pedestrian signals/crosswalks
	Pedestrian signs
	Curb ramps
	Yield, 2-Way stop signs
	4-Way stop signs
	Traffic circles
	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
	Fences (temporary/flexible)
	Hedges
	Landscape (desert)
	Grass

Category	Item / Segment Name
	Other safety elements
	Average number of lanes
	Traffic direction (1 = 1-way street, 2 = 2-way 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 fountains
	Bicycle racks
	Street vendors/vending machines
	Covered transit shelters
	Transit timetables
	Proportion of street having shade (trees, overhead coverage, <0.25, 0.26 -0.75, >0.75 = 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/ empty lots/bldgs
	Graffiti
	Sidewalk condition/mainenance (poor, fair, good= 1,2,3)

APPENDIX III: CONTINGENCY TABLES

Contingency Tables for Walking to Specific Places and Various Land-Uses

		Worship places			
		Agree	Neutral	Disagree	Total
Walking to specific place	Walkers	11	7	9	**27**
		7.36	5.89	13.75	
		3.64	1.11	-4.75	
	Neutral	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	
Total		**30**	**24**	**56**	**110**

		Restaurants			
		Agree	Neutral	Disagree	Total
Walking to specific place	Walkers	17	7	6	**30**
		12.26	7.83	9.91	
		4.74	-0.83	-3.91	
	Neutral	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 stores			
		Agree	Neutral	Disagree	Total
Walking to specific place	Walkers	18	6	7	**31**
		11.86	6.20	12.94	
		6.14	-0.20	-5.94	
	Neutral	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	Neutral	Disagree	Total
Walking to specific place	Walkers	7	3	18	**28**
		2.59	2.59	22.81	
		4.41	0.41	-4.81	
	Neutral	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**

		Post offices			
		Agree	Neutral	Disagree	Total
Walking to specific place	Walkers	9	6	14	**29**
		5.65	3.59	19.76	
		3.35	2.41	-5.76	
	Neutral	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**

		Bus stations			
		Agree	Neutral	Disagree	Total
Walking to specific place	Walkers	22	7	4	**33**
		13.54	6.77	12.69	
		8.46	0.23	-8.69	
	Neutral	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	Neutral	Disagree	Total
Walking to specific place	Walkers	12	9	8	**29**
		6.16	8.98	13.86	
		5.84	0.02	-5.86	
	Neutral	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	Neutral	Disagree	Total
Walking to specific place	Walkers	11	7	10	**28**
		6.31	7.57	14.13	
		4.69	-0.57	-4.13	
	Neutral	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	Neutral	Disagree	Total
Walking to specific place	Walkers	12	8	9	**29**
		7.12	8.65	13.23	
		4.88	-0.65	-4.23	
	Neutral	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 and Various Land-Uses

		Post offices Agree	Neutral	Disagree	Total
Walk to visit friends	Frequent 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**

		Clinics/pharmacies Agree	Neutral	Disagree	Total
Walk to enjoy outdoors	Frequent 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**

		Restaurants Agree	Neutral	Disagree	Total
Walk to get out with others	Frequent 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	Neutral	Disagree	Total
Walk to visit friends	Frequent 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	Neutral	Disagree	Total
Walk to visit friends	Frequent 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**

		Post offices Agree	Neutral	Disagree	Total
Walk to get out with others	Frequent 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**

		Worship places			
		Agree	Neutral	Disagree	
Walk to get out with others	Frequent 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**	

		Banks			
		Agree	Neutral	Disagree	Total
Walk to get out with oth-ers	Frequent 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**

		Bus stations			
		Agree	Neutral	Disagree	Total
Walk to get out with oth-ers	Frequent 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 IV: TABLES OF REGRESSION MODELS' OUTPUTS

Table IV-1: 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 <5 yrs	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 IV-2: Linear Regression Output for Amenities and 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 <5 yrs	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 IV-3: 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 + Landuse"

"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	0.08	.
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 <5 yrs	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 IV-4: 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 <5 yrs	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

ACRONYMS AND ABBREVIATIONS

ACS	American Community Survey
ANOVA	Analysis of Variance
BMC	Baltimore Metropolitan Council
CDC	Centers for Disease Control and Prevention
CEEC	Civil and Environmental Engineering and Constructions
FAR	Floor Area Ratio
GIS	Geographic Information Systems
ICC	Intra-Class Correlation Coefficient
IRB	Institutional Review Board
LOS	Level of Service
LUTRAQ	Land-Use, Transportation and Air Quality Connection
MAPS	Microscale Audit of Pedestrian Streetscapes
mph	Miles per Hour
MPO	Metropolitan Planning Organization
MVPA	Moderate and Vigorous Physical Activity
NDOT	Nevada Department of Transportation
NEWS	Neighborhood Environment Walkability Scale
NEWS-A	Neighborhood Environment Walkability Scale - Abbreviated
NHTS	National Household Travel Survey
PA	Pennsylvania
PEDS	Pedestrian Environment Data Scan
PEF	Pedestrian Environmental Factor
PEI	Pedestrian Environment Index
RTOR	Right Turn on Red
SPACES	Systematic Pedestrian and Cycling Environmental Scan
SPSS	Software Package for the Social Sciences
TAZ	Traffic Analysis Zone
TIGER	Topologically Integrated Geographic Encoding and Referencing
UK	United Kingdom
UNLV	University of Nevada Las Vegas
VMT	Vehicle Miles Traveled
WPS	Walkable Places Survey
WPDI	Walking Permeability Index

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