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A GIS Based Approach to Measure Walkability of a Neighborhood

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ABSTRACT

Obesity has become one of the major issues in the United States. Research done by Center for Disease Control and other organizations revealed the relationship between obesity and physical inactivity. This is a major concern to the planners today, as the built environment affects the walkability of a neighborhood and influences the pedestrian's choice of walking. In this thesis, an effort is made to identify the measures of walkability and incorporate them into a GIS based model that would help in determining the level of walkability in a neighborhood. The model is then tested on a neighborhood in St Louis named Central West End.

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1. INTRODUCTION

1.1. Background of the Study

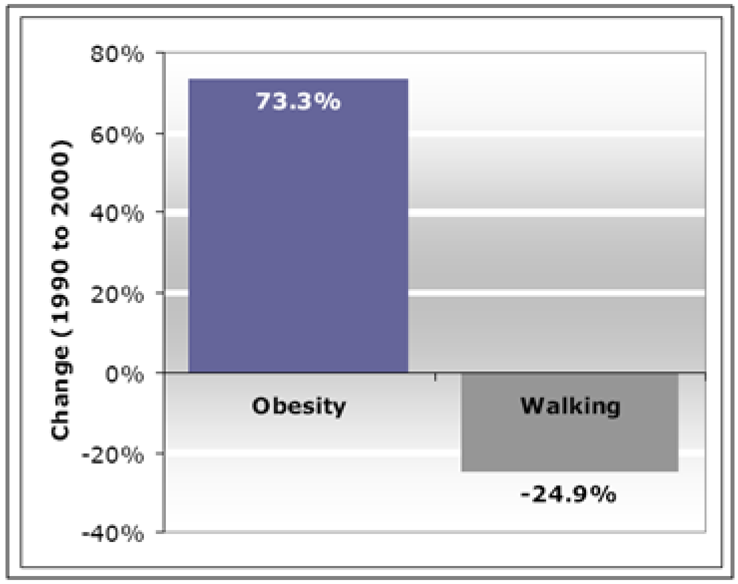
Urban planning, since its conception has been influenced by public health. Historically, urban planning was considered as a solution to alleviate the public health issues, especially overcrowding and sanitation. The early actions of planning by urban planners and futurist architects like Fredrick Law Olmsted and Frank Lloyd Wright indeed were in response to the unprecedented public health issues in those times. Major planning achievements such as Land-Use planning and zoning were the solutions to the health problems of the public caused by haphazard development of industries and residences (Ackerson 2005).

Planning advancements of yesteryears in zoning that were believed to be a *boon* for public health has lately been realized to be a *bane* considering the same health issues. With the zoning laws put in place, land uses have been segregated. This segregation of land uses mixed with urban sprawl has made automobiles an inevitable mode of transportation, reducing the physical activity in public resulting in associated health problems.

1.2. Walking and Health

The sprawling development and streets filled with cars create a negative environment for walking or bicycling as a major means of transportation. With the trends showing the increased levels of obesity, America has now declared obesity as public health issue at a national level.

Figure 1: Trend in Adult Obesity and Walking Rates (1990 to 2000)



Source: Ernst 2004, 24

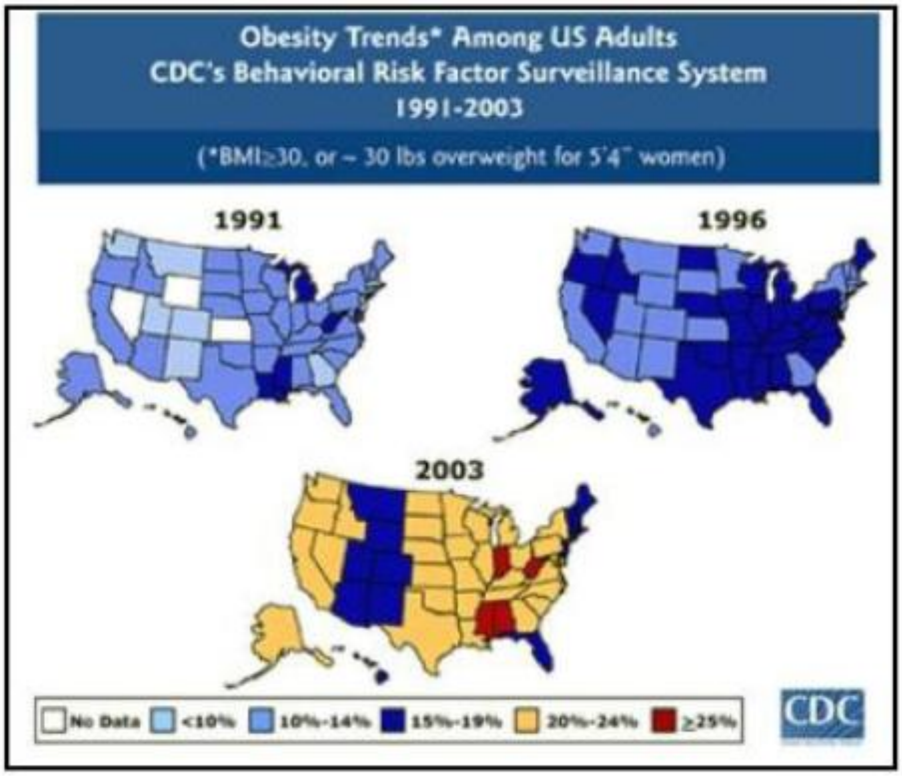
Physical inactivity or walking less is resulting in the increased percentage of children who are obese or overweight. It is the same scenario with adults as well. The figures below show the trends in increased levels of obesity from 1980 to 2003. The portion of people who walk to work dropped by 25 percent between 1990 and 2002, at the same time that the percentage of the population who are obese jumped 70 percent (Ernst 2004).

Walking is the most prevalent form of basic physical activity, and public health officials blame physical inactivity for an estimated 250,000 deaths annually. Moderate physical activity has been linked to a wide range of benefits, including lowering the risk for heart disease, stroke, colon and breast cancer, diabetes, and high blood pressure. Studies have also shown its benefits in warding off high cholesterol and depression.

According to the *Surface Transportation Policy Project*'s report, the medical costs of physical inactivity are estimated at about $76 billion per year. Meanwhile, the federal transportation program, which weighs in at about $46 billion per year, spends less than one percent of that – about $240 million annually – on creating safer places to walk and bicycle.

The level of planning for automobile-oriented transportation networks are so seamless that commuters have negligible issues in going from the garages of their homes to the basements in their worksites without so much as a short walk. There is no such planning for pedestrians, bicycle and transit facilities that would encourage walking and make walking safer. For that to happen there is every need to design wider sidewalks, improved lighting, safe crossings and attractive transit wait areas can combine to improve the experience of walking. Communities that are designed with an emphasis other travel options – walking, biking and transit improves physical activity and better health (Ernst, 2004).

Figure 2: Obesity Trends among US Adults from 1991 to 2003



Source: www.cdc.gov

1.3. Need for Walkable Communities:

The STTP states that the reasons behind such low percentages of pedestrians in U.S. are believed to be because getting places on foot is still difficult in many parts of the U.S., and in far too many cases, unsafe. Recent public health studies have found that per mile, people out walking in the United States are three times as likely to be killed as in Germany, and over six times as likely to be killed as in the Netherlands. Transportation engineering solutions to the problem of the unsafe walking environment do exist, but implementation has been spotty and slow (Ernst, 2004).

During the period between 1998 and 2003, only 1.1 percent of federal transportation funding was put into improvements in pedestrian and bicycle facilities, despite the fact that over 13 percent of all traffic deaths are people on foot or bicycle. In fact, 17 percent of traffic fatalities among people 65 and over were pedestrians and bicyclists in 2002 (FARS, 2002).

Improving the walking and bicycling environment is already a high priority among the general population. In a poll released last year, 42 percent of Americans reported that "dangerous intersections make crossing the street difficult in the area close to where [I] live." Almost 9 out of 10 (87 percent) supported the proposal to "use part of the transportation budget to design streets with sidewalks, safe crossing and other devices" (STPP 2003).

1.4. Roadmap:

The background of the study is established, explaining the health issues caused due to physical inactiveness in Chapter 1: Introduction. This chapter discusses in detail about the need for creating walkable communities, health benefits of walkability. Chapter 2: Problem Statement and Methodology explains the problem statement, aim of the study and the methodology, explaining the flow of the thesis.

The remaining chapters in this thesis will cover literature review, measures of walkability, description of the case study – Central West End, the GIS model for walkability index and the document concludes with the chapter of results and conclusions. In Chapter 3: Literature Review, walkability is studied in detail about the characteristics, benefits, barriers and measures. In addition to this, the various models developed based on walkability are studied, which forms the basis of measures to be used in the following chapters. In Chapter 4: measures of Walkability, the walkability measures are established based on the previous chapter. In Chapter 5: Walkability Index – A Spatial Model, the working of the GIS model is explained. In Chapter 6: Measuring Walkability of Neighborhood: Central West End, a neighborhood in St Louis, is selected as the study Area. This area is then evaluated more in detail with respect to walkability using the GIS model, to determine the walkability index of the neighborhood. The thesis report is then concluded with a chapter on Findings and Conclusion, which explains the users, advantages of the model, short comings and future directions.

PROBLEM STATEMENT & METHODOLOGY | 2

2. PROBLEM STATEMENT & METHODOLOGY

There has been a growing interest in understanding the correlation between the attributes of the built environment and physical activity (Leslie et al, 2004). Leslie et al in their report mention that “In Australian studies, Giles-Corti and Donovan have demonstrated that having greater access to recreational facilities is associated with an increased likelihood of being active and that both objective (access to open spaces) and perceived (aesthetic) environmental attributes are associated with walking at recommended levels. Walking is the most common adult physical activity behavior and walking in and around local neighborhoods is an important component of most adults’ total physical activity” (Leslie et al 2004, 227).

Considerable amount of research is being taken place in the studying the factors that influence people to walk in particular to the environmental factors. A wide range of factors have been associated with walking behavior by public health professionals and transport and town planners, due to the recognition that neighborhood design and land use may affect transportation choice, such as automobile, public transit or walking/cycling (Coffee, 2005).

2.1. Problem Statement

A range of characteristics of walkability have been identified from the literature and grouped as proximity and connectivity (Sallis et al, 2004). In many of the studies, land use mix, street network and retail access are given importance in measuring the walkability. This thesis focuses on studying different models of walkability in order to suggest a GIS – Based walkability index that can be used as an evaluation tool for neighborhoods in general. A GIS approach is followed for the present study because GIS is a software that has ability of analyzing data both spatially and non-spatially and has the capacity of integrating large disparate data, that will be used in the process of calculating the walkability Index of a neighborhood. The specific aim of the present study is to construct a GIS based model for creating walkability Index for a neighborhood, with measures identified from the literature review, namely, street connectivity, proximity, density, land use mix and safety.

2.2. Research Questions:

i. What variables are most appropriate for measuring neighborhood walkability?

ii. How can the measures of walkability be incorporated into a GIS based model?

2.3. Methodology

Walkability has been gaining great importance in recent years and is becoming an important component of planning and designing communities in order to make them more pedestrian and bike friendly. The following steps were followed in the completion of the study:

Step 1. Conduct a thorough literature study on the concept of walkability, including its various elements, characteristics, indicators, benefits, and barriers, in order to help frame the concept.

Step 2. Review the walkability models developed in the past, and study the measures, and indicators used by them for evaluating walkability.

Step 3. Establish a set of measures of walkability based on steps 1 & 2which would later be used for walkability index.

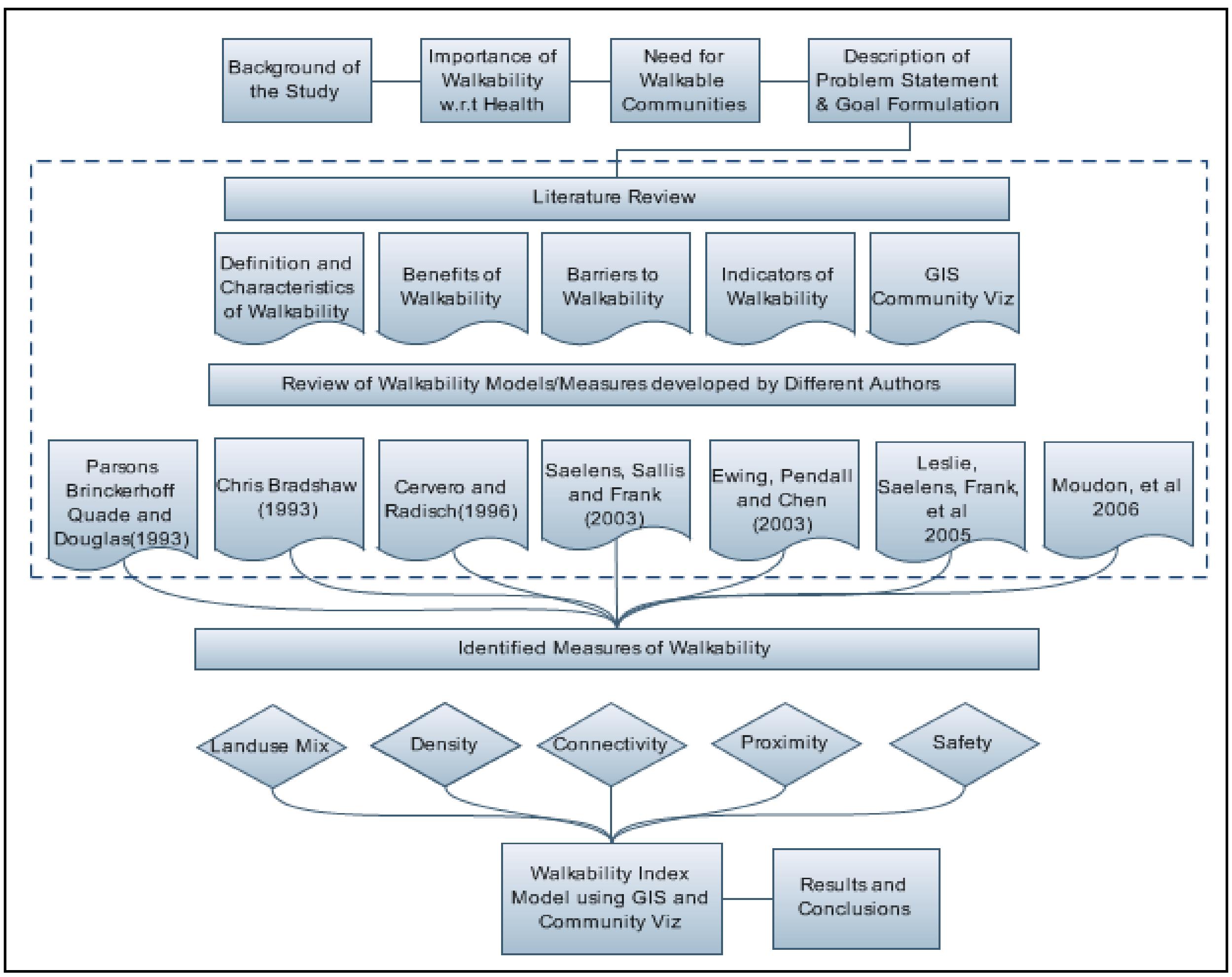
Step 4. Create a GIS Model that can appraise the selected study area based on the walkability indicators identified in step 3. This model would give the walkability Index of the neighborhood.

Step 5. Select a study area for evaluating the walkability Index using GIS

Step 6. Evaluate the selected neighborhood using the model and the measures developed to determine and analyze the walkability of the community.

Step 7. Results and conclusions accomplished in the model.

Figure 3: Methodology



Source: Author

LITERATURE REVIEW 3

3. LITERATURE REVIEW

3.1. Purpose and Scope

The purpose of this literature review is to study in detail the meaning of the term walkability, its characteristics and the various elements of walkability. The chapter deals with major issues of walkability such as the benefits, barriers. There are numerous benefits of walking including health, transportation, environmental, economic, social and overall quality of life benefits. The barriers of walkability are also plenty in number which obstruct the pedestrians' choice of walking in neighborhoods. This chapter deals with all the afore mentioned issues. This chapter proves to be essential in determining the various aspects of walkability in a neighborhood as it lays the foundation for identifying the indicators of walkability in the subsequent chapters.

3.2. Definition of Walkability

Walkability has been defined in many ways taking different factors into consideration under different scenarios. Walkability reflects the overall support for pedestrian travel in an area. Walkability takes into account the quality of pedestrian facilities, roadway conditions, land use patterns, community support, security and comfort for walking. Walkability may be defined as the "The extent to which walking is readily available to the consumer as a safe, connected, accessible and pleasant activity" (www.tfl.gov.uk).

According to Dan Burden, "Walkability *is the cornerstone and key to an urban area's efficient ground transportation. Every trip begins and ends with walking. Walking remains the cheapest form of transport for all people, and the construction of a walkable community* *provides the most affordable transportation system any community can plan, design, construct and maintain. Walkable communities put urban environments back on a scale for sustainability of resources (both natural and economic) and lead to more social interaction, physical fitness and diminished crime and other social problems. Walkable communities are more liveable communities and lead to whole, happy, healthy lives for the people who live in them"* (www.walkable.org).

3.3. Characteristics of Walkability

Walkability can be evaluated at various scales. At a site scale, walkability is affected by the quality of pathways, building access ways and related facilities. At a street or neighborhood level, it is affected by the existence of sidewalks and crosswalks, and roadway conditions (road widths, traffic volumes and speeds). At the community level it is also affected by land use, accessibility, roadway Connectivity, such as the relative location of common destinations and the quality of connections between them (Litman 2004).

Chris Bradshaw[1], in his paper presented to the 14th International Pedestrian Conference, mentions that walkability has four basic characteristics:

i. A "foot-friendly" man-made, physical micro-environment which has wide, level sidewalks, small intersections, narrow streets, adequate trash cans, good lighting with no obstructions on the roads.

[1] Chris Bradshaw is a retired municipal planning official who has been active in walking advocacy since 1980 and car sharing entrepreneurship since 2000. He presented twice at the Boulder International Pedestrian conferences, 1988 & 1993.

ii. A full range of useful, active destinations within walking distance: shops, services, employment, professional offices, recreation, libraries.

iii. A natural environment that moderates the extremes of weather- wind, rain, sunlight - while providing the refreshment of the absence of man's overuse. It has no excessive noise, air pollution, or the dirt, stains, and grime of motor traffic.

iv. A local culture that is social and diverse. This increases contact between people and the conditions for social and economic commerce.

The London Planning Advisory Committee has described the following to be the five Cs that characterize the walkability of a place (www.tfl.gov.uk).

i. Connectivity: The extent to which the walking network is connected to key attractors like public transport interchanges, homes, places of work and leisure destinations. With streets connected, people can walk from one place to another without facing any obstacles.

ii. Conviviality: The extent to which walking is a pleasant activity in terms of interaction with people and the built environment, including other road users. Pedestrian routes which are built in such a way are perceived to be friendly and attractive.

iii. Conspicuity: The extent to which walking routes and public spaces are safe and inviting, with attention paid to lighting, visibility and surveillance. This also includes availability of maps and signage.

iv. Convenience: The extent to which walking is able to compete with other modes in terms of efficiency through the implementation of above factors.

v. Comfort: The extent to which walking is made more enjoyable through high quality pavement surfaces, attractive landscaping and architecture, the efficient allocation of road space and control of traffic.

Table 1: Elements of Walkability, Definition and Benefits

Element	Definition	Typical benefits
Pedestrian permeability	The extent to which an accessible environment is provided for pedestrians, free of obstruction and severance.	Reduced waiting times at traffic signals and crossings Pedestrians having priority at side road crossings Pedestrians continuing to use routes which are stopped up for other traffic The implementation of traffic calming, low-speed zones and home zones
Connections to transport	The extent to which the walking network integrates with likely trip origins and destinations, including the public transport network.	The pedestrian network linking to obvious trip ends, such as shops, supermarkets, public spaces and community services Particular attention paid to the interface between trip ends and the pedestrian network, such as providing shelters, seating, and pedestrian signage The environment in the immediate vicinity of public transport nodes and interchanges being more intensively developed and being pedestrian-friendly
Strategic planning	The extent to which the local policies and strategies encourage walking as a mode of transport.	Coordinated land-use and transport planning Controls on development which promote walking Controls on development which encourage increased housing densities around transportation nodes and interchanges Travel plans for school, work, shopping and leisure facilities, including, where appropriate, personal travel plans A regular program of walkability audits The active promotion of walking as a travel mode

Source: www.ltsa.govt.nz

3.4. Benefits of Walkability

Walking is an essential activity in everybody's daily routine. Walking is also an integral element in the majority of trips made by other modes. Walking is generally the first and last mode used irrespective of the major mode of transportation, providing a key interface between land use and motorized travel (www.ltsa.govt.nz).

Making walking a favorable choice of transportation and walkability a viable option, results in a variety of benefits, including basic mobility, consumer cost savings, efficient land use, community livability, improved fitness and public health, economic development, and support for equity objectives (www.walkinginfo.org). The major benefits of walking are detailed in the following pages:-

3.4.1. Health Benefits

The health benefits of regular physical activity are far-reaching: reduced risk of coronary heart disease, stroke, diabetes, and other chronic diseases; lower health care costs; and improved quality of life for people of all ages. Regular exercise provides the opportunity for health benefits for older adults such as a stronger heart, a more positive mental outlook and an increased chance of remaining indefinitely independent—a benefit that will become increasingly important as our population ages in the coming years. The *Center for Disease Control* recommends that some kind of physical activity like walking for about 30 minutes a day can prove to be very beneficial from health point of view. (www.walkinginfo.org)

3.4.2. Transportation Benefits:

Walking and bicycling can help to reduce roadway congestion. Many streets and highways carry more traffic than they were designed to handle, resulting in gridlock, wasted time and energy, pollution, and driver frustration. Walking requires significantly less space per traveler than driving. Roadway improvements to accommodate pedestrians can also enhance safety for motorists. For example, adding paved shoulders on two-lane roads has been shown to reduce the frequency of run-off-road, head-on, and sideswipe motor vehicle crashes. (www.walkinginfo.org)

3.4.3. Environmental/Energy Benefits:

Motor vehicles create a substantial amount of air pollution. In fact, according to the EPA, transportation is responsible for nearly 80 percent of carbon monoxide and 55 percent of nitrogen oxide emissions in the U.S. Not surprisingly, many metropolitan areas do not meet the air quality standards specified in the 1990 Clean Air Act Amendments. Although individual cars are much cleaner today than they were in earlier years, if total traffic continues to grow, overall air quality will deteriorate. Moreover, every day cars and trucks burn millions of barrels of oil, a non-renewable energy source (www.walkinginfo.org).

3.4.4. Economic Benefits:

Walking is an affordable form of transportation. Car ownership is expensive, and consumes a major portion of many Americans' income. When safe facilities are provided for pedestrians, people can walk more and spend less on transportation, meaning they have more money to save or spend on other things (www.walkinginfo.org).

Table 2: Economic Impacts of Walkability

Table 6 Walkability Economic Impacts

Name	Description	Measuring Techniques
Accessibility	Degree that walking provides mobility options, particularly for people who are transportation disadvantaged.	Travel modeling, analysis of travel options.
Consumer cost savings	Degree to which walking provides consumer transportation cost savings.	Consumer expenditure surveys
Public cost savings (reduced external costs)	Degree that walking substitutes for vehicle travel and reduces negative impacts.	Determine to what degree walking reduces motor vehicle travel, and the economic savings that result.
Efficient land use	Degree that walking helps reduce the amount of land used for roadway and parking facilities, and helps create more accessible, clustered land use.	Identify the full economic, social and environmental benefits of more pedestrian-oriented land use.
Livability	Degree that walking improves the local environment.	Property values, business activities, consumer preference surveys.
Public fitness and health	Degree that walking provides physical exercise to people who are otherwise sedentary.	Travel and health surveys to determine the number of people who benefit from walking exercise.
Economic development	Degree to which walking makes commercial areas more attractive and shifts consumer expenditures to goods that provide more regional economic activity and employment.	Market surveys and property assessments. Input-output table analysis.
Equity	Degree that walkability helps achieve various equity objectives.	Various indicators of horizontal and vertical equity.

Source: Litman 2004, 14

3.4.5. Quality of Life Benefits:

Better conditions for walking have intangible benefits to the quality of life in cities and towns. In a growing number of communities, the level of walking is considered an indicator of a community's livability—a factor that has a profound impact on attracting businesses and workers as well as tourism. In cities and towns where people can regularly be seen out walking, there is a palpable sense that these are safe and friendly places to live and visit.

The social interaction possible when the number of people walking increases is a major factor for improving quality of life. Comfortable and accessible pedestrian environments offer alternatives to personal vehicles, which limit opportunities for social contact with others. By providing appropriate pedestrian facilities and amenities, communities enable the interaction between neighbors and other citizens that can strengthen relationships and contribute to a healthy sense of identity and place. (www.walkinginfo.org)

3.4.6. Social Justice Benefits:

Perhaps the most important factor in walking and social justice is choice. When providing pedestrian facilities such as sidewalks and crosswalks, communities allow people to choose how they want to travel. One consequence of not installing these facilities is to force people to travel by personal vehicle or to engage in unsafe walking practices. For those who do not have the option to drive, such as adolescents, those unable to afford a car, and people with certain disabilities, this lack of choice in transportation creates an inconvenient and socially unjust barrier to mobility.

The high cost of car ownership means that low-income families will have to spend a greater portion their income on owning and operating a car or choose not have one. If automobile travel is the only feasible mode of transportation in a community, low-income families are placed at a large disadvantage with very limited mobility. By providing safe and convenient pedestrian facilities, the community can ensure that all citizens have access to a viable mode of transportation (www.walkinginfo.org).

Table 3: Economic, Social and Environmental Benefits of Walkability

Table 4 Land Use Benefits of Improved Walkability

Economic	Social	Environmental
Improved accessibility, particularly for non-drivers. Reduced transportation costs. Increased parking efficiency (parking facilities can serve more destinations). Can increase local business activity and employment. Support for transit and other alternative modes. Special support for some businesses, such as walking tourism. Health cost savings from improved exercise.	Improved accessibility for people who are transport disadvantaged. Reduced external transportation costs (crash risk, pollution, etc.). Increased neighborhood interaction and community cohesion. Improved opportunities to preserve cultural resources (e.g., historic buildings). Increased exercise.	Reduced land needed for roads and parking facilities. Openspace preservation. Reduced energy consumption and pollution emissions. Improved aesthetics. Reduced water pollution. Reduced "heat island" effects.

Source: Litman 2004, 9

3.5. Barriers to Walkability

Pedestrians, in many places face problems in walking due to obstacles on their way. The knowledge and awareness of the barriers that influence people's willingness and choice to walk are the first steps for individuals, organizations, and communities to make the changes that will effectively reduce or eliminate such barriers (www.walkinginfo.org). The barriers of walking can be broadly categorized into following:

3.5.1. Physical Environment:

Physical barriers are the most obvious deterrent to walking (www.walkinginfo.org). Some of the reasons include:

- Missing footpaths or sections of footpath
- Poor quality (cracked, uneven or slippery) walking surfaces
- Obstacles on the footpath, including poorly placed street furniture
- Lack of maintenance of footpaths, including litter, dog fouling, and overhanging vegetation
- Increased distances imposed by road layouts, barriers, footbridges and subways
- Lack of continuous signing to potential destinations
- Uncertainty about whether a route is fully accessible
- Lack of continuous pedestrian routes
- Missing or unsuitable crossing treatments creating severance
- Poor quality lighting
- Speeding traffic
- Lack of rest areas and seating
- Traffic fumes and noise
- No through routes which require indirect routes
- Public routes which appear to be private
- Lack of shade
- Lack of shelter from inclement weather
- Lack of interesting features on the route.

3.5.2. Social and Perceptual Deterrents:

Social and perceptual deterrents are important. Potential reasons include:

- Perceived lack of time to make journeys
- Lack of confidence in the walking infrastructure
- Confusion about which route to take and how far the destination is
- Perception that pedestrians generally have a low social status, especially in relation to car drivers
- Perceived risk to personal security and/or a lack of surveillance
- Perception that motorists do not properly understand the rights of pedestrians. (www.walkinginfo.org)

3.5.3. Organizational and Institutional Issues

There are several organizational and institutional issues that cause major barriers that make walking a difficult option for pedestrians (www.walkinginfo.org). These include:

- Land use planning which has resulted in longer distances between walking trip origins and destinations
- Other modes of travel are prioritized more highly than walking, resulting in pedestrians not being realistically accommodated within schemes designed for other travel modes

- Lack of knowledge and expertise amongst infrastructure providers and relevant professions regarding the ways to provide for walking
- Tolerating obstructions which are placed in the footpath by third parties
- Difficulties in quantifying changes in pedestrian numbers as a result of potential interventions
- Difficulties in justifying walking schemes through 'traditional' economic criteria
- Businesses paying mileage travel allowances to car drivers for very short trips
- Lack of research into pedestrians and walking journeys
- Insufficient resources allocated to walking schemes.

3.6. A Summary of Studies on Walkability

There have been numerous studies on walkability taken up in the past. In this section of the report, an effort is made to emphasize some of these studies that form the base for identifying the measures of walkability to be used in formulating the model. The following seven studies on walkability were identified by Coffee (2005) in his report.

a. <u>Parsons Brinckerhoff Quade and Douglas Inc (1993):</u>

According to a 1993 report by Parsons Brinckerhoff Quade and Douglas Inc. on the pedestrian environment in Oregon, as a part of the land use, transport and air quality research in Portland, it was reported that increase in the quality of pedestrian environment could achieve 10% reduction in vehicle miles traveled (Leslie et al Health & Place 13 (2007)). The factors that were used for this study in categorizing the walkability of neighborhoods were:

- Ease of street Crossing
- Sidewalk continuity
- Street Connectivity
- Topography

b. Chris Bradshaw (1993)

In a paper presented at the 14th International Pedestrian Conference, Colorado, Bradshaw came up with a rating system to measure the walkability index of a neighborhood. Bradshaw (1993), apart from including the aspects of proximity and connectivity as the measures of walkability, he used the following set of indicators to measure the walkability index of a neighborhood:

- Density, persons per acre
- Parking spaces off-street per household
- Number of sitting spots per household
- Chance of meeting someone while walking
- Age at which a child is allowed to walk alone
- Women's ranking of safety
- Responsiveness of transit services
- Number of neighborhood places of significance
- Acres of parkland and
- Sidewalks

c. <u>Cervero and Radisch (1996)</u>

In the study by Cervero and Radisch in 1996, a comparison was done on choices between a pedestrian and an automobile oriented neighborhood in San Francisco. The measures used in this study are more in detail compared to the previous study mentioned above. The indicators that were in calculating the walkability of the neighborhood are:

Pedestrian – Oriented neighborhoods:

- Older
- High residential density with greater number of apartments and attached housing units
- High number of blocks and intersection
- Mixed-use of land
- Grid-like street pattern
- Greater number of 4-way intersections than "T" intersections and cul-de-sacs
- Traditional design qualities
- Integrated network of sidewalks and pedestrian paths
- Shade trees in planting strips

d. <u>Saelens, Sallis and Frank (2003)</u>

Saelens, Sallis and Frank (2003) examined the correlation between environmental factors of walking and biking from transportation planning studies. The main aspect of this study was linking health with planning research. The prominence of neighborhood design and land use in affecting the transportation choices is also examined in this study. The factors that affected the preferences of the user between motorized and non-motorized transportation were categorized into the following:

- Proximity
    - Density
    - Land use
- Connectivity
    - Ease of moving between origins and destinations

e. <u>Pendall and Chen (2003)</u>

In studies by Ewing, Pendall and Chen in 2003, walkability was studied in the context of much larger problem. The emphasis in this study was on examining the links between urban sprawl and traffic, air pollution, central city poverty and degradation of scenic areas. By defining sprawl as low density, segregated land uses, lack of thriving central areas and limited travel choices, the walkability aspect was thus highlighted in this study.

The measures used in this study included:

- Residential density
- Neighborhood land use mix
- Strengths of centers and
- Accessibility of street network

f. <u>Leslie, Saelens, Frank, Owena, Baumand, Coffee, Hugo (2003)</u>

In Leslie et al's report on *Walkability of Local Communities* (2005), GIS was used to measure the features of the built environment that may influence adults' physical activity. In this study, the measures that were used to calculate the walkability index were:

- Connectivity

- Dwelling density
- Land Use attributes
- Net retail area

g. Moudon, Lee, Cheadle, Garvin, Johnson, Schmid, Weathers, Lin(2006)

Moudon, et al (2006), reviewed the theories that defined neighborhoods and proposed an empirical approach to identify measurable attributes and thresholds of walkable neighborhoods. This study is a step ahead of the previous ones, as it not only which identified environmental attributes that are positively associated with walking, but also came up with values for residential density, street-blocks lengths around homes, distances to food and daily retail facilities from home and threshold distances for eating/drinking establishments and grocery stores. Measures and threshold values were calculated for the following:

- Residential Density
- Block size
- Sidewalks
- Attractor Destinations
- Deterrent Destinations
- Perceived Number of Central Activities in and Geographic Extent of Walkable Neighborhood.

According to the studies mentioned above, there are a wide range of characteristics that are correlated to the walkability of a neighborhood. Throughout the literature, studies on walkability and models developed; there is a consistent emphasis on connectivity, proximity, land use mix, density and safety. The tables below show the broad groups of measures that have been mentioned consistently in the literature.

Table 4: Measures of Walkability as Described by the Authors

Parsons Brinckerhoff Quade and Douglas Inc	Chris Bradshaw	Cervero and Radisch	Saelens, Sallis and Frank	Pendall and Chen	Leslie, Saelens, Frank, Owena, Baumand, Coffeee, Hugo	Moudon, Lee, Cheadle, Garvin, Johnson. Schmid, Weathers, Lin
Ease of street Crossing	Density	Residential density	Proximity	Density	Connecti-vity	Residential density
Sidewalk continuity	Parking	Number of blocks and intersection	Density	Land Use Mix	Dwelling density	Block size
Street Connectivity	Sitting Spots	Mixed-use of land	Land use	Strengths of Centers	land use attributes	Sidewalks
Topography	Meeting spots	Grid-like street pattern	Connectiv-ity	Street Network	Net Retail area	Attractor destinations
	Age at which children can walk alone	Greater number of 4-way intersect-ions	Ease of moving			Deterrent destinations
	Percep-tion of Safety	Traditional design qualities				Central Activities
	Transit Services	Integrated network of sidewalks and pedestrian paths				
	Places of Signific-ance	Shade trees in planting strips				
	Parkland					
	Sidewalks					

Source: Author

Table 5: Measures of Walkability mentioned by various Authors

Measures	Authors
Connectivity	Parsons Brinckerhoff Quade and Douglas Inc (1993), Leslie, Saelens, Frank, Owena, Baumand, Coffeee, Hugo (2003), Pendall and Chen (2003), Cervero and Radisch (1996), Saelens, Sallis and Frank (2003), Chris Bradshaw (1993)
Proximity	Saelens, Sallis and Frank (2003), Cervero and Radisch (1996), Chris Bradshaw (1993)
Density	Moudon, Lee, Cheadle, Garvin, Johnson. Schmid, Weathers, Lin(2006), Bradshaw(1993), Saelens, Sallis and Frank (2003), Leslie, Saelens, Frank, Owena, Baumand, Coffeee, Hugo (2003), Pendall and Chen (2003), Cervero and Radisch (1996)
Land Use Mix	Leslie, Saelens, Frank, Owena, Baumand, Coffeee, Hugo (2003), Pendall and Chen (2003), Cervero and Radisch (1996), Saelens, Sallis and Frank (2003)
Safety	Bradshaw (1993)

Source: Author

Having identified the measures of walkability in this chapter, the next chapters deal with the description on how these measures would be incorporated into the GIS model in measuring the walkability of a neighborhood

MEASURES OF WALKABILITY 4

4. MEASURES OF WALKABILITY

In the previous chapter, 5 measures have been identified based on the literature. Due to the consistent use of these measures by renowned authors on walkability, these measures have been selected to be incorporated in the GIS based model, which can be of potential use to planners, developers and decision makers in evaluating the walkability of a community. The 5 measures are:

i. Connectivity Measure
ii. Proximity Measures
iii. Density Measures
iv. Land Use Mix Index
v. Safety measures

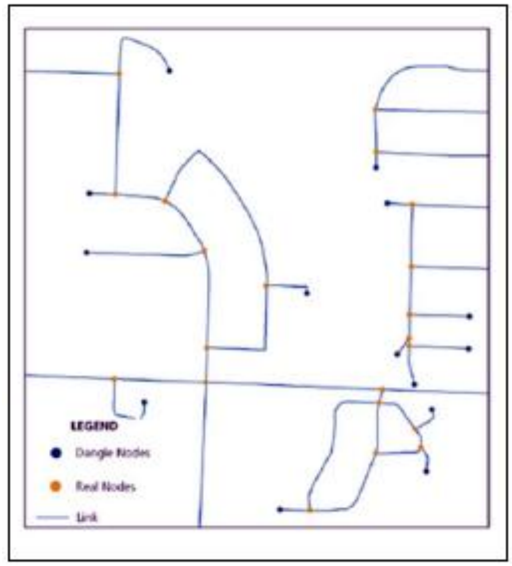
4.1. Connectivity Measures

It is difficult to bicycle and walk safely and comfortably around a community where connections are few and far between. The Victoria Transport Policy Institute states that,

"Connectivity refers to the directness of links and the density of connections in path or road network. A well connected road or path network has many short links, numerous intersections, and minimal dead ends (cul-de-sacs). As connectivity increases, travel distances decrease and route options increase, allowing more direct travel between destinations, creating a more accessible and resilient system." (Tresidder 2005)

4.1.1. Connectivity Definitions

Figure 4: Connectivity Definitions



Source: Tresidder 2005, 5

Link: A roadway or pathway segment between two nodes. A street between two intersections or from a dead end to an intersection.

Node: It is defined as the endpoint of a link, either a real node or a dangle node

4.1.2. Measuring Connectivity

There are several methods of evaluating connectivity one of most common measures of evaluating connectivity is Gamma Index. ***Gamma index*** is the ratio of the number of links in the network to the maximum possible number of links between nodes.

$$\textit{Gamma Index Formula} = \frac{\textit{actual number of links}}{3*(\textit{number of nodes} - 2)}$$

This measure comes from geography. Values range from 0 to 1.

4.2. Proximity to Nearest Activity Places

The concept of accessibility is frequently cited in the literature and it is worth providing a brief description of this oft-used term. Accessibility has been defined as the "intensity of the possibility of interaction" (Hansen 1959). The level of accessibility is reflected in both the nature of nearby destinations and characteristics of the routes themselves – the ease of use and appeal of those destinations. There is a wide range of variables that can be measured regarding destinations, including both quantifiable data as well as highly qualitative information, ranging from the quantity of destinations to the appeal of shopping areas. The second group of variables, which are related to routes and are equally wide ranging include such measures as route distance, travel time, and variety of scenery along the route.

Proximity to activity places is one of the most critical factors in determining the friendliness of a neighborhood to walkability. Proximity to daily activities promotes the concept of walkability. There are several activities that should be within walkable distance (write about walkability needs of elderly). The activity places are primarily categorized into 5 categories, Educational, recreational, medical, Food, Shopping, and Public Transit. (www.walkscore.com)

Table 6: Major Walking Destinations in the Neighborhood

Educational Facilities	Recreational Facilities	Medical Facilities	Food Facilities	Shopping and Retail Facilities	Public Transit
Schools	Parks	Clinics	Restaurants	Books and Retail	Bus Stops
Colleges	Fitness Centers	Physicians	Fast-food	Department Stores	Transit Station
Universities	Land marks	Hospitals	Ice Cream Shops	Grocery Stores	
Libraries	Theaters	Drug Stores		Convenience Stores	
	Churches	Pharmacies			

Source: Author

Proximity for the purpose of this study is defined as the shortest distance by road to the closest facility.

Table 7: Level of Walkability Based on Proximity

Rank	Distance
Highly walkable	<0.25 Miles
Walkable	0.25 – 0.5 Miles

Moderate walkability	0.5 – 0.75 Miles
Low walkability	0.75 – 1.5 Miles
Not walkable	+1.5 Miles

Source: Author

4.3. Density Measure:

In 1997, Cervero and Kockelman used density measures to conduct a study of urban design variables believed to affect travel behavior (Cervero 1997). Densities proved to exert the strongest influence on personal business trips. Residential neighborhoods with easily accessible commercial activities tended to average significantly less vehicle miles traveled (VMT) per household. Interestingly, the dimension of 'walking quality' was moderately associated with travel demand. That is to say, the influence of attractive sidewalks on mode choice for non-work trip making was stronger than that of density. Moreover, neighborhoods with high shares of four-way intersections tended to average less single-occupant vehicular travel for non-work purposes, which indicate grid street patterns may reduce VMT.

The density measure can be calculated several ways for the purpose of the study the density is measured as net residential density. Net Household Density is the ratio of total number of Households to the residential land in the neighborhood.

Net Dwelling Density = Di/RAi

Where D = dwelling count for each CCD

RA = residential area for each CCD

This results in a number usually between 0 and 30. Based on the classification given by Moudon, et al., density is categorized in to the following 4 categories

Table 8: Density Level Based on Number of Households per Acre

Type	Measure
High Density	20 Households or more per acre
Moderate Density	15-20 Households per acre
Low Density	10-15 Households per acre
Sprawl	Less than 10 Households

Source: Author

4.4. Land Use Mix Index

Land use unlike other measures, is not a single measure but an indication of heterogeneity (or diversity) of land use mix in each neighborhood. Measures of diversity are often applied in demographic analysis and include the entropy index and interaction index. For the purpose of the study only entropy index is used for measuring the diversity of land uses mix.

<u>Entropy Index</u>

The entropy index uses the following formula, where k is the category of land use and N is the number of land use categories and P is the percent of each land use in the neighborhood. (Leslie, et al 2005)

$$\frac{\sum_k (p_k \ln p_k)}{\ln N}$$

The entropy equation results in a score of 0–1, with 0 representing homogeneity (all land uses are of a single type), and 1 representing heterogeneity (the developed area is evenly distributed among all land use categories)

4.5. Safety Measures

For a place to be walkable, it has to ensure safety. Safety is the first and foremost concerns of any pedestrian. Again to ensure safety, the foremost related issues are provision of infrastructure. The perception of safety in terms of crime and traffic are considered to be crucial factors of walking and biking rates and thus community health. Jane Jacobs, a co-creator of the term 'social capital,' argues many of the same points as Robert Putnam regarding the influence of public safety on walkability. Jacobs argues that city streets must have clearly defined public and private spaces. Secondly, she insists buildings must face the sidewalk so there are many 'eyes on the street.' This ensures that strangers and residents can be seen and held accountable for their actions by anyone watching. Finally, Jacobs believes streets must have people – to increase the number of eyes, but also generate activity and life (Jacobs 1961; Putnam 2000).

Jacobs suggests that informal social control, including the shopkeeper protecting his/her customers, the couple walking to a movie, and parents running errands, collectively provide a layer of oversight that protects individuals on the street. The most essential element creating this atmosphere is a substantial number of shops, stores, restaurants, bars, and public places that attract 'good people.' The upshot of full sidewalks is that nothing goes unnoticed, including crime. Wilson and Keeling recall the effect foot patrol officers had on Newark residents when they replaced car patrols (Wilson 1982). Although foot patrols had no effect on crime per se they fooled the residents into thinking the streets were safer. The foot patrols effectively elevated the level of public order in these neighborhoods, and to the extent that residents felt free to go outside they too increased the level of order. Together they increased the number of eyes on the street. These results suggest that programs that promote walking and biking to schools may increase residents' perception of safety simply by elevating the number of people on the street.

Safety measures are taken from Chris Bradshaw's walkability index. According to him, neighborhood would be considered safe, based on a woman's perception of walking on the streets. He ranked the safety based on these four parameters (source: walkability Index by Chris Bradshaw)

Table 9: Safety Measures of Walkability

Rank	Distance
Highly walkable	"I walk alone anywhere anytime"
Moderate walkability	"I walk alone, but am careful of routes"
Low walkability	"I must walk with someone at night"
Not walkable	"I never walk, except to car visible from entrance"

Source: Bradshaw 1993

Summary:

These measures will now be used in calculating the walkability Index. The table below shows the variables of the walkability to be used in the following chapter.

Table 10: Measures of Walkability and its Variables

Measures	Variables
Connectivity	Gamma Index
Proximity	Network Analysis
Density	Net Dwelling Density
Land Use Mix	Entropy Equation
Safety	Bradshaw's perception of Safety

Source: Author

WALKABILITY INDEX: A GIS MODEL | 5

5. WALKABILITY INDEX: A GIS MODEL

This chapter deals with the description of the model by explaining the measures that are used, methodology of the model, and reclassification of the walkability measures to achieve the final walkability score of the study area.

5.1. Creating the walkability index

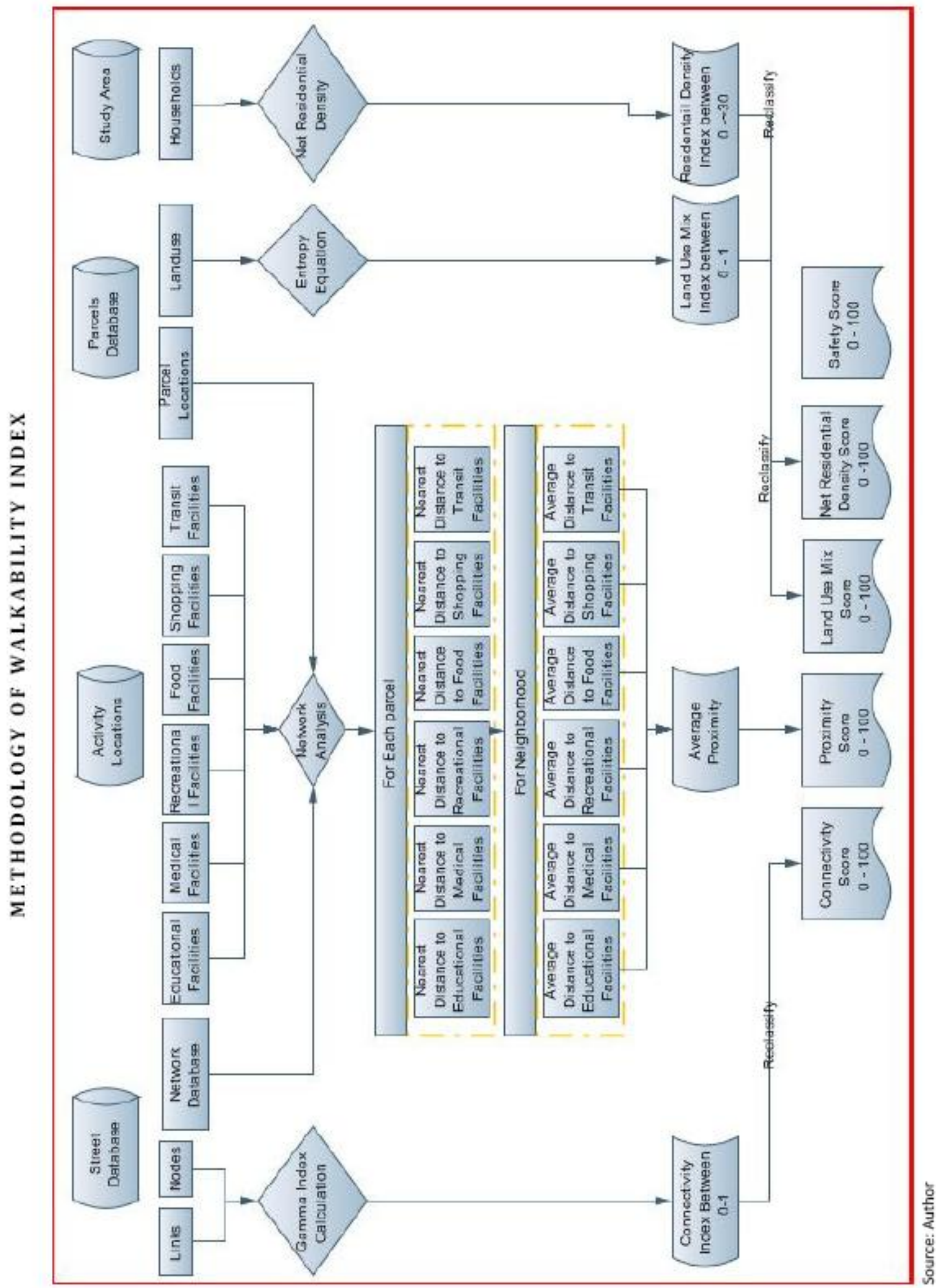
The walkability index is calculated using the above data sets. There are several steps involved in arriving at the final score they are as follows:

1. **Data Collection and processing**: Data sets mentioned above are collected from different sources like City of St Louis, ESRI, Tele Atlas and InfoUSA Business Listings and are compiled and processed to ensure compatibility and consistency.
2. **Analysis:** using the walkability variables defined in chapter 4 (table 10), formulas are created and implemented using the CommunityViz software, using the spatial inputs.
3. To compare the results of the five walkability measures, a means of standardization was required the methods applied was to standardize measures in to percentages. The 0-1 score for measures Connectivity Index, land Use Mix Index and Net household density, is summed for each CCD resulting in a possible score of 4–40. The resulting walkability index is further classified into quartiles with the 1st quartile used to identify low walkability CCDs and the 4th quartile identifying high walkability CCDs. The final walkability indexes are mapped using GIS to visually identify areas in the Adelaide Statistical Division that are conducive or not to walking activities

4. Final Scores: The final scores, after averaging the individual scores gives the walkability index of the neighborhood.

   The figure 5 shown below, explains the methodology of the GIS model

Figure 5: Methodology of GIS Model

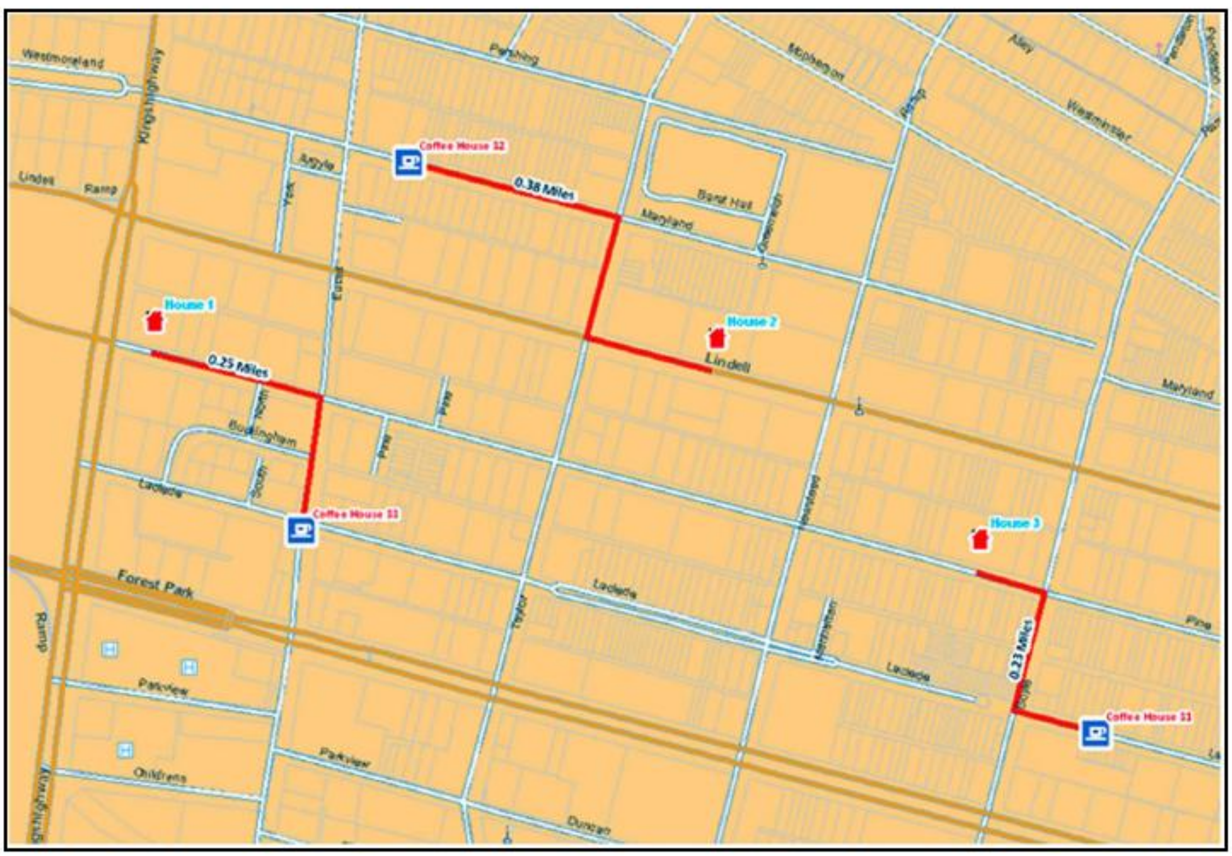


Source: Author

5.2. Calculating closest facilities:

As explained before the distance to each the facilities from each parcel in the neighborhood is calculated using the "Find Closest facility" function of the Network Analyst Extension of the ArcGIS System. For instance the in the figure below (Figure 42) the closest coffee house distance from each of the 3 houses is calculated using network analyst and the Distances are stored in a table. Likewise the process is repeated for all the houses and for all the facilities creating a matrix which would look like table below. The table in which these distance are stored is called "Walkability_Table".

Figure 6: Map Showing Closest Facility Locations



Source: Author

Table 11: Sample matrix of Parcels and Closest facilities, Walkability_table sample

House ID	Distance to Book Stores	Distance to Churches	Distance to Coffee Houses
1	0.10	0.07	0.41
2	0.11	0.08	0.42
3	0.12	0.09	0.43
4	0.12	0.10	0.43
5	0.13	0.11	0.44
6	0.14	0.11	0.45
7	0.15	0.12	0.46
8	0.16	0.13	0.46
9	0.16	0.13	0.47
10	0.17	0.12	0.48
11	0.18	0.12	0.49

Source: Author

5.2.1. Average of Closest Facilities distances:

The calculated distances to closest facilities from each parcel in the neighborhood is then give a score of 0 – 100, basing on the walkability standards (Anjali, 2006) of the elderly, using community viz and stored in a table for further classification and analysis. The formula used for calculating the walkability score to for each parcel in neighborhood is as follows:

Table 12: Formulae for Calculating Closest Facility Distances

Book Stores Walkability	**Type: Double**
	Formula:
	IfThenElse (If ([Attribute:Walkability_table:Books_Dist] <= 0.25),
	Then (100),
	If ([Attribute:Walkability_table:Books_Dist] > 0.25 And [
	Attribute:Walkability_table:Books_Dist] <= 0.5),
	Then (75),
	If ([Attribute:Walkability_table:Books_Dist] > 0.5 And [
	Attribute:Walkability_table:Books_Dist] <= 0.75),
	Then (50),
	If ([Attribute:Walkability_table:Books_Dist] > 0.75 And [
	Attribute:Walkability_table:Books_Dist] <= 1.5),
	Then (25),
	Else (0))

Drug Stores	Type: Double

Walkability	Formula:
	IfThenElse (If ([Attribute:Walkability_table:Pharmacies_Dist] <= 0.25),
	Then (100),
	If ([Attribute:Walkability_table:Pharmacies_Dist] > 0.25 And [
	Attribute:Walkability_table:Pharmacies_Dist] <= 0.5),
	Then (75),
	If ([Attribute:Walkability_table:Pharmacies_Dist] > 0.5 And [
	Attribute:Walkability_table:Pharmacies_Dist] <= 0.75),
	Then (50),
	If ([Attribute:Walkability_table:Pharmacies_Dist] > 0.75 And [
	Attribute:Walkability_table:Pharmacies_Dist] <= 1.5),
	Then (25),
	Else (0))

Education Facilities Walkability	Type: Double
	Formula:
	IfThenElse (If ([Attribute:Walkability_table:Schools_Dist] <= 0.25),
	Then (100),
	If ([Attribute:Walkability_table:Schools_Dist] > 0.25 And [
	Attribute:Walkability_table:Schools_Dist] <= 0.5),
	Then (75),
	If ([Attribute:Walkability_table:Schools_Dist] > 0.5 And [
	Attribute:Walkability_table:Schools_Dist] <= 0.75),
	Then (50),
	If ([Attribute:Walkability_table:Schools_Dist] > 0.75 And [
	Attribute:Walkability_table:Schools_Dist] <= 1.5),
	Then (25),
	Else (0))

Food Facilities Walkability	Type: Double Formula: IfThenElse (If (((([Attribute:Walkability_table:Coffee_Dist] + [Attribute:Walkability_table:Icecream_Dist] + [Attribute:Walkability_table:Pizza_Dist] + [Attribute:Walkability_table:Restraunts_Dist]) / 4)) <= 0.25), Then (100), If (((([Attribute:Walkability_table:Coffee_Dist] + [Attribute:Walkability_table:Icecream_Dist] + [Attribute:Walkability_table:Pizza_Dist] + [Attribute:Walkability_table:Restraunts_Dist]) / 4)) > 0.25 And ((([Attribute:Walkability_table:Coffee_Dist] + [Attribute:Walkability_table:Icecream_Dist] + [Attribute:Walkability_table:Pizza_Dist] + [Attribute:Walkability_table:Restraunts_Dist]) / 4)) <= 0.5), Then (75), If (((([Attribute:Walkability_table:Coffee_Dist] + [Attribute:Walkability_table:Icecream_Dist] + [Attribute:Walkability_table:Pizza_Dist] + [Attribute:Walkability_table:Restraunts_Dist]) / 4))

	> 0.5 And ((([Attribute:Walkability_table:Coffee_Dist] + [Attribute:Walkability_table:Icecream_Dist] + [Attribute:Walkability_table:Pizza_Dist] + [Attribute:Walkability_table:Restraunts_Dist]) / 4)) <= 0.75), Then (50), If (((([Attribute:Walkability_table:Coffee_Dist] + [Attribute:Walkability_table:Icecream_Dist] + [Attribute:Walkability_table:Pizza_Dist] + [Attribute:Walkability_table:Restraunts_Dist]) / 4)) > 0.75 And ((([Attribute:Walkability_table:Coffee_Dist] + [Attribute:Walkability_table:Icecream_Dist] + [Attribute:Walkability_table:Pizza_Dist] + [Attribute:Walkability_table:Restraunts_Dist]) / 4)) <= 1.5), Then (25), Else (0))

Medical Facilities Walkability	Type: Double
	Formula:
	IfThenElse (If (([Attribute:Walkability_table:Hospital_Dist] + [Attribute:Walkability_table:Physicians_Dist] / 2) <= 0.25),
	Then (100),
	If (([Attribute:Walkability_table:Hospital_Dist] + [Attribute:Walkability_table:Physicians_Dist] / 2) > 0.25 And ([Attribute:Walkability_table:Hospital_Dist] + [Attribute:Walkability_table:Physicians_Dist] / 2) <= 0.5),
	Then (75),
	If (([Attribute:Walkability_table:Hospital_Dist] + [Attribute:Walkability_table:Physicians_Dist] / 2) > 0.5 And ([Attribute:Walkability_table:Hospital_Dist] + [Attribute:Walkability_table:Physicians_Dist] / 2) <= 0.75),
	Then (50),
	If (([Attribute:Walkability_table:Hospital_Dist] + [Attribute:Walkability_table:Physicians_Dist] / 2) > 0.75 And ([Attribute:Walkability_table:Hospital_Dist] + [Attribute:Walkability_table:Physicians_Dist] / 2) <= 1.5),
	Then (25),
	Else (0))

Parks and Fitness Facilities Walkability	Type: Double Formula: IfThenElse (If (([Attribute:Walkability_table:Parks_Dist] + [Attribute:Walkability_table:Fitness_Dist] / 2) <= 0.50), Then (100), If (([Attribute:Walkability_table:Parks_Dist] + [Attribute:Walkability_table:Fitness_Dist] / 2) > 0.5 And ([Attribute:Walkability_table:Parks_Dist] + [Attribute:Walkability_table:Fitness_Dist] / 2)

	<= 0.75), Then (75), If (([Attribute:Walkability_table:Parks_Dist] + [Attribute:Walkability_table:Fitness_Dist] / 2) > 0.75 And ([Attribute:Walkability_table:Parks_Dist] + [Attribute:Walkability_table:Fitness_Dist] / 2) <= 1.0), Then (50), If (([Attribute:Walkability_table:Parks_Dist] + [Attribute:Walkability_table:Fitness_Dist] / 2) > 1.0 And ([Attribute:Walkability_table:Parks_Dist] + [Attribute:Walkability_table:Fitness_Dist] / 2) <= 2.0), Then (25), Else (0))

Public Transit Facilities Walkability	Type: Double
	Formula:
	IfThenElse (If ([Attribute:Walkability_table:Transit_Dist] <= 0.25),
	Then (100),
	If ([Attribute:Walkability_table:Transit_Dist] > 0.25 And [Attribute:Walkability_table:Transit_Dist] <= 0.5),
	Then (75),
	If ([Attribute:Walkability_table:Transit_Dist] > 0.5 And [Attribute:Walkability_table:Transit_Dist] <= 0.75),
	Then (50),
	If ([Attribute:Walkability_table:Transit_Dist] > 0.75 And [Attribute:Walkability_table:Transit_Dist] <= 1.5),
	Then (25),
	Else (0))

Recreational Facilities Walkability	Type: Double
	Formula:
	IfThenElse (If (([Attribute:Walkability_table:Recreational_Dist] + [Attribute:Walkability_table:Theaters_Dist] / 2) <= 0.5),
	Then (100),
	If (([Attribute:Walkability_table:Recreational_Dist] + [Attribute:Walkability_table:Theaters_Dist] / 2) > 0.5 And ([Attribute:Walkability_table:Recreational_Dist] + [Attribute:Walkability_table:Theaters_Dist] / 2) <= 0.75),
	Then (75),
	If (([Attribute:Walkability_table:Recreational_Dist] + [Attribute:Walkability_table:Theaters_Dist] / 2) > 0.75 And ([Attribute:Walkability_table:Recreational_Dist] + [Attribute:Walkability_table:Theaters_Dist] / 2) <= 1.0),
	Then (50),
	If (([Attribute:Walkability_table:Recreational_Dist] + [

	Attribute:Walkability_table:Theaters_Dist] / 2) > 1.0 And ([Attribute:Walkability_table:Recreational_Dist] + [Attribute:Walkability_table:Theaters_Dist] / 2) <= 2.0), Then (25), Else (0))

Religious Facilities Walkability	Type: Double
	Formula:
	IfThenElse (If ([Attribute:Walkability_table:Churches_Dist] <= 0.25),
	Then (100),
	If ([Attribute:Walkability_table:Churches_Dist] > 0.25 And [
	Attribute:Walkability_table:Churches_Dist] <= 0.5),
	Then (75),
	If ([Attribute:Walkability_table:Churches_Dist] > 0.5 And [
	Attribute:Walkability_table:Churches_Dist] <= 0.75),
	Then (50),
	If ([Attribute:Walkability_table:Churches_Dist] > 0.75 And [
	Attribute:Walkability_table:Churches_Dist] <= 1.5),
	Then (25),
	Else (0))

Shopping Facilities Walkability	Type: Double Formula: IfThenElse (If ((([Attribute:Walkability_table:Convinience_Dist] + [Attribute:Walkability_table:Department_Dist] + [Attribute:Walkability_table:Groceries_Dist]) / 3) <= 0.25), Then (100), If ((([Attribute:Walkability_table:Convinience_Dist] + [Attribute:Walkability_table:Department_Dist] + [Attribute:Walkability_table:Groceries_Dist]) / 3) > 0.25 And (([Attribute:Walkability_table:Convinience_Dist] + [Attribute:Walkability_table:Department_Dist] + [Attribute:Walkability_table:Groceries_Dist]) / 3) <= 0.5), Then (75), If ((([Attribute:Walkability_table:Convinience_Dist] + [Attribute:Walkability_table:Department_Dist] + [Attribute:Walkability_table:Groceries_Dist]) / 3) > 0.5 And (([Attribute:Walkability_table:Convinience_Dist] + [Attribute:Walkability_table:Department_Dist] + [Attribute:Walkability_table:Groceries_Dist]) / 3) <= 0.75), Then (50), If ((([Attribute:Walkability_table:Convinience_Dist] + [Attribute:Walkability_table:Department_Dist] + [Attribute:Walkability_table:Groceries_Dist]) / 3) > 0.75 And (([Attribute:Walkability_table:Convinience_Dist] + [Attribute:Walkability_table:Department_Dist] + [Attribute:Walkability_table:Groceries_Dist]) / 3) <= 1.5),

	Then (25), Else (0))

Source: Author

After classifying them in to 10 categories mentioned above, the average scores for each category is then calculated indicating the average closest distance for each facility category for the whole neighborhood. The formula used for calculating the average distances are as follows

Table 13: Proximity to Facilities

Book Stores Proximity	**Units:** **Formula:** Mean ([Attribute:Walkability_table:Book Stores Walkability])
Drug Stores Proximity	Units: Formula: Mean ([Attribute:Walkability_table:Drug Stores Walkability])
Educational Facilities Proximity	Units: Formula: Mean ([Attribute:Walkability_table:Education Facilities Walkability])
Food Facilities Proximity	Units: Formula: Mean ([Attribute:Walkability_table:Food Facilities Walkability])
Medical Facilities Proximity	Units: Formula: Mean ([Attribute:Walkability_table:Medical Facilities Walkability])
Parks and Fitness Facilities Proximity	Units: Formula: Mean ([Attribute:Walkability_table:Parks and Fitness Facilities Walkability])
Public Transit Facilities Proximity	Units: Formula: Mean ([Attribute:Walkability_table:Public Transit Facilities Walkability])
Recreational facilities Proximity	Units: Formula: Mean ([Attribute:Walkability_table:Recreational Facilities Walkability])
Religious Facilities Proximity	Units: Formula: Mean ([Attribute:Walkability_table:Religious Facilities Walkability])
Shopping facilities Proximity	Units: Formula: Mean ([Attribute:Walkability_table:Shopping Facilities Walkability])

Source: Author

5.3. Entropy equation

The entropy equation has primarily 2 parts the calculation of individual land use percentages and the calculation of entropy index. The individual land use percentages are calculated using community viz using the following formula.

Table 14: Calculation of Land Use Percentages

Commercial: **Pc**	**Type: Double** **Formula:** (([Attribute:StudyArea:Commercial] / [Attribute:StudyArea:Acres]) * 100)
Institutional: **Pin**	Type: Double Formula: (([Attribute:StudyArea:Institutio] / [Attribute:StudyArea:Acres]) * 100)
Manufacturing: **Pm**	Type: Double Formula: (([Attribute:StudyArea:Industrial] / [Attribute:StudyArea:Acres]) * 100)
Other: **Po**	Type: Double Formula: (([Attribute:StudyArea:Other] / [Attribute:StudyArea:Acres]) * 100)
Residential: **Pr**	Type: Double Formula: (([Attribute:StudyArea:Residentia] / [Attribute:StudyArea:Acres]) * 100)
Recreational: **Prec**	Type: Double Formula: (([Attribute:StudyArea:Recreation] / [Attribute:StudyArea:Acres]) * 100)

Source: Author

After calculating the individual land use percentages the entropy index is calculated using the formula and the results are stored for further classification.

Table 15: Formula to Calculate Entropy Index

Land Use **Mix**	**Units:** **Formula:** -(((Max ([Attribute:Study_Area_LUM:Pc]) / 100) * Ln (Max ([Attribute:Study_Area_LUM:Pc]) / 100)

	) + ((Max ([Attribute:Study_Area_LUM:Pk]) / 100) * Ln (Max ([Attribute:Study_Area_LUM:Pk]) / 100)) + ((Max ([Attribute:Study_Area_LUM:Pm]) / 100) * Ln (Max ([Attribute:Study_Area_LUM:Pm]) / 100)) + ((Max ([Attribute:Study_Area_LUM:Pin]) / 100) * Ln (Max ([Attribute:Study_Area_LUM:Pin]) / 100)) + ((Max ([Attribute:Study_Area_LUM:Prec]) / 100) * Ln (Max ([Attribute:Study_Area_LUM:Prec]) / 100)) + ((Max ([Attribute:Study_Area_LUM:Po]) / 100) * Ln (Max ([Attribute:Study_Area_LUM:Po]) / 100))) / Ln (6)

Source: Author

5.4. Net residential Density

Net residential density is calculated and rated on a scale of 0-100 using the flowing formula in community viz.

Table 16: Formula to Calculate Net Residential Density

Household Dwelling Density	**Units:**	
	Formula:	
		Get ([Attribute:Study_Area_LUM:HHDs]) / Get ([Attribute:Study_Area_LUM:Residentia])

Source: Author

5.4.1. Gamma Index Calculation

The connectivity index is calculated using the no of links and no of nodes stored in the study area layer using the following formulas:

Table 17: Formulae to Calculate Connectivity Index

Street Links	**Type: Double** **Formula:** Count ([Layer:Streets_Links], Where (Intersects ([Layer:StudyArea])))
Street Nodes	Type: Double Formula: Count ([Layer:Street_Nodes], Where (Intersects ([Layer:StudyArea])))
Connectivity Index	Units: Formula: (Max ([Attribute:Study_Area_LUM:Street Links])) / (3 * (Max ([Attribute:Study_Area_LUM:Street Nodes]) - 2))

Source: Author

5.4.2. Reclassifying Individual Indices

The different indices and measures calculated are then reclassified to on a scale of 0 - 100. The following formulas are used in community viz to perform the reclassification process and arrive at the final walkability scores.

Table 18: Formulae for Reclassification of Indices

Connectivity Score	**Units:** **Formula:** [Indicator:Land Use Mix] * 100

Density Score	Units:
	Formula:
	IfThenElse (If ([Indicator:Household Dwelling Density] >= 20),
	Then (100),
	If ([Indicator:Household Dwelling Density] < 20 And [Indicator:Household Dwelling Density] >= 15),
	Then (75),
	If ([Indicator:Household Dwelling Density] < 15 And [Indicator:Household Dwelling Density] >= 10),
	Then (50),
	If ([Indicator:Household Dwelling Density] < 10 And [Indicator:Household Dwelling Density] >= 5),
	Then (25),
	Else (0))

Land Use Mix Score	Units: Formula: [Indicator:Land Use Mix] * 100
Proximity Score	Units: Formula: ([Indicator:Book Stores Proximity Score] + [Indicator:Drug Stores Proximity Score] + [Indicator:Educational Facilities Proximity Score] + [Indicator:Food Facilities Proximity Score] + [Indicator:Medical Facilities Proximity Score] + [Indicator:Parks and Fitness Facilities Proximity Score] + [Indicator:Public Transit Facilities Proximity Score] + [Indicator:Recreational facilities Proximity Score] + [Indicator:Religious Facilities Proximity Score] + [Indicator:Shopping facilities Proximity Score]) / 10
Safety	Units: Formula: [Assumption:Safety]

Source: Author

MEASURING WALKABILITY OF CENTRAL WEST END | 6

6. MEASURING WALKABILITY OF CENTRAL WEST END

In the previous chapter, the GIS model, the measures and variables of walkability that went into the model and the running of the model were explained. This chapter deals with using a study area to measure its walkability index.

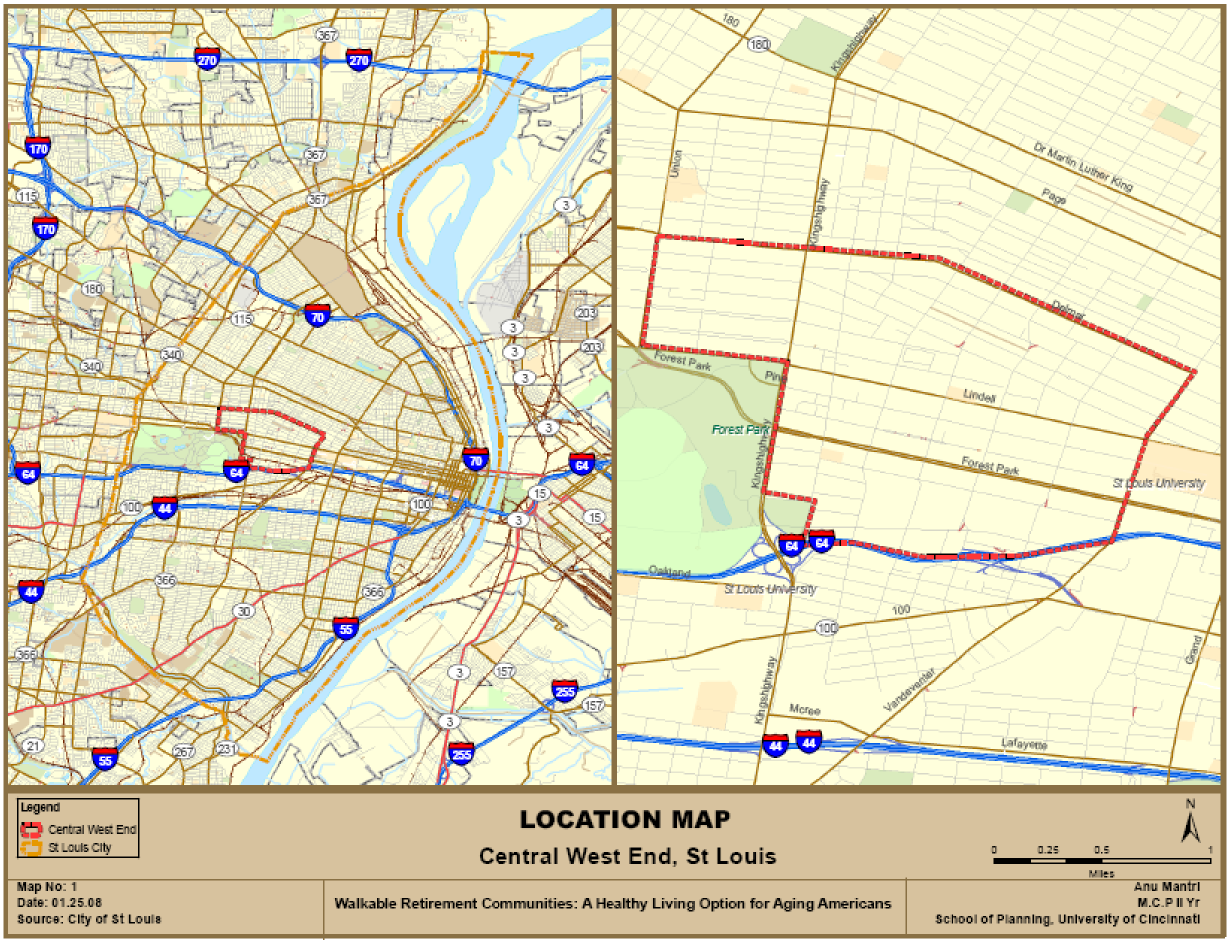
6.1. Study Area

Central West End, a neighborhood in St Louis is chosen for the purpose of study area. This particular place has been selected because of its strong walkable characteristics observed by the author. The streets in the neighborhood are always busy with people walking in and out of cafes & restaurants, jogging & biking, borrowing books at the library. Interestingly, the demographic mix is multi-generational and multi-racial due to the public schools, universities, in the vicinity.

6.1.1. Location

The area chosen for the case study is called Central West End (CWE), one of the 79 neighborhoods in St Louis, Missouri. CWE is a broad area to the west of Midtown, along the City's central corridor. It is bounded on the north by Delmar Boulevard, on the south by Highway 40 (I-64), on the west by De Baliviere Avenue and its projection across Forest Park and on the east by Vandeventer Avenue. (http://stlouis.missouri.org)

Figure 7: Location Map of Central West End



Source: City of St Louis

The area of CWE was created in the late 19th century, as part of the St Louis city's westward expansion and the building boom, of the 1904 World's fair (Development Strategies). CWE is a unique neighborhood with a diverse community. It is one of the few neighborhoods, which has a true "Cosmo-Culture". The area has a fine balance of homeowners, renters, and businesses (http://stlouis.missouri.org).

CWE is a vibrant neighborhood with a good land use mix of residential, commercial and institutional and there are umpteen numbers of cultural, recreational and medical facilities. This neighborhood is densely designed with all the facilities placed in close proximity of each other making it a safe and walkable community.

Figure 8: A Lively Street in Central West End with Mixed Land-Use

Source: www.slfp.com

6.1.2. Cultural and Recreational Amenities:

Forest Park is one of the largest urban parks in the United States with an area of 1,293 acres. Apart from being the major lung-space of CWE , it serves as a sports center for golf, tennis, baseball, bicycling, boating, fishing, handball, ice skating, roller blading, jogging, rugby and more.

Figure 9: History Museum in Forest Park, Central West End

Source: Development Strategies 2003

Figure 10: Art Museum in Forest Park, Central West End

Source: Development Strategies 2003

Forest Park, which is located in less than half mile from CWE, is home to some of the finest cultural institutions, including the Art Museum, the Zoo, Art Museum, History Museum, Science Center and an outdoor theatre.

The neighborhood also stands as a landmark for its richness in the places of worship, serving every major religious denomination. Some of the famous landmarks include Cathedral Basilica of St Louis and the Archdiocese of St Louis. (stlouis.missouri.org)

Figure 11: Cathedral Basilica of Saint Louis

Source: www.cathedralstl.org

6.1.3. Food and Entertainment:

CWE's primary commercial and entertainment area gives an image of a European city, with densely designed shops and restaurants. The streets in this area are lined with restaurants, cafes, bars, and shops, as well as small office spaces. This area is a destination point for both tourist and residents of St. Louis who come to eat at some of the region's best restaurants and shop at the boutiques and antique stores unique to the area.

Figure 12: Coffee Shop with Outside Seating Area

Source: www.cwecartel.com

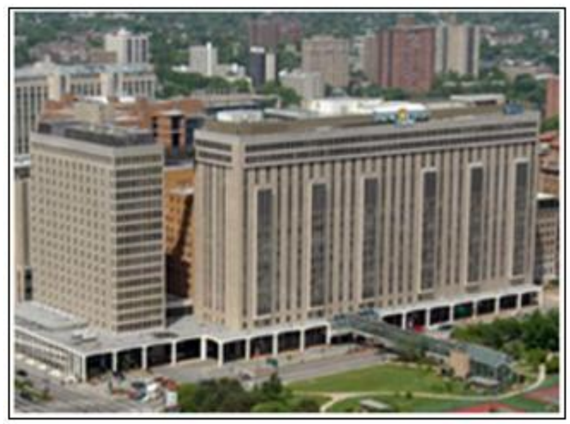
6.1.4. Educational Facilities:

Residents of CWE have access to a wide array of educational facilities. There are good number of both public and private elementary, middle, and high schools, in and around the neighborhood. Several institutions of higher education are found within three miles of the neighborhood, including Harris Stowe College, Saint Louis University, and Washington University.

6.1.5. Medical Facilities:

CWE is home to few of the most prestigious hospitals and medical institutions, including Barnes-Jewish Hospital, St Louis Children's Hospital, Washington University School of Medicine, and numerous other clinics and medical-related training facilities. The location of these medical centers in such close proximity is an added advantage for the aging adults from health care perspective.

Figure 13: Barnes Jewish Hospital



Source: Development Strategies 2004

6.1.6. Public Transportation

The city of St. Louis has a public transportation system operated by the Bi-State Development Agency, which has 600 active buses and 120 fixed routes serving much of the St. Louis area, providing 38.2 million rides a year, with an average daily ridership of 107,800. Bi-State also operates MetroLink a 28-mile light rail system. Both these modes of transit work in collaboration, by providing linkages. There are quite many bus stops in the neighborhood and three Metro Link stops in and around the neighborhood.

6.2. Data sets

There are several datasets used in evaluating the 5 measures using GIS and Community Viz. The data sets can be categorized in to 3 categories Parcel Data, Business Data, Street Data. The different data sets and critical information associated with each GIS data set is explained in the Table 8.

Table 19: Description of Parcel Data Sets

File	Type	Source	Description
Parcels	Shapefile, Polygon Data	City of St Louis, 2006	Area of Parcel, Land Use Code
Study Area	Shapefile, Polygon Data	City of St Louis, 2006	Study Area Definition with, Population Data, Household Data, Land Use Information, Area in Acres
CWE_Parcels	Shapefile, Polygon Data	City of St Louis, 2006	Centroids of the Parcel Polygons, with Data
Churches	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Clinics	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Coffee Shops	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Convenience Stores	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Department Stores	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Grocery Stores	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Hospitals	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Ice Cream Shops	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information

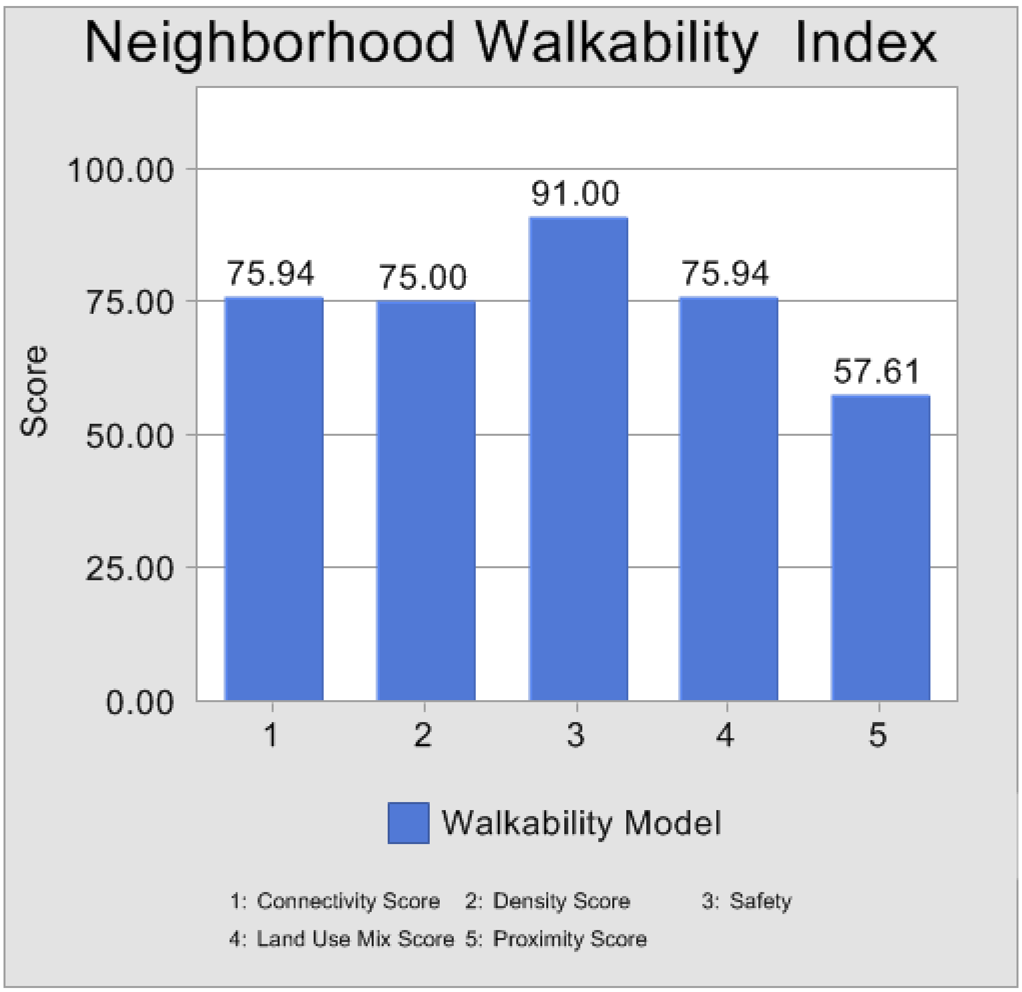
Pharmacies	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Physicians	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Pizza	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Restaurants	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Schools Universities and Colleges	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Theaters	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Book Stores	Shapefile, Point Data	InfoUSA Business Listings, 2007	Location Information
Streets	Shapefile, Line data	Tele Atlas, 2007	Location Data
Streets_ND	Network Data Set	Tele Atlas, 2007	Length & Speeds of Roads
Street Links	Shapefile, Line Data	Tele Atlas, 2007	No of Links and Location
Street Nodes	Shapefile, Point Data	Tele Atlas, 2007	No of Nodes and Location

Source: Author

6.3. Results – Walkability Index

After running the complete model, the walkability Index for the Central West End Neighborhood resulted to be high, proving that the neighborhood is highly walkable. The figure below shows the result, in terms of percentage for each indicator individually. The average of the scores of all the indicators gives the final walkability score for the neighborhood

Figure 14: Walkability Index of Central West End



Source: Author 1

The above figure depicts the walkability score of the individual walkable elements. As shown in the figure, each measure is given an individual score based on the calculations of street connectivity in the neighborhood, the mix of land use, the proximity to major destinations, and safety. Hence the results suggest that, from ***connectivity*** point of view, the neighborhood is given a score of **75.94** on a scale of 0-100, 0 being the least walkable and 100 being the most walkable. Similarly, on the same scale, the ***density*** score is **75**, ***Safety*** score is 91, the score based on ***land use mix*** is **75.94** and ***proximity*** is **57.61.** Based on the results, it can be concluded that the neighborhood selected, falls under highly walkable category.

<u>Calculating Overall Walkability Score:</u>

To calculate the overall walkability score of the neighborhood, the scores of all the measures can be averaged, which would score the neighborhood on a 0-100 scale. In this case, the walkability score of the neighborhood would be (75.94 + 75 + 91 + 75.94 + 57.61)/5 which equals **75.09**. Therefore the overall walkability score of the neighborhood is 75.

In this case all the measures are given equal ranking and hence the scores are averaged out without further math. But in reality, an individual's perception of priority on the measures of walkability may differ. For instance, it might be utmost important to an individual that the safety be given 30% more weightage than the rest. In this case, the walkable scores can be further reclassified based on the weightages assigned and the overall walkability score would change accordingly.

Thus the walkability of a neighborhood is measured based on individual scores of measures as well as in a combined way to arrive at the walkability score of a neighborhood.

SUMMARY & CONCLUSIONS | 7

7. SUMMARY & CONCLUSIONS

In this chapter, the use of the model in terms of data collection, creation or duplication, and working of the model is explained. The potential users of the model, advantages of the model, short comings are the other aspects discussed as a part of this chapter. The report is concluded by giving future directions.

7.1. Using the Model:

Though the model currently is embedded in to the Central West End Community, the frame work can be easily adopted and more communities can be analyzed using this model. For doing so there are primarily 3 steps, they are:

1. **Data collection and preprocessing:** The Parcel Data, Business Data, Street Data with the required data attributes should be collected and compiled and made model ready so that the formulas can be used on them.
2. **Creating or replicating the model workflow using CommunityViz:** The formulas used in the current neighborhood, central west end, available in **Chapter 5,** can be easily used or the new study area using CommunityViz Software.
3. **Running the model and analyzing the results:** Using CommunityViz the model can be run, that would generate a bunch of new attributes and subsequent results that would evaluate the walkability of the neighborhood though charts.

7.2. Potential users:

This model provides an objective analysis of walkability that can be quantified and compared with other communities for their relative advantages and disadvantages. This model can be potentially used by different groups,

- **Communities** – Communities can use the results of this model to attract people preferring active living, thorough publishing these results and comparing them with some of his competition.
- **Planners** – Planners can use this model to analyze existing neighborhoods and analyze their strengths and weaknesses, may be use the results of the model in public hearings to convince people about the changes that he plans to bring to the community to make it an active place for living.
- **Developers** – Developers can use this tool to evaluate their plans even before the communities are built and use the results of this model to either amend his plans to make his plans more walkable or use the results of the model to generate publicity and image in general public, by comparing his community scores with his competition's.
- **Home Buyers and Individuals**– General Public and Home Buyers can use this model for rating their own neighborhood for walkability measures and to compare different neighborhoods for better walkability that would help them evaluate the quality of neighborhood.

7.3. Advantages of model

Integration: There are models which analyze neighborhoods like walk score and index but confined to proximity, safety factor of neighborhoods, this model provides a comprehensive outlook of neighborhoods in terms of land use mix, density, safety, connectivity and proximity.

Flexibility: CommunityViz is an easy to use GIS based software – this model can be easily adapted to different communities, using the formulas and work flow that has been implemented in this particular study area.

7.4. Short Comings

Data Constraints: the data available for this community may not be readily available for all communities and may require extensive data collection and GIS database building, even in the case of data availability manipulation of data may be essential before that community can use the formulas and workflows used for analyzing walkability measures used in this model else new formulas and workflow has to be adopted.

Hard coding: Even though this model is a framework on which several other communities can be analyzed, this model and the workflow and the formulas are confined and stitched to the current neighborhood, new models has to be created for every neighborhood wanting to analyze walkability measures.

Use of other measures/variables of walkability: There are several other methods of evaluating neighborhood's walkability and more indices can be added in future providing comprehensive outlook. For instance the diversity of land uses are measured by employing the entropy index but it can also be measured using Simpson Index. Similarly, network connectivity can also be measured by Eta index.

Objectivity of safety: Safety has to be objective. Due to data constraints, quantifiable data has not been discussed in this model; rather safety has been taken up as a perceived measure. With availability of street light, crime data or other safety measures, the safety could be measured objectively.

7.5. Future directions:

Improve Flexibility and User Friendliness: This model functionality and user experience can be improved by adding functionality like ability to input GIS files into the model to get results instead of building a whole new model for analysis.

Global Model and Indicators: A model with widely accepted indicators and a commonly available model can be developed for usage of general public. A Web based model like walk score: can be web based for public use.

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APPENDIX

CommunityViz:

CommunityViz is a GIS-based decision-support tool for land-use planning and resource management. It works as an extension to ArcGIS. In Version 3, it includes two components which are Scenario 360 and SiteBuilder 3D (www.communityviz.com). In this thesis, Scenario 360 is used in building the model, for analyzing the indices.

Scenario 360

Scenario 360, which is employed for the purpose of this project, is a decision-support technology is designed to help people visualize, analyze and communicate about geographic decisions. Its purpose is to help people make informed, collaborative decisions about the future of their community, their land, and their world. Scenario 360 can be used to calculate potential positive and negative impacts of all kinds – economic, social, and environmental – and compare results after assumptions or details have been changed. In short, you can try out your choices in the computer before actually implementing them in the real world (www.communityviz.com).

Why Scenario 360?

The objective of this project is to create an interactive tool that would enable communities and decision makers to analyze their communities for walkability and friendliness to elderly, Scenario 360 is a perfect tool that would make the process of making decisions about communities more participative, can involve the people whom it affects, and can be more effective. (www.communityviz.com)

Strengths of Scenario 360 software

a. Scenario 360 helps users to view, project, analyze, and understand potential alternatives and impacts via visual exploration and scenario analysis. It allows users to experiment with hypothetical scenarios, challenge assumptions on the fly, and view impacts of changes (www.communityviz.com).

b. A powerful decision-making framework, Scenario 360 assists people and groups in bringing diverse information to a central location. Proposals, assumptions and impacts can be viewed side by side to illustrate the choices that need to be made. Economic, social, environmental and visual considerations can all be measured and compared, leading to holistic, informed decisions (www.communityviz.com).

c. Scenario 360 provides users with the ability to make data dynamic. This very powerful feature means that data about features on a map can be driven by formulas so that changes made to one aspect of an analysis drive recalculations and responsive changes throughout the entire analysis. Dynamic data allows you to experiment with alternatives and view the impacts of changes immediately.

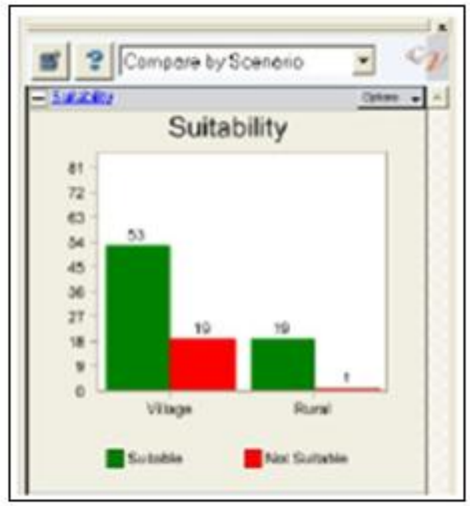
Components of Scenario 360

Visualize:

Dynamic Charts: Scenario 360 includes special charts that provide dynamically updated visual displays of information you want to know. You can set up the charts to display a single variable, multiple variables, multiple scenarios, and previous values (www.communityviz.com).

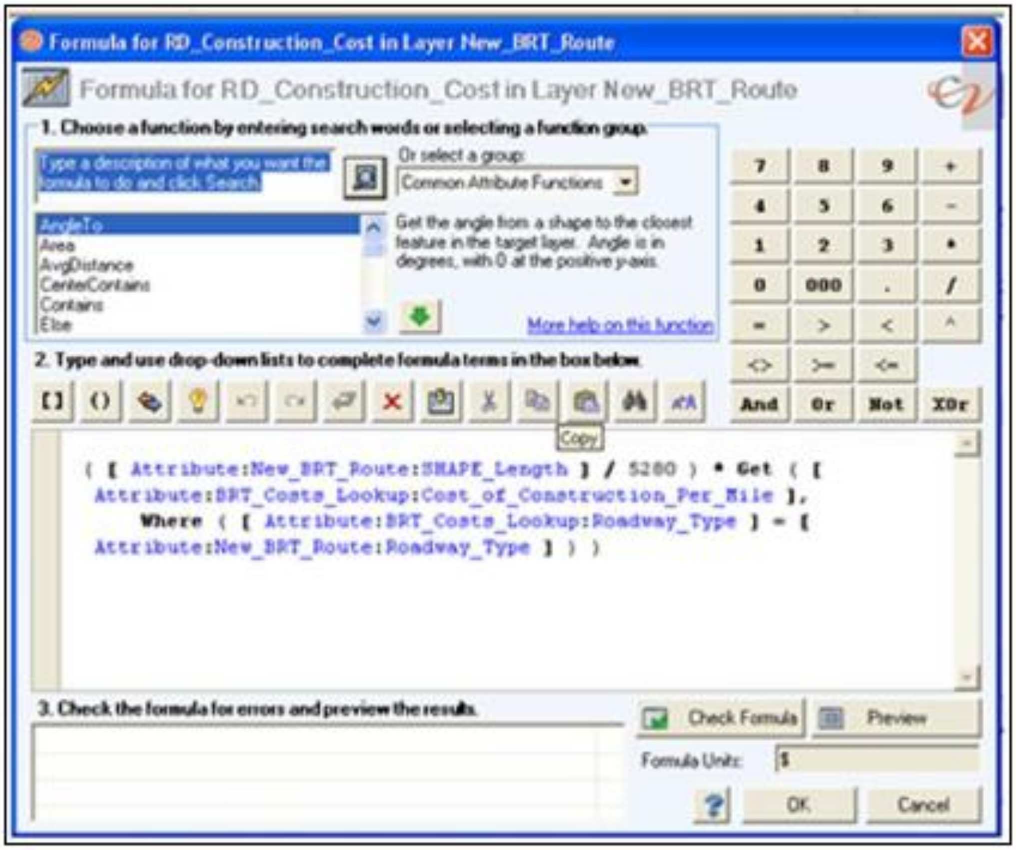
Analyze:

Scenarios: Scenario 360 allows you to create, analyze, and display multiple geographic alternatives - such as land-use plans, growth patterns, or project sites - and compare them all side-by-side. One of many ways is with our Scenario Sketch tools. Compare how they look on a map; compare their quantitative effects; compare how each responds to changes in assumptions or external influences. And with the Scenario Comparison feature, you can display maps, charts, and images in a tiled display that makes it easy to compare, present, and review alternatives and their impacts.

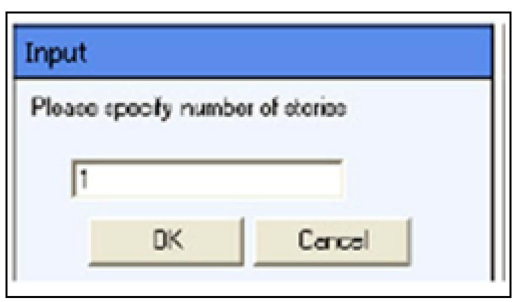


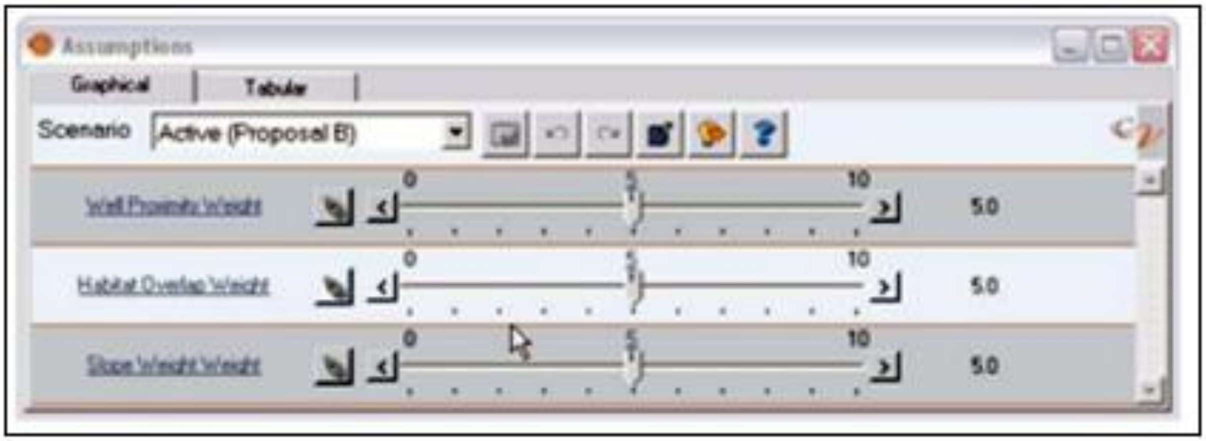
Source: www.communityviz.com

Dynamic Formulas: Scenario 360 handles spatial data somewhat like a Microsoft Excel® - spreadsheet handles numbers. Spatial information, tabular information, and user-changeable assumptions for variables like unit costs or growth rates can all be used to write formulas. The formulas' results will give you information you need to make geographic decisions, such as how much an alternative will cost or which parcel of land is most suitable for a given application. Because the formulas are dynamic, the results update automatically as you make changes to assumptions, edit the map, or experiment with other choices.



<u>Intuitive Control:</u> The intuitive, highly visual controls on Scenario 360 are designed to be easy to understand. Slider bars, for example, encourage viewers to vary assumptions and change weighting factors to see the results. Large, colorful icons are associated with common functions. Toolbars, windows, charts and other screen elements can be moved around, reorganized, and resized to suit individual preferences. And built-in, context-sensitive help is always available in case it's needed.





<u>Automated Alerts:</u> Scenario 360 lets you create your own alerts to notify you when certain thresholds are crossed as you experiment with changes to your analysis. For example, set an alert that marks when a school runs out of capacity, or one that highlights all the parcels that meet your criteria for a particular use.