Spatial Assessment of Walkability Index – A Case Study in Chicago

BY

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THESIS

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Dedicated to my mother, father, siblings and fiancé

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LIST OF ABBREVIATIONS

AT – Active Transportation

BMI – Body Mass Index

BiWET – Bikeability and Walkability Evaluation Table Audit Tool

BRDI – Bus Route Density Index

BSDI – Bus Stop Density Index

CCD – Census Collection District

CDI – Commercial Density Index

CHRTI – Chicago Regional Household Travel Inventory

CMAP – Chicago Metropolitan Agency for Planning

CR_ADI – Crime Rate per Area Density Index

CR_CADI – Crime Rate per Capita Density Index

FMLM – First mile last mile

GIS – Geographic Information Systems

HIA – Health Impact Assessment

LDI – Land Use Diversity Index

NCI – Network Connectivity Index

PDI – Population Density Index

PWI – Pedestrian Walkability Index

TIGER – Topographically Integrated Geographic Encoding and Referencing

ABSTRACT

There is evidence that the current epidemic of obesity and overweight is contributed to by urban environments that discourage walking and other physical activities. Many research has been conducted creating various indices that aim at describing "walkability" in combining built environment characteristics the contributes to promoting or inhibiting the physical activity of walking.

In this research, the assessment of built environment characteristics, public transit serviceability and safety aspects were studied and prioritized for The City of Chicago on a Census Tract geographic level. First, population and built environment characteristics have been analyzed leading to the generation of four (4) indices. Second, public transit characteristics regarding serviceability have been studied yielding two (2) indices. Third, safety aspects that may impact one's decision on whether to select walking as mode of transport have been considered resulting in two (2) indices. Fourth, The Pedestrian Walkability Index is created and defined as the product of eight (8) components representing population density, land-use diversity (using concept of entropy), commercial density, network connectivity, public transit serviceability – two (2) indices – and crime-rate density – two (2) indices. The index was used to model walkability on the Census Tract geographic level for the City of Chicago. The model then, was validated using Chicago Metropolitan Agency for Planning (CMAP) dataset.

1. INTRODUCTION

1.1 Study Background and Motivation

A fair, efficient and effective transportation system serves diverse transportation demands. For example, a sidewalk that forces pedestrians to use an automobile to chauffer their children to local destination to which they would prefer an active mode of transportation, walking or bicycling, is inefficient, or if commuters drive to their destination due to inadequate mobility options rather than using public transit or rideshare.

A research conducted by McGinnis in the early 1990s found that 200,000 to 300,000 premature deaths were attributed to physical inactivity in the United States (McGinnis 1992). For urban planners, policymakers, and public health officials in U.S. cities, health risks associated with insufficient exercise are becoming increasingly important topics to address accounting for obesity as one of the most pressing epidemics of the 21st century. The physical activity of walking is likely the most effective and convenient exercise required to achieve recommended physical activity levels that mitigate or minimize health risks associated with obesity and inadequate exercise.

The practice of urban planning can either promote walking and alternative transportation-mode usage, or promote inactivity and automobile dependency (Dannenburg et al. 2003) . As rapid growth in the residential and commercial sectors continues of large U.S. cities, sprawled out suburban development outside such large cities grows as well. In most cases, suburbs are automobile-dependent in nature of their design, which, in return, encourages sedentary lifestyle leading to health problems such as obesity. According to a study conducted by Cervero and Duncan in 2003, obesity resulting from sedentary lifestyles adds as much as $76 billion annually to medical expenses in the U.S. (Cervero and Duncan 2003). Using an automobile as a primary transportation mode and failure to attain recommended physical activity levels easily achieved by walking are traits exhibited in residents of such neighborhoods.

Benefits attained through daily walking activities are well understood and documented. A 33% decrease in risks of cardiovascular disease is associated with walking ten or more city blocks per day (Frumkin 2001). For someone to effectively harvest the benefits of physical activity through walking, one's local environment should be welcoming and have high walkability characteristics. Even though exercise benefits of walking can be attained through fitness centers and recreational amenities, neighborhoods with welcoming walking environments tend to provide for a more convenient physical activity options (Leslie et al. 2005).

The term "walkability" of a neighborhood or community may be defined as the extent to which the physical makeup, i.e., characteristics, of the built environment in addition to the diversification and utilization of land use have the tendency to either promote of inhibit local residents ability to walk for purpose of leisure, exercise, accessing a service, or getting to home or work (Leslie et al. 2005). There are many aspects and design features of the built environment that affect walkability. Proximity, i.e., distance between places, and connectivity, i.e., ease of travel between an origin and a destination, are typically reflected on relevant community characteristics (Norman et al. 2006).

An emphasis on proximity and connectivity is well exhibited in the City of San Francisco, which possesses attributes revealing of traditional urban communities of the 1930s. Much of the city's current built environment was developed and established around that time. Community characteristics such as high residential density, diverse land usage and grid-like street patterns with relatively small block sizes promoted walkability for people residing within such communities than do people residing in sprawling areas such as majority of suburbs (Saelens, Sallis, and Frank, n.d. 2003)

When measuring or quantifying walkability of a neighborhood or community, these characteristics emphasize the importance of density, diversity and connectivity. According to a research conducted by Cervero and Kockelman, residential density, continuity and competence of the roadway network, viability of public transit, perceived safety as it relates to crime and the diversification of land use are important environment characteristics commonly used to quantify how walkable a neighborhood or community may be (Cervero and Kockelman 1997). Table 1.1 shows how each community or neighborhood characteristic affects walking behavior uniquely.

From the importance of health benefits to the challenges of fossil fuel dependency, the motivation of this thesis is drawn to assess walkability. In this thesis, The City of Chicago is studied and analyzed. With a population of 2.7 million people (U.S. Census 2017), the Chicago Transit Authority (CTA) operates the nation's second largest public transportation system.

Table 1. Elements of Neighborhood-Scale Environmental Characteristics and Relationship to Walkability (Leslie et al. 2005).

Environmental Attributes	Implied Relationship with Walkability
Residential density	High-density neighborhoods encourages mixed-use development (improves accessibility to variety of interests and increases utility)
	Associated with increase in retail/services variety (results in shorter, more walkable distance between interests)
Street Connectivity	High intersection densities provide more potential routes for walking and greater accessibility
	Greater neighborhood connectivity, shorter distance to destinations
Public transit density	High public transit density provides shorter, more walkable distances to alternative modes of transportation (buses, etc)
	Use of more accessible bus stops encourages walking between leisure, work and home
Crime Density	High-density crime discourages walking in neighborhoods
	Sense of lack of pedestrian safety encourages more protected automobile use and alternate transportation methods
Land use mix	Multiple and diverse retail/services opportunities encourage more specialized, frequent, and shorter shopping trips by foot
	More land use mix means more varied and interesting built environment, creating neighborhoods conducive to walking

1.2 Study Scope and Objective

In this thesis, the focus is on the development of a new and easily computable measure of assessing pedestrian walkability based on built environment characteristics, public transit serviceability and safety related aspects for urban neighborhoods that best utilize available data. The objective is to demonstrate the applicability of the developed framework in assessing walkability for The City of Chicago on a census tract geographic level, and thereafter, recommend policy-sensitive strategies that are likely to have a positive impact on improving walkability for the city.

1.3 Overall Study Framework

In this thesis, the analysis conducted on built environment characteristics, public transit serviceability and safety related aspects is performed using a spatial approach. Eight indices are created using Geographic Information Systems (GIS) resulting from the analysis, and one index – Pedestrian Walkability Index (*PWI*) – is the final walkability measure combing all sub-indices. The *PWI* is then validated using the Household Travel Survey dataset provided by CMAP resulting from a survey conducted between 2007 and 2008.

1.4 Organization of the Thesis

Starting by reviewing the literature, this thesis begins with existing strategies, methods and tools adopted to create some of the most commonly used indices assessing walkability. Follows, is the methodological approach illustrating the framework adopted in this thesis, in which the creation of the *PWI* and its validation are explained. In chapter 4, the spatial analysis and modeling results of all eight indices and their combination are presented and statistically evaluated. In chapter 5, the results are used to identify neighborhoods with low walkability index and thereafter, strategies are recommended. In chapter 6, this thesis is concluded by presenting limitations, discussion of results as they relate to walkability in addition to directing future work in this domain.

2. LITERATURE REVIEW

This chapter discusses commonly used practices and their underlying methodologies, frameworks and tools used in the literature for the assessment of walkability. There has been increased interest shown by public and academic entities in assessing and better understanding attributes such as built environment characteristics, public transit serviceability and safety related aspects for urban neighborhoods as they relate to physical activity and the impacts resulting from it.

2.1 Public Health and the Environment

Being overweight or even obese, diabetes, heart disease and some forms of cancer can be considered major risk factors resulting from physical inactivity according to the United States Department of Health and Human Services (USDOH 2006). A research conducted in Australia reviled that over 30% of adults have a tendency of being physically inactive in their leisure time (Owen, Bauman, and A. 1997), and more than 50% perform inadequate physical activity levels to attain minimum health benefits required for good health (Booth et al. 1997).

Internal-combustion individually-owned automobiles and the large-scale transportation network created to accommodate them, have an adverse impact on public health and the environment. Such impacts can range from air and noise pollution to the emissions of greenhouse gasses and the hazards resulting from traffic. These impacts exert burdens on the environment and its inhabitants (Haines and Dora 2012). The need for physically-demanding travel has been reduced due to the comfort and readiness provided by motorized transportation; this in return has led to increased levels of inactivity (González-Gross and Meléndez 2013).

Promoting walking and cycling as a transportation mode complimented by public transportation is a promising strategy to not only address issues related to traffic congestion and environmental issues, but also to provide for a sustainably healthier lifestyle (de Hartog et al. 2010). A systematic review study conducting a Health Impact Assessment (HIA) of a mode shift to Active Transportation (AT) concluded: despite risk of injury resulting from exposure to motorized traffic and their emissions, the health benefits reaped through increased physical activity strongly outweighed detrimental effects of traffic incidents and environmental pollution (Mueller et al. 2015).

2.2 Travel Demand and the Built Environment

In urban planning, one of the most heavily researched topics is the moderation of travel demand through modification and alteration of the built environment. The original "three Ds," (Cervero and Kockelman 1997), are density, land-use diversity and pedestrian oriented design, extended later to also include destination accessibility and distance to transit (Ewing and Cervero 2001).

Density is a measure of the subjective variable of interest per a specific unit area. Population, employment, dwelling units, etc., can be the subjective variable of interest indicating potential origins and destinations of generated trips. Land-use diversity is a measure of how diverse a specific area is as it pertains to the number of different land-uses and how they're utilized. This specific measure is calculated using the concept of entropy where a higher entropy value represents a more diverse land-use and a lower entropy value represents a less diverse land-use (Peiravian, Derrible, and Ijaz 2014).

Pedestrian oriented design is a measure of physical characteristics of a street or pedestrian pathway network. This measure can range from highly-integrated well-connected urban grids to sprawled out suburban stress forming long curvy roadway loops. Occasionally, pedestrian oriented design is measured as sidewalk coverage, building setbacks, pedestrian walkways, average street widths, landscaping coverage and other physical characteristics the pertains to the pedestrian environment. Destination accessibility is a measure of the proximity or ease of access, measured as distance or time, to destinations such as attractions and employment location. This measure may be regional or local (Handy 1993)

2.3 Crime and Constrained Physical Activity

There exists well documented evidence in the literature that certain socio-demographic groups in society tend to be more fearful of crime than other groups (Hale 1996). Particularly, women and elderly people have a tendency to feel more physically vulnerable resulting a greater concern regarding their safety. Having a first-hand experience with crime, i.e., being a victimized, or hearing about it second-hand can lead to greater fear of crime.

One of the barriers to achieving adequate levels of physical activity is perceived safety of crime (Miles and Panton 2006). In a study relating physical activity to perceived crime, Ferraro defined crime as “an emotional reaction of dread or anxiety to crime or symbols that a person associates with crime”. In their study, the defined two patterns where people may alter their behavior to alleviate their fear of crime: 1. People will constrain their behavior that exposes them to potential dangerous situations by avoiding being in some places; and 2. People will use a protective behavior, where safe-guarding measure are taken into account or upgraded (Ferraro et al. 1987).

In another study conducted by Ross, it was found to be plausible for people who fear crime to constrain their physical activity, particularly in such activities involve walking (Ross 1993).

2.4 Existing Strategies for Assessing Walkability

It has been a major challenge to measure how friendly an environment is towards pedestrians and only few methods and indices have been developed to deal with such a challenge. One approach was to analyze, visually and quantitatively, the pedestrian path network in key urban areas with a goal of providing tools that help in the evaluation and planning applications in pedestrian-oriented projects. Such analysis was conducted using Topographically Integrated Geographic Encoding and Referencing (TIGER) street data from the U.S. Census Bureau for areas surrounding schools and public transportation destinations (Schlossberg 2006). In doing so, the utilization of three Geographic Information Systems (GIS) methods was performed. Such methods used the concentration of street intersections, stratification of street networks and size of pedestrian catchment areas, in addition to introducing “impedance” helping to identify automobile-oriented neighborhoods from pedestrian-oriented ones. (Weyman et al. 2008), conducted a study analyzing nine previously identified urban environmental variables using GIS to both measure and compare walkability between neighborhoods in a given city. In this study it was concluded: “urban development in Toronto dating from the mid-20th century and earlier generated higher walkability, while development since the mid-20th century has been inconsistent in generating built environments amenable to pedestrians” (Ibid 320).

A study conducted by Leslie developed an index using four measures for Adelaide, Australia: dwelling density, intersection density, land use, and retail areas (Neville Owen et al. 2007). The walkability index calculated is the summation of all four measures each with a score ranging between one and ten for each Census Collection District (CCD) yielding a value ranging between one and four. Then, the walkability index developed was categorized into quartiles with the first and fourth quartile classifying low and high walkability of CCDs respectively. GIS software was then utilized to generate a heat map visually representing CCDs that are conducive or not to walking. To determine how well the developed method is performing and to check the performance of the walkability index, field validation was conducted in Adelaide. The research team systematically visited local areas corresponding to each of the walkability quartile categories identified by the index. The research team concluded that majority of selected areas’ characteristics confirmed to the classification of walkability derived in GIS. It was then determined by the study team that the methodology at hand was a valid one in identifying walkability in subjective areas based on the selected attributes (Leslie 2005).

Hoedl and Clifton conducted a survey-based study with an environmental audit approach resulting in the Bikeability and Walkability Evaluation Table Audit Tool (BiWET). Researchers' approach – to get a quick overview of environmental characteristics along a route or in a spatial area – was to develop a simple yet efficient auditing tool (Hoedl 2010; Clifton et al. 2007). In the development process of this auditing tool, the following environmental attributes were included: traffic safety, attractiveness of the surroundings, presence and location of trees, green space availability, publically open space, land-use, walking and cycling infrastructure characteristics. The BiWET is based on the evaluation of ten variables and, as the name suggests, the tool is formulated in a table format comprised of rows that represent a unit of ten variables and columns that represent the rating of each variable. The evaluator cycles through a subjective route while evaluating the ten variables inputting values into each corresponding cell in the BiWET audit instrument. Researchers then measured the reliability of the audit instrument by assessing twenty-four different routes in the City of Garz, Austria. Researchers rated the reliability of the BiWET audit tool as efficient and highly reliable instrument in assessing the environmental parameters for walking and cycling.

Walk Score ™ is a measure of walkability for any address. The Walk Score ™ Advisory Board developed the methodology behind such a measure. This measure of walkability of any address analyzes hundreds of walking paths to nearby amenities. The range of Walk Score is zero to one hundred, with zero and one hundred described as car dependent and walker's paradise respectively. Point or score allocation is performed based on distance from and to amenities in each category of classification. Locations/addresses situated within a 5-minute walk duration are given highest points and an algorithm using a decay function is utilized to allocate points for location further away from amenities with zero-point allocation resulting in a walk that exceeds thirty-minutes duration (Carr, Dunsiger, and Marcus 2010). Walk Score ™, in recent years, has been adopted as a valid and reliable tool for the estimation of access to nearby facilities. In a neighborhood walkability study, Walk Score was calculated for two hundred and ninety six participants within residential addresses objectively cross-referencing street connectivity, residential density, access to public transit and crime using GIS and subjectively cross-referencing perceived crime, access to amenities perceived walkability within the neighborhood. Results of this study suggest a significant positive correlation between Walk Score ™ and several objective and subjective measures of the built environment. This study, however, also observed a positive correlation between Walk Score ™ and Crime which presents a limitation to be cautioned about (Carr, Dunsiger, and Marcus 2010).

3. DATA

In this study, data extracted from CMAP datasets and U.S. Census Bureau are used for the primary reason of validation the *PWI*. The CMAP dataset is utilized to conclude statistics on trips conducted using walk mode to then correlate this data with the *PWI* developed. The U.S. Census Bureau is utilized to gather date relating to the built environment, public transit serviceability characteristics and crimes. All shapefiles, i.e., geographic maps used in GIS for the spatial analysis, are extracted from the U.S. Census Bureau.

3.1 Chicago Metropolitan Agency for Planning (CMAP)

In this study, data extracted from CMAP database was used for validation of the *PWI*. This dataset was latest household travel survey conducted between year of 2007 and 2008. The travel survey conducted by CMAP is a complete and comprehensive travel and activity survey for northeastern Illinois. In their survey, a total of 10,552 households contributed to by participating yielding a detailed travel inventory for each member of their households. Distribution of the results closely matched northeastern IL's household population by county. Table 3.1 is a representation of the resulting data collected in comparison with northeastern IL population.

Table 2. CMAP Survey and Northeastern IL Population (U.S. Census Bureau, Census 2010)

County	Completed Surveys		Northeastern IL Population	
	No. of HH	%	No. of HH	%
Cook	6,986	66.20%	1,974,181	67.10%
Du Page	994	9.40%	325,601	11.10%
Grundy	67	0.60%	14,293	0.50%
Kane	463	4.40%	133,901	4.60%
Kendall	73	0.70%	18,798	0.60%
Lake	988	9.40%	216,297	7.40%
McHenry	369	3.50%	89,403	3.00%
Will	612	5.80%	167,542	5.70%
NE Illinois Region	10,552	100.00%	2,940,016	100.00%

With a study objective of providing for a statistically valid set of data that in return is primarily used in forecast of travel demand modeling, it is important that the survey be designed with a sampling approach that is reflective of the full diversity of behavioral elements of travel activity taking place in the study area. All households residing in the CMAP modeling area were defined as the survey population. The CMAP modeling area is currently defined by eight counties in Illinois: Cook, Du Page, Kane, Kendall, Lake, McHenry and Will, and the Northwestern Indiana Regional Planning Commission (NIRPC): Lake, La Porte and Porter counties in Indiana. This, as a result, leads to a total study area comprised of over 3.2 million households. The distribution of those households can be seen below in Table 3.2.

Table 3. Counties and Household in the Study Area (U.S. Census Bureau, Census 2010)

County	Total Households	% of Total Households in Study Area
Cook (IL)	1,974,181	61.40%
Du Page (IL)	325,601	10.10%
Grundy (IL)	14,293	0.40%
Kane (IL)	133,901	4.20%
Kendall (IL)	18,798	0.60%
Lake (IL)	216,297	6.70%
McHenry (IL)	89,403	2.80%
Will (IL)	167,542	5.20%
Lake (IN)	181,589	5.70%
Porter (IN)	41,086	1.30%
La Porte (IN)	54,721	1.70%
Total	3,217,403	100.00%

In this study, and with the purpose of completing coverage of the Directory/Address-based samples, a dual frame sampling approach was applied combining the strengths of Random Digit Dialing (RDD). A more comprehensive coverage of the study area, improved accuracy in location and achieving higher efficiency reaching households in the study area were provided using this approach.

In order to support future usage into activity-based or tour-based models of this dataset, a census tract classification variable was created to reflect on the environment in which travel took place. This was done with the rationale that higher population and job densities reflect more urbanized sections of the region, in addition to level of transit service, including bus and rail, available. These measures include:

1. Population Density
2. Job density
3. CTA train stations within tract
4. METRA and South Shore (NICTD) stations within tract
5. CTA bus miles of service within tract
6. PACE bus miles of service within tract
7. Bus miles of service within tract (provided by local carriers)

The development of a valid model is highly relevant to the classification that takes into account the environment in which travel takes place. Many studies have shown non-motorized travel is higher in higher density areas, as to the availability of more destination within walking or biking distance, as opposed to travel in lower density areas which tends to be predominantly by auto.

For a region that provides for many transportation options, including both motorized and non-motorized, model validity requires sufficient data for users using each mode of travel. For this data collection procedure, transit service in the region includes: PACE and CTA bus systems, CTA, METRA and South Shore Railroad with a higher level of overlap of service in and near the census tract of the downtown area and decrease with distance from it. VISUM was then utilized to identify the availability of different transit options. Two variables were created for each census tract: a level of service and access to transit variable.

The level of service variable was created on the bases of calculating the length of serviced bus lines that are located within each census tract, then it was divided by the size of each corresponding census tract to yield a level of service value that is reflective of the size of each census tract. The access to transit variable on the other hand was determined by calculating the portion of the area of the census tract intersected by a 0.5 miles buffer size created around CTA rail stops and 1 mile around METRA and South Shore Railroad stations.

For each census tract, a value ranging between 0 and 100 was received for each of the two variables of interest. Capping of the maximum value at the 95th percentiles for both Illinois and Indiana counties, the following tables 3.3 and 3.4 show the standardized variable.

Table 4. Stratification Variables for the Illinois Counties (CHRTI 2010)

Variable	Minimum	Maximum	Mean	St. Dev.
Population densities	0	100	31.6	28.9
Job densities	0	100	26.5	26.3
Level of service	0	100	21	19.4
Access to service	0	100	13.3	19

Table 5. Stratification Variables for the Indiana Counties (CHRTI 2010)

Variable	Minimum	Maximum	Mean	St. Dev.
Population densities	0.4	100	33.4	29
Job densities	0.3	100	34.2	28.5
Access to bus service	0	100	21.1	30.6
Access to train service	0	100	16.2	25.4

The resulting outcome had a total 14,390 regional households with a full and complete participation in the Travel Tracker Survey conducted with the support of the Chicago Regional Household Travel Inventory (CHRTI). Data provided by participating households includes: household composition, ownership of vehicles and travel attributes randomly assigned 24- or 48-hour travel period. After properly weighing the data provided by the 14,390 households, details for about 38,745 household members, 25,746 vehicles and 184,194 unlinked trips. After expanding to the survey area, the travel data provided details for 3,218,100 households, 8,727,717 persons, 5,588,431 vehicles and 39,956,631 trips. To summarize, on average, households reported 9.28 daily trips and 3.45 daily persons trip on day one, and 7.59 average daily household trips and 2.90 average daily persons trips on day 2. Table 3.5 below provides for an inventory summary.

Table 6. Inventory Summary (CHRTI 2010)

Survey Indicators	Weighted Data	Expanded Data
Total households Surveyed	14,390	3,218,100
Total members surveyed	38,745	8,726,717
Total household Vehicles	25,746	5,588,431
Total trips (unlinked) day 1	133,549	29,278,426
Total trips (unlinked) day 2	50,645	10,678,205
Average HH trip rate - day 1	9.28 trips	-
Average person trips rate - day1	3.45 trips	-
Average HH trip rate - day 2	7.59	-
Average person trip rate - day 2	2.90 trips	-

Figure 3.1 is a representation of counties comprising the CMAP and NIRPC metropolitan planning organizations regions color-coded in green and yellow respectively.

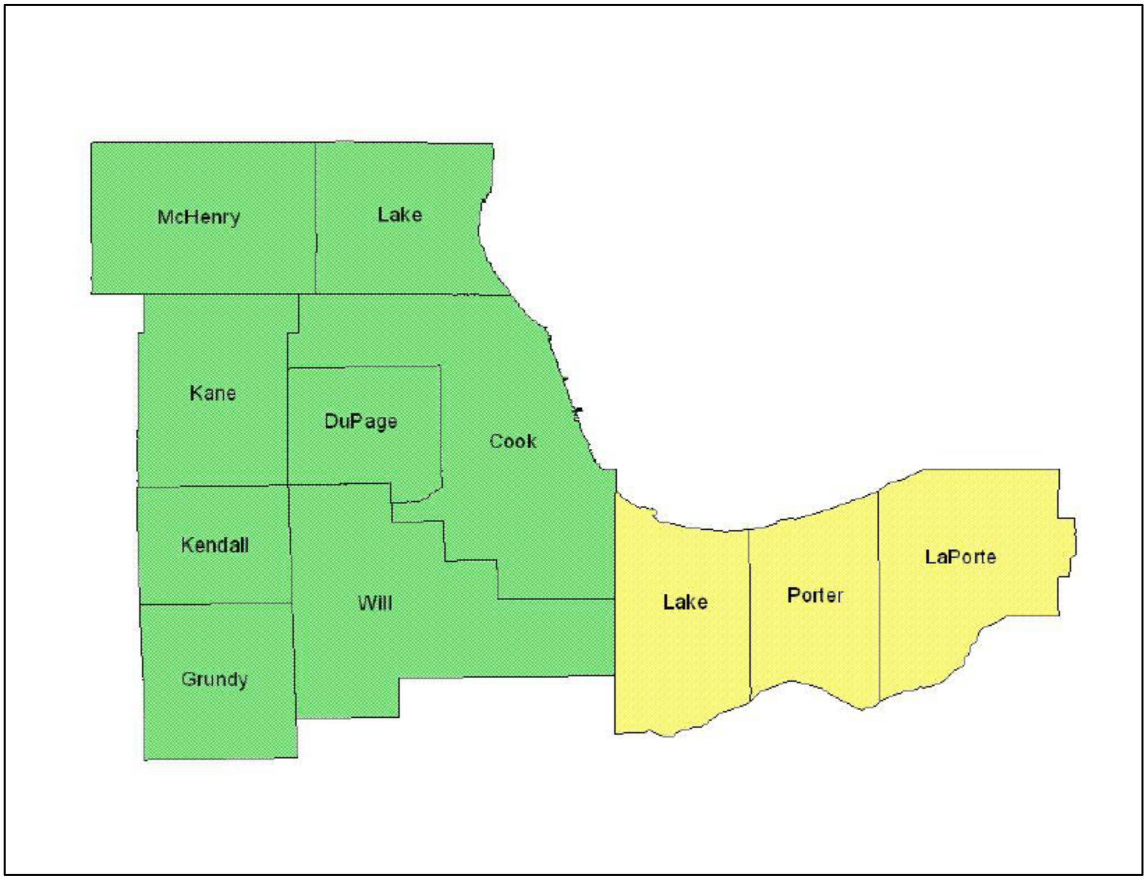

Figure 1. MPO Regions (CHRTI)

The total participating households in this survey reported an average household size of 2.71 persons for both regions. Table 3.1 is representation of the distribution of household by size. In the CMAP region, households reported an average of 2.72 members, while in the NIRPC region reported an average of 2.61 persons.

Table 7. Household Size (CRHTI 2010)

	No.	Household Size				Mean	SE Mean
		1	2	3	4+		
CMAP	10552	26.4%	28.7%	16.0%	28.9%	2.72	0.00
NIRPC	3838	25.0%	31.8%	17.4%	25.8%	2.61	0.00
Urban	6986	31.2%	25.5%	18.0%	25.3%	2.65	0.00
Suburban	6895	18.6%	34.3%	12.1%	35.1%	2.83	0.00
Rural	509	17.2%	36.1%	22.7%	24.0%	2.64	0.00
Total	14390	26.3%	29.0%	16.1%	28.6%	2.71	0.00

Regarding household vehicle ownership, 1.74 was reported to be the regional average per household split into 1.71 vehicles on average of the CMAP region, and 2.0 vehicles on average for the NIRPC. As can be expected, households located in urban counties owned fewer vehicles as opposed to households located in suburban and rural counties. 1.49, 2.15 and 2.02 vehicles on average were reported for households located in urban, suburban, and rural counties respectively. Table 3.7 is a representation of household vehicle ownership.

Table 8. Household Vehicles (CRHTI 2010)

	No.	Household Vehicles					Mean	SE Mean
		0	1	2	3+	Total		
CMAP	10552	13.7%	31.2%	34.3%	20.8%	100.0%	1.71	0.00
NIRPC	3838	5.3%	30.7%	36.9%	27.0%	100.0%	2.00	0.00
Urban	6986	19.4%	34.1%	29.2%	17.4%	100.0%	1.49	0.00
Suburban	6895	2.9%	27.0%	42.0%	28.1%	100.0%	2.15	0.00
Rural	509	3.2%	22.0%	51.4%	23.4%	100.0%	2.02	0.00
Total	14390	13.0%	31.2%	34.5%	21.3%	100.0%	1.74	0.00

Across the region, 1.45 workers on average were reported per household. This was reported to be the same number for both Illinois and Indiana regions. Moreover, the highest average worker count was exhibited in suburban county households with 1.74 workers, as opposed to urban counties with 1.29 workers on average per household. Table 3.8 is a representation or workers per household in the study region.

Table 9. Household Workers (CRHTI 2010)

	No.	Household Vehicles				Mean	SE Mean
		0	1	2+	Total		
CMAP	10552	17.0%	36.3%	46.7%	100.0%	1.45	0.00
NIRPC	3838	20.6%	33.8%	45.6%	100.0%	1.44	0.00
Urban	6986	21.1%	40.2%	38.7%	100.0%	1.29	0.00
Suburban	6895	11.5%	28.2%	60.3%	100.0%	1.74	0.00
Rural	509	9.9%	42.2%	47.9%	100.0%	1.45	0.00
Total	14390	17.3%	36.1%	46.6%	100.0%	1.45	0.00

Lower income was report in the NIRPC region as compared to the CMAP region, with 58% of NIRPC households reporting an income of less $50,000 in comparison with 50% of CMAP households. 31% of households located in rural counties reported an income of less than $50,000 in comparison with 53% in urban county and 50% of suburban county households. Table 3.9 is a representation of household income distribution in the study region.

Table 10. Household Income (CRHTI 2010)

	Household Income							Total
	<$20K	$20-<$35K	$35-<$50K	$50-<$60K	$60-<$75K	$75-<$100K	$100K+	
CMAP	17.8%	16.5%	15.9%	6.3%	14.1%	10.3%	19.0%	100.0%
NIRPC	22.1%	19.7%	16.4%	8.4%	12.3%	11.2%	10.0%	100.0%
Urban	21.7%	15.1%	16.2%	6.2%	10.3%	10.5%	20.0%	100.0%
Suburban	14.1%	19.9%	15.7%	6.8%	19.0%	9.9%	14.6%	100.0%
Rural	3.1%	13.7%	13.7%	8.9%	24.4%	13.0%	23.2%	100.0%
Total	18.3%	16.8%	15.9%	6.5%	13.9%	10.4%	18.2%	100.0%

Most of this study's participants reported owing their homes making up 73% of total participants. Households in the CMAP region reported less home-ownership than households in the NIRPC region. The highest rate of home-ownership was reported in rural counties with an 89% rate, while households in urban counties reported at 65%. Table 3.10 is a representation of home-ownership in the study region.

Table 11. Household Ownership Status (CRHTI 2010)

	Owner/Renter Status		
	Own	Rent	Total
CMAP	72.2%	27.8%	100.0%
NIRPC	80.3%	19.7%	100.0%
Urban	65.4%	34.6%	100.0%
Suburban	84.8%	15.2%	100.0%
Rural	88.7%	11.3%	100.0%
Total	72.9%	27.1%	100.0%

Travel behavior details were provided for a total of 38,745 persons across the 14,390 participating households. A consistent distribution of gender was exhibited in the reported records. Figure 3.2 is a representation of gender distribution of respondents.

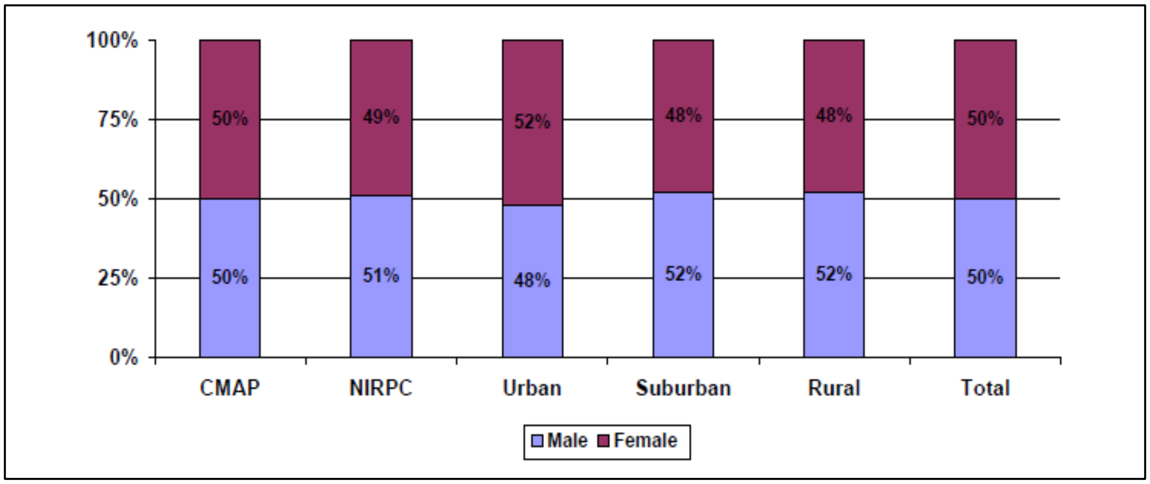

Figure 2. Respondents Gender

A younger age group was exhibited in households of the CMAP region in comparison with households in the NIRPC. Highest proportion of members under age 18 was reported living in rural counties. On the other hand, the highest proportion of members age 65 or older was reported living in suburban counties. Table 3.11 is a representation of age distribution in the study area.

Table 12. Respondents Age (CRHTI 2010)

	Respondents Age						Mean
	Under 18	18 to 24	25 to 44	45 to 64	65+	Total	
CMAP	25.2%	19.4%	22.8%	24.2%	8.4%	100.0%	32.96
NIRPC	25.4%	16.9%	24.3%	25.8%	7.7%	100.0%	33.71
Urban	26.2%	20.8%	22.5%	22.8%	7.8%	100.0%	32.00
Suburban	23.6%	17.8%	23.1%	26.3%	9.3%	100.0%	34.51
Rural	26.8%	8.1%	28.1%	30.5%	6.6%	100.0%	34.68
Total	25.3%	19.2%	22.9%	24.3%	8.3%	100.0%	33.02

With regards to education level, 33% of all residents reported less than a high school diploma. Moreover, respondents in the CMAP region and urban and rural counties exhibited a higher number of graduate-level education attained. Table 3.12 represents educational level among respondents in the study region.

Table 13. Educational Attainment (CRHTI 2010)

	Educational Attainment					
	Less than High School Grad	High School Grad	Some College	Associate & Technical	Bachelor	Total
CMAP	34.5%	21.0%	13.6%	6.2%	14.6%	100.0%
NIRPC	32.5%	28.1%	14.9%	6.6%	11.7%	100.0%
Urban	37.7%	16.6%	14.2%	6.0%	14.8%	100.0%
Suburban	29.1%	30.1%	13.2%	6.3%	13.2%	100.0%
Rural	28.5%	23.6%	11.6%	7.5%	18.3%	100.0%
Total	34.3%	21.6%	13.7%	6.2%	14.4%	100.0%

Regarding race distribution, about 66% of respondents were reported to be white and 19% African American. A higher diversity was exhibited in the CMAP region in comparison to the NIRPC region, as were urban county residents compared to rural county residents. Table 3.13 is a representation of ethnicity distribution in the study region.

Table 14. Ethnicity (CRHTI 2010)

	Race/Ethnicity					
	White	Black/ African American	American Indian, Alaskan Native	Asian	Other	Total
CMAP	66.6%	19.2%	0.0%	0.3%	13.8%	100.0%
NIRPC	76.9%	18.6%	0.1%	0.1%	4.3%	100.0%
Urban	60.1%	26.9%	0.0%	0.3%	12.7%	100.0%
Suburban	77.5%	7.1%	0.1%	0.2%	15.1%	100.0%
Rural	99.4%	0.3%	0.0%	0.0%	0.2%	100.0%
Total	67.5%	19.2%	0.0%	0.3%	13.0%	100.0%

Majority of workers who didn't work from home traveled to work using an automobile making up 78% of total travel modes. This proportion exhibited an increase to 96% for commuters from NIRPC region, 92% for commuters in suburban counties and 94% for commuters in rural counties. The highest reported number of bus rides was exhibited in the CMAP region and the urban counties, similarly were rail commuters. Table 3.14 is a representation of typical mode to work distribution.

Table 15. Typical Mode to Work (CRHTI 2010)

	Typical Mode of Transportation to Work					
	Auto	Bus	Rail	Shared Ride / Taxi	Other	Total
CMAP	76.7%	9.7%	7.8%	0.2%	5.7%	100.0%
NIRPC	95.8%	0.1%	2.4%	0.1%	1.6%	100.0%
Urban	66.2%	14.2%	11.4%	0.3%	7.9%	100.0%
Suburban	92.4%	2.8%	2.5%	0.0%	2.2%	100.0%
Rural	94.1%	0.1%	2.7%	0.0%	3.2%	100.0%
Total	78.3%	8.9%	7.3%	0.2%	5.3%	100.0%

Almost 25% of commuters reported that their vehicle was required for work. 21% of CMAP regional commuters and 29% or NIRPC commuters were included in that figure. Commuters from rural, suburban and urban-based counties reported needing a car at work with 28%, 26% and 17% respectively. Figure 3.3 is a representation of the distribution of respondents requiring a vehicle at work.

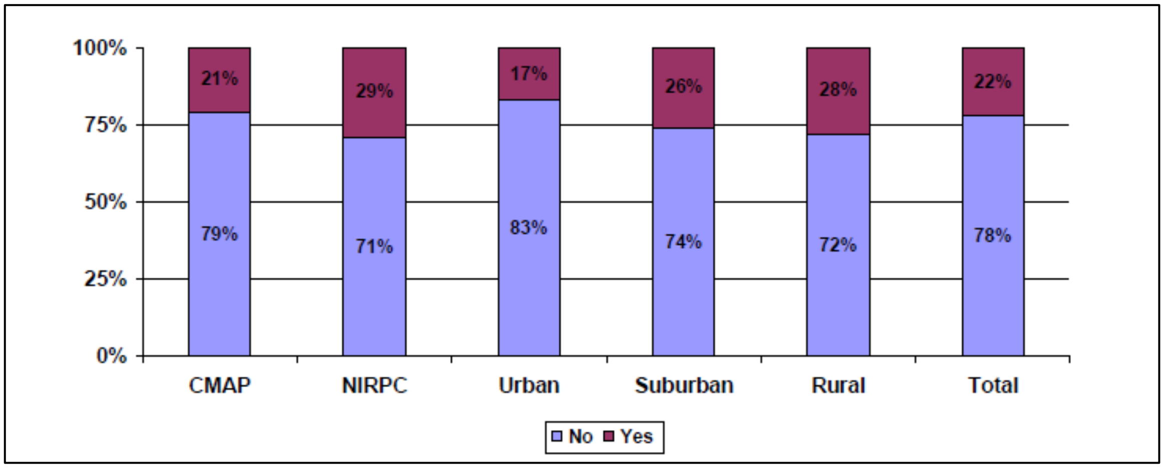

Figure 3. Vehicle Required at Work (CRHTI 2010)

In this study, data extracted from CMAP datasets was used for the primary reason of validating the *PWI*. From the dataset, number of walk trips per census tract for The City of Chicago is used for correlation with *PWI* values. Number of walk trips was normalized, i.e., values ranging between zero and one, to provide for a region-specific measure that is comparable with *PWI*. Appendix A. represents the normalized values of number of walk trips reported through CMAP dataset within the study area for each census tract. Moreover, data relating to crimes was also extracted and utilized for the development of safety attributes used for the development of the *PWI*.

3.2 United States Census Bureau

Through the United States Census Bureau, two forms of datasets have been extracted for the development of the *PWI*. Statistical data, such as population counts, and data in the form geographic maps, such as census tract geographic zones, have been gathered and utilized to develop the *PWI* as can be seen on Figure 4.

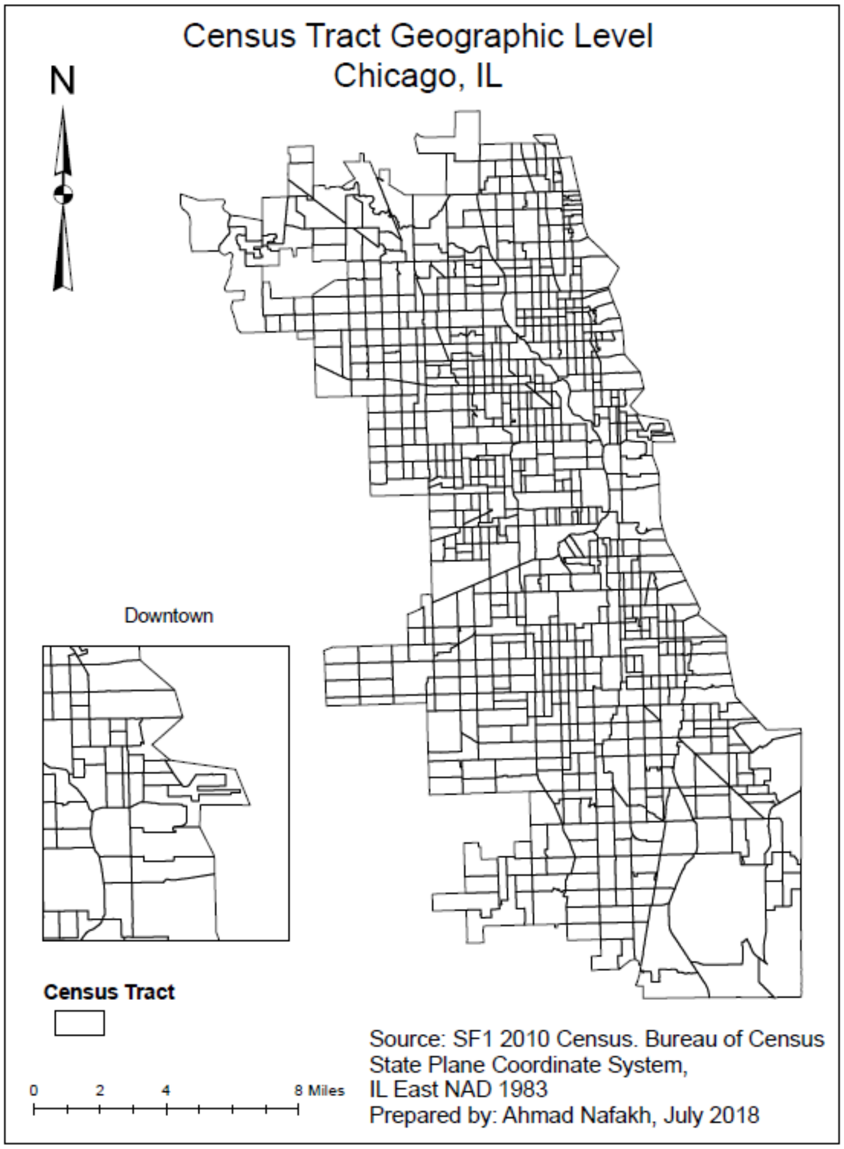

Figure 4. Census Tract Geographic Level - Chicago IL (U.S. Census 2010)

Mandated in the United States Constitution, population counts are conducted once per decade. Every resident of the United States is accounted for in the process of population counting. Through the population counts, it is determined how many seats each state will have in the U.S. House of Representatives, a process also known as "appointment." This process of population counting is also used to distribute billions of dollars in federal funds to local communities.

The Census dataset used in this study was collected in the year of 2010. And the next Census will be conducted in 2020. The 2020 data collection process will account for an increasingly diverse population that is continuously growing of around 330 million people in more than 140 million housing units (U.S. Census 2017).

With regards to data in the form of geographic maps, Topological Integrated Geographic Encoding and Referencing (TIGER) products have utilized to generate and then calculate relative built environment attribute used in the development of the *PWI*. TIGER products are the result of spatial extracts from the Census Bureau's database. This database contains geographic features such as roadway networks, railroads and rivers in addition to legal and statistical geographic areas.

Data in the form of "Shapefile," i.e., files used for spatial analysis in GIS, have been extracted to then be analyzed leading to the generation of maps that visually represents the result of the analysis. Shapefiles that were used in this study include:

1. Census tracts
2. Land-use
3. Roadway network
4. Building footprints
5. Serviced bus route (served by public transit)
6. Bus stops (served by public transit)

All geographic data used in the development of the *PWI* was extracted for the years 2008-20010 depending on the availability of historic data. The reason behind not selecting the most current statistical and geographical data available was due to the limit in availability of population counts to the year of 2010. This selection provides for a more accurate representation of built environment attributes as they relate to population densities. Figure 3.2.1 below is a representation of a simplified GIS model that uses data on known spatial locations integrating data.

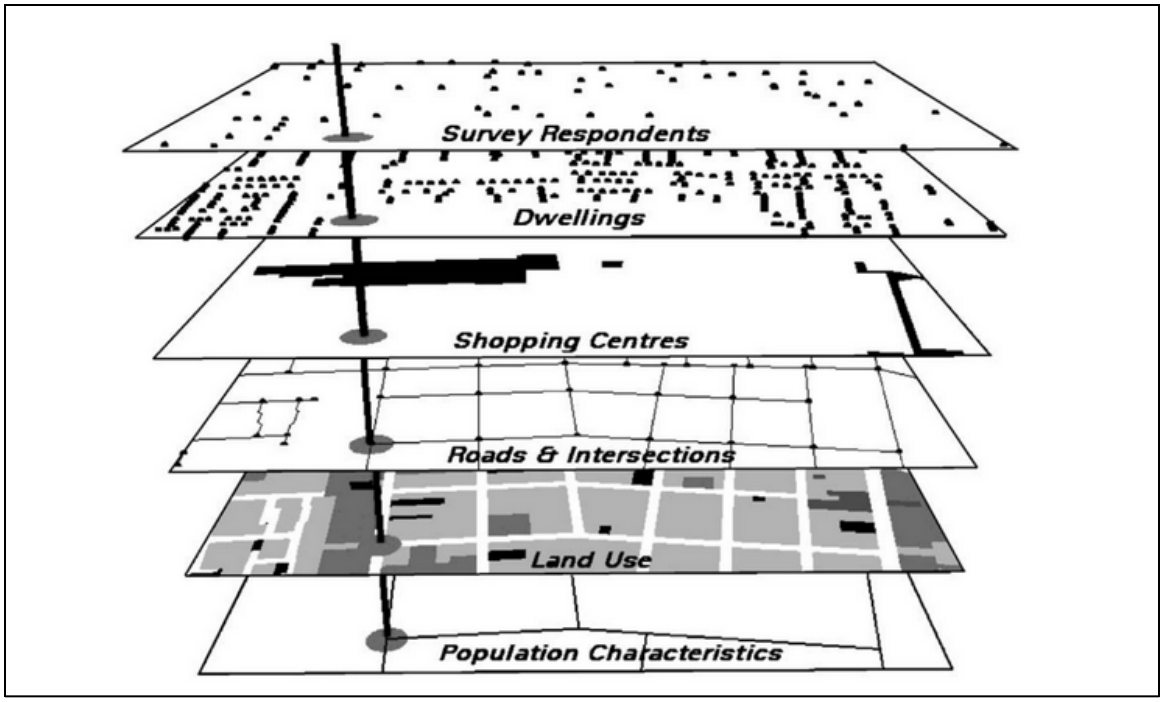

Figure 5. Simplified GIS Model Using Census Data (Leslie 2007)

4. RESEARCH METHODOLOGY AND FRAMEWORK

4.1 Geographic Information Systems (GIS)

Capturing, storing, analyzing, modeling, retrieving and visually presenting spatially referenced data can be performed using GIS, which is a computer-based tool. A sophisticated database is used by GIS software allowing for the analysis of data by location and reveling valuable trends, information, and relationships otherwise missed or overlooked in spreadsheets and conventional statistical methods.

A referencing algorithm relates date to actual known location on the Earth's surface. This insures correct and accurate projection of data onto visual maps by employing a defined and location-specific coordinate system. In concept, GIS uses a series of layers, one on top of the other, tying each observation to a point, a line, or an area with its relative information. For example, a population layer may have population numbers for a city concentrated in points located at the centroid of each census tract. This population layer can be overlaid with the census tract layer having information of areas of each census tract. In addition, a third layer containing roadway networks can overlay both layers with information related to length of roadway segment. Having all three layers overlaying one another, an analysis can be conducted representing population per unit area, roadway segments per unit area, and population per unit length of roadways.

GIS processing of maps and data uses vertical cutting of layers of relevant information analyzing the relationships between phenomena co-located in space.

After geographic-referencing of data has been conducted (that is, data having a specific coordinate system represented on the map) data analysis depending on the scope and purpose of the study can begin.

Even though there exists a considerable amount of environmental variation within cities and, ideally, the smallest geographic level should be selected for an analysis with a purpose of quantifying walkability related to the built environment, the availability of data was the driving force behind selecting the census tract as the geographic level of analysis for this research. This research utilizes GIS to conduct a walkability analysis using census tract as the geographic level for The City of Chicago.

4.2 Development of Pedestrian Walkability Index

The Pedestrian Walkability Index (*PWI*) in this study is developed using eight different measures, sub-indices, related to the built environment, public transit serviceability and safety; population density index (*PDI*), land-use diversity index (*LDI*), net commercial density (*CDI*), network connectivity index (*NCI*), public transit serviceability, comprised of two indices: bus stop density index (*BSDI*) and bus route density index (*BRDI*) and crime rate density, comprised of two indices: crime rate per area density index (*CR_ADI*) and crime rate per capita density index (*CR_CADI*). The eight measures described above are selected in this study because they capture relevant aspects of an urban community, or neighborhood design, serviceability and safety, that in return, is likely to either promote or inhibit the physical activity of walking. Also, these measures have been used in many studies and have shown a positive correlation with walking except for crime.

A study conducted by Rutt and Coleman using statistical analysis has demonstrated that Body Mass Index (BMI) and land-use diversity in a neighborhood with low-income had a positive relationship (Rutt, Coleman 2005). In another study consisting of 715 participants, analysis methods of improved sampling on data collected showed that the purpose of walking for exercise related to population density of a neighborhood or community has a positive relationship (Forsyth et al. 2007). Moreover, a study using ten U.S. cities presented results showing a direct and positive relationship between walkability in a neighborhood or community and level of business diversity, i.e., net commercial density; in addition to a positive and direct relationship between walkability and the percentage of four-way intersections, i.e., connectivity. Cervero and Kockelman found that residential density, public transit serviceability, crime rates and diverse land-use are significant environmental attributes used with the purpose of measuring walkability (Cervero and Kockelman 1997). Provided the emphases of relevance of the selected measures, the following subsections define each of the eight measure and how they were developed, followed by the final index – *PWI* – combining all.

4.2.1 Land-Use Diversity Index (LDI)

Measurement of land use diversity is measurement of how homogenous or heterogeneous land-use is for a specific geographic level, for this study it's the census tract geographic level (i.e., all residential or mix of residential, commercial and other uses). Many studies have shown that mixed land-use is generally supportive of walking and has a positive relationship in a neighborhood or community. The land-use types considered in this study are residential, commercial, institutional and open-space land uses, all of which can be related to walking. Figure 6 is an illustration of land-use types used in this study.

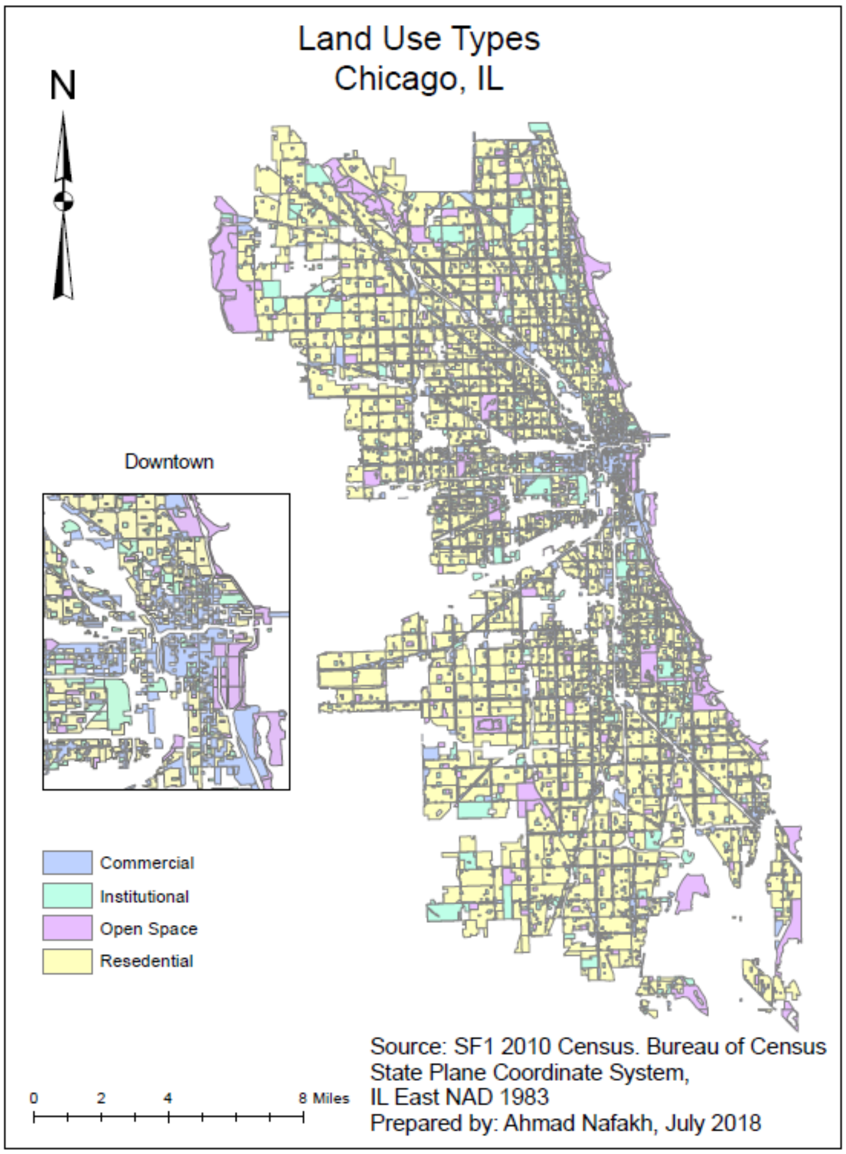

Figure 6. Land Use Types - Chicago IL (U.S. Census 2010)

In a meta review conducted by Saelens and Handy, of thirteen previous studies of walkability as it relates to the built environment, showed that the more diverse land-use is, the more supportive of walking is the environment (Sealens et al. 2008). In their review, extensive support for walking in correlation to land-use diversity was shown.

In this research, how a diverse land-use is in a given census tract is computed using concepts of entropy. The concept of entropy was originally defined in statistical mechanics and applied in information theory. In the field of economics and transportation, the concept of entropy was applied to study biodiversity and to measure inequalities. Frank and Pivo first used a version of the entropy concept in a study of classic mode choice (Frank and Pivo 1994). In their study, a positive relationship relating land-use diversity with walking, biking, and transit trips was concluded (Manaugh et al. 2013).

The mathematical formulation for entropy is defined as:

$$E_i = -\frac{\sum_{j=1}^{k}(L_j * ln\ (L_j))}{ln\ (K_i)} \quad for\ K_i > 1$$

$$E_i = 0\ for\ K_i = 1$$

L_j is the ratio of surface area of land-use type j $d$ivided by the surface area of the census tract where it is located, i.e., zone i. Since measurement of homogeneity or heterogeneity is the target, K_i is the total number of land-use types located within the census tract of interest.

Here, measurement of land-use diversity is calculated using the concept of entropy. Entropy for zone i, is found to then be divided by the highest entropy value calculated across all zones in The City of Chicago. The formulation of the measure of land-use diversity, as a result, is defined as:

$$LDI_i = \frac{E_i}{max\ (E_i)},\ 0 \leq LDI_i \leq 1$$

The rationale behind dividing by the maximum entropy found across the study area is to normalize its value and have a region-specific measure allowing for a more convenient city-wide comparative analysis.

For example, a zone (i.e., a census tract) containing 50% commercial and 50% institutional land-uses yields an entropy value of:

$$E = -\frac{0.5*ln(0.5)+0.5*ln(0.5)}{ln(2)} = 1.$$

A higher *LDI* value means that within a given zone, land-use diversity is higher and, therefore, this diversity in land-use is likely to better facilitate utilizing the physical activity of waking for one's daily activity between different destinations (loo and chow 2006). A direct and positive relationship between *LDI* and *PWI* is concluded.

4.2.2 Population Density Index (PDI)

Measurement of population density is a measure of how many people reside in a given zone divided the total area of that zone. Population density is an important factor relating to walkability of a neighborhood or community due to that fact that higher density tends to create a critical mass of people which in return encourages more people to walk resulting in a feel of safety.

A study by Frank and Pivo shows that with higher population density and employment density, higher traffic congestion occurs, which at a certain threshold it becomes much more convenient to use walking as a transport mode as to selecting an automobile (Frank and Pivo 1994). Using Puget Sound Travel Survey and census data for a census tract geographic level in their study, it was concluded that more walking for shopping trips is exhibit in areas with a population density of thirteen or more people per acre.

In this study, *PDI* in a given census tract is calculated using number of people per unit area of a census tract. The mathematical formulation of population density is defined as:

$$PDI_i = \frac{\left(\frac{P_i}{A_i}\right)}{max\left(\frac{P_i}{A_i}\right)},\ 0 \leq PDI_i \leq 1$$

P_i is the number of total population residing in zone i, and A_i is the surface area of the census tract where that population is located. *PDI* is also normalized $0 \leq PDI_i \leq 1$ *similar* to *LDI* described above, providing for a region-specific measure.

A higher *PDI* value translates to a higher population density residing in a specific census tract. Going back to Jacob's conditions for diversity, the denser the neighborhood is the more "eyes-on-the-street" which in return provides for a more feel of safety and security in an environment better welcoming walkability (Jacobs 1961). A study conducted by Loo and Chow concluded that in higher population density neighborhoods, access to services becomes easier within walking distance specially for low-mobility groups (Loo and Chow 2006).

In city centers where walking distances are observed to be noticeably and expectedly shorter, population densities are higher (Dobesova and Krivka 2012). Similar to the measure of land-use diversity, a direct and positive relationship between *PDI* and *PWI* is concluded.

4.2.3 Net Commercial Density Index (CDI)

In an urban environment, commercial developments tend to be a destination for wok, entertainment, shopping, public services, and for some, for residence. In an urban setting where commercial density is high, the more people's daily needs can be fulfilled for destinations with close proximity to each other. This, in return encourages people to walk as to drive to such places.

Commercial density in a given urban setting represents the presence of different commercial, financial and other public service developments. Such developments are often needed during one's daily activities in a community. A study conducted by Koh and Wong concluded that the ratio of commercial development in an urban environment, in addition to other factors, stimulates the tendency of walking in that environment (Koh and Wong 2013).

In this study, *CDI* in a given census tract is defined as the net commercial area of commercial developments divided by the area of the census tract where its located. For a more accurate representation of the net commercial area, the gross floor area of commercial developments is taking into account by accounting for the number of floors in each commercial development. The mathematical formulation of *CDI* is defined as:

$$CDI_i = \frac{\left(\frac{GFA_i}{A_i}\right)}{max\left(\frac{GFA_i}{A_i}\right)},\ 0 \leq CDI_i \leq 1$$

GFA_i is the gross floor area of commercial development, i.e., sum of product of development's footprint multiplied by the number of commercial floors corresponding to that development for census tract i, and A_i is the total rea of the census tract where the commercial development is located. Similar to previous indices, the use of the denominator in the *CDI* formulation is to provide for a normalized index, i.e., ranging between zero and one, similar to the *LDI* and *PDI* described in previous subsections.

Generally speaking, the higher that *CDI* value is for a specific census tract, it is suggested that close proximity and more diversity in commercial development is exhibited, as a result, providing people with a more encouraging environment to walk. It is concluded that the relationship between *CDI* and *PWI* is direct and positive. Commercial land-use and corresponding building footprints used in this study can be seen on Figure 7.

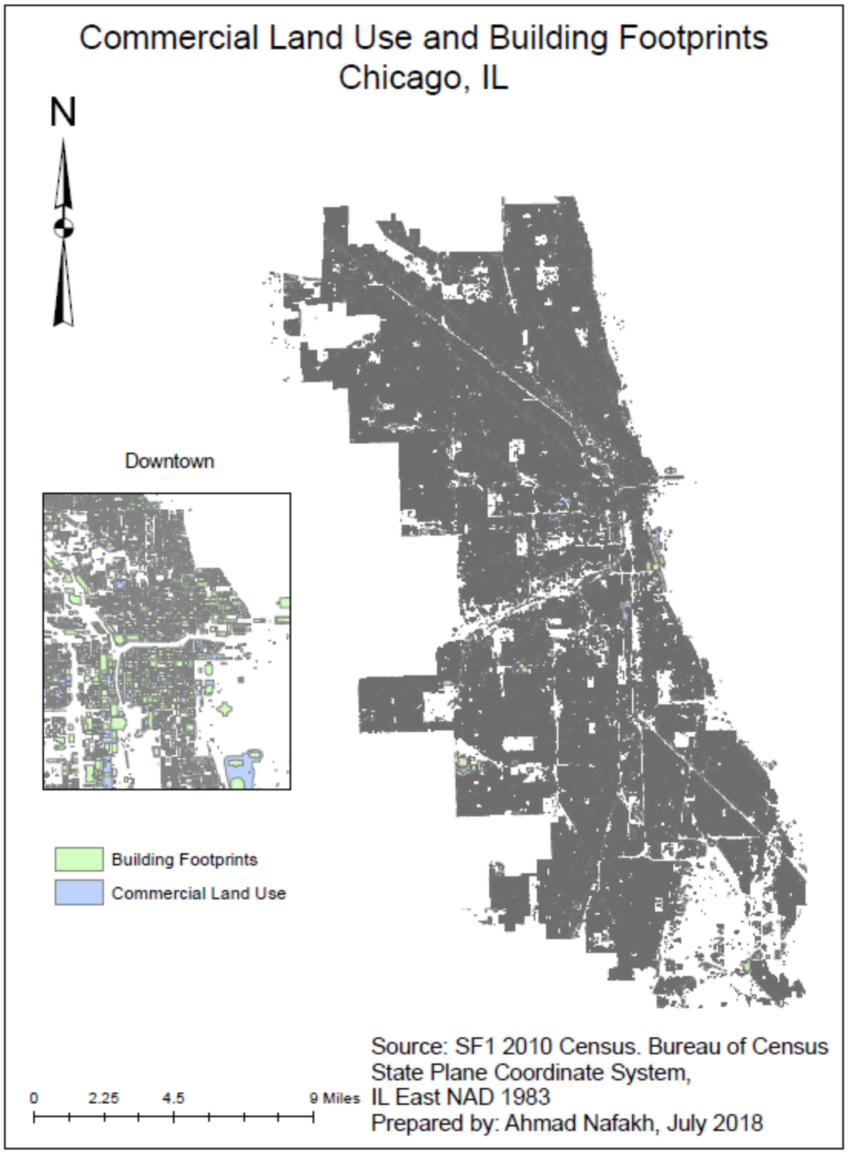

Figure 7. Commercial Land-Use and Building Footprints - Chicago IL (U.S. Census 2010)

4.2.4 Network Connectivity Index (NCI)

Roadway networks in an urban environment are usually adjacent by sidewalk designed for pedestrians. The smaller the block size is the more perimeter the area has, and such perimeter can be vibrantly activated through retail and commercial developments. The more activated a perimeter is the more animated and interesting an area becomes for pedestrians (Sevtsuk 2017).

NCI is measure of connectivity of crossing streets in a given area. It also can be viewed as an approximation of block size, which is one of the four factors of diversity pointed out by Jacobs (Jacobs 1961).

In this study, *NCI* in a given census tract is defined as the total number of streets crossing at an intersection divided by the area of the census tract where they're located. The mathematical formulation of *NCI* is defined as:

$$NCI_i = \frac{\left(\frac{\sum n_{ij}}{A_i}\right)}{max\left(\frac{\sum n_{ij}}{A_i}\right)},\ \ 0 \leq NCI_i \leq 1$$

n_{ij} is an equivalency factor computed for every intersection in the study area. The equivalency factor for intersection j in census tract i is the number of roadway links intersecting or meeting at that intersection. $\frac{\sum n_{ij}}{A_i}$ is the sum of intersection equivalency factor for intersection j in census tract i. in other words, the equivalency factor for an intersection is the total number of roadway segments originating from, passing through or ending at that intersection. So, a six-legged intersection has an equivalency factor of six, and a t-intersection has an equivalency factor of three. Figure 8 is a representation of the roadway network utilized to generate the equivalency factor for each intersection in The City of Chicago.

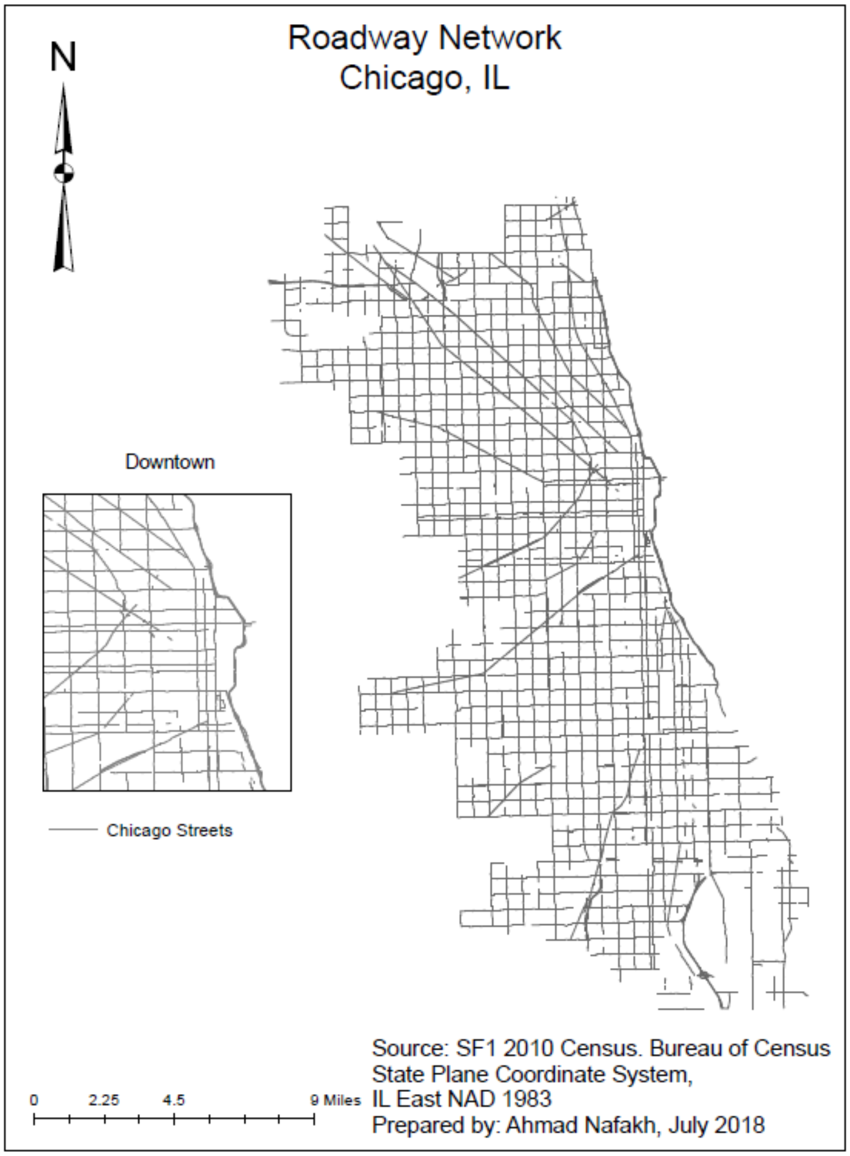

Figure 8. Roadway Network - Chicago IL (U.S. Census 2010)

In this study, the higher the *NCI* is the smaller the block size. In practice, a smaller block size tends to provide for a friendlier environment for pedestrians, while at the same time, providing for more route choices and the option to change routes more frequently. Smaller block sizes have a tendency to increase delay for motorized vehicles that discourages their usage and, in return, encourages walking. Similar to the previously described indices, *NCI* has a direct and positive relationship with *PWI*. In performing the spatial analysis for this index using GIS, highways, interstates and their ramps have been excluded to inhibit the artificial inflation of number of intersection that lack crosswalks or do not relate to walkability in this context.

4.2.5 Bus Route Density Index (BRDI)

Measurement of bus route density is a measure of the length of serviced bus routes in a given zone divided by the length of total routes in that zone. This index can be thought of as the level of service of the bus system. The subjective bus system in this context in the public transit system in The City of Chicago, i.e., CTA Bus System. Bus route density is an important factor as it relates to walkability in the context that, usually, majority of bus rides are accessed by riders walking to and from buses, and the more serviced a route is, i.e., the higher the level of service is, the more walkable areas adjacent to that route may become.

In an urban environment, high population density, high network connectivity and high commercial density are likely to provide for a more walkable environment, as mentioned above in the description of each of those indices. In a more walkable environment people are still likely to conduct trips that may not be convenient through walking, yet not justify the usage or owning of an automobile. For example, visiting a friend that is located on the other side of the city, or going to the lake. Public transit may be a very feasible and economical option in that regard as opposed to automobile usage. In particular, the bus system has been selected in this study due to the vast majority or route options it serves and provide in contrast to the CTA "L" Light Rail System. There are many U.S. cities that are making big-scale investments in their public transportation infrastructure in an attempt to lower automobile usage, encourage compact and urban development, and limit greenhouse gas emissions (McAslan 2017). CTA Bus routes analyzed in this study can be seen on Figure 8.

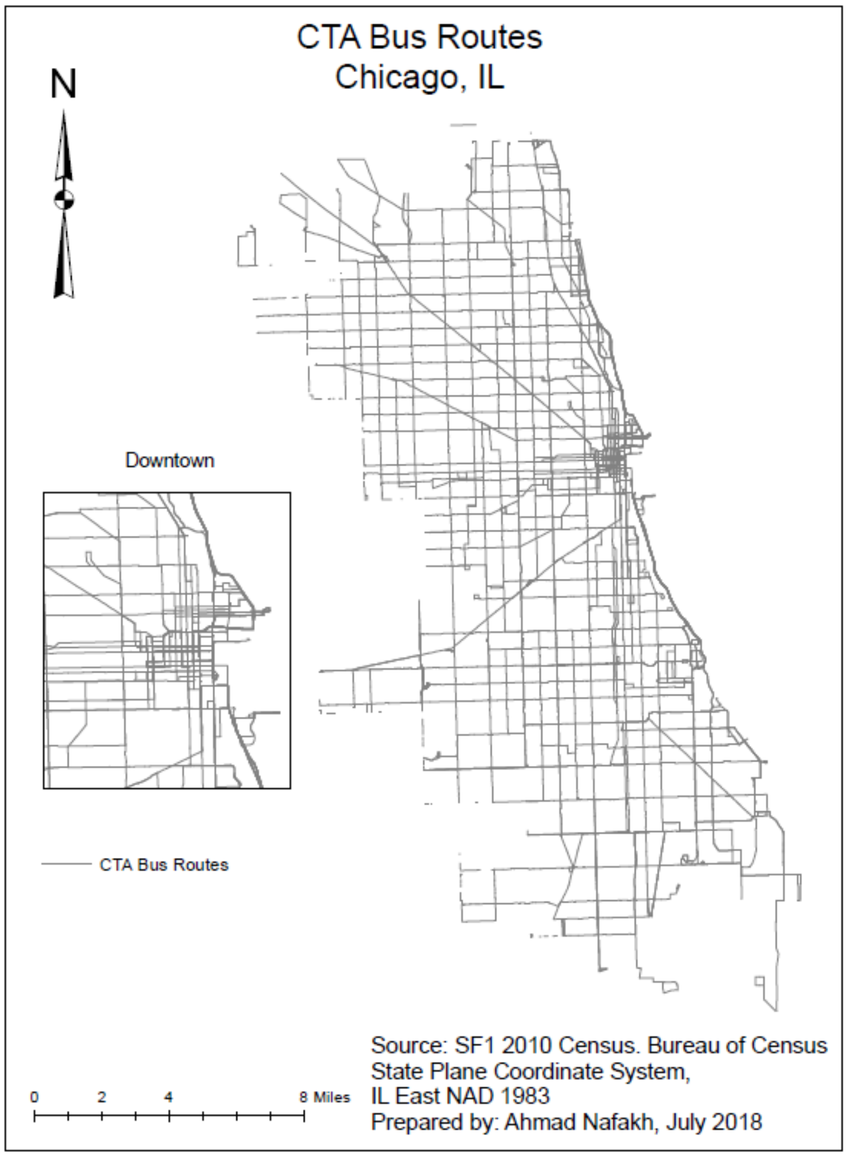

Figure 9. CTA Bus Routes - Chicago IL (CMAP 2010)

In this study, *BRDI* in a given census tract is defined as the total length of routes serviced by the CTA Bus System divided by the total length of routes in the census tract where they're located. The mathematical formulation of *BRDI* is defined as:

$$BRDI_i = \frac{\left(\frac{SR_i}{TR_i}\right)}{max\left(\frac{SR_i}{TR_i}\right)},\ 0 \leq BRDI_i \leq 1$$

SR_i is the total length of routes serviced by the CTA Bus System in a given zone, and TR_i is the total length of routes in that zone. The denominator in the *BRDI* is used again as a normalizing factor, i.e., having a value range between zero and one.

In this study, the higher the *BRDI* is the more serviced the roadway network. If an urban environment provides for more serviced bus routes, it is likely to be more pedestrian friendly promoting walking and the use of public transit as to using an automobile. Similar to the previously described indices, *BRDI* has a direct and positive relationship with *PWI*.

4.2.6 Bus Stop Density Index (BSDI)

Measurement of bus stop density is a measure of the number of bus stops along the bus routes serviced by the CTA Bus System in a given zone divided by the area of that given zone. In a similar context to the *BRDI*, the *BSDI* captures an important characteristic of the CTA Bus System which is the close proximity of access points to the bus, i.e., bus stops. To use the bus system, one should cover additional trips from and to the access points. These trips are referred to as first-mile-last-mile trips (FMLM). The FMLM trip becomes an issue that deviates people from deciding to use the bus and look for more convenient transport options if it falls outside their comfort distance, that is, the distance one is willing to walk to access the bus. Bus stops for the CTA Bus System analyzed in this study can be seen on Figure 9.

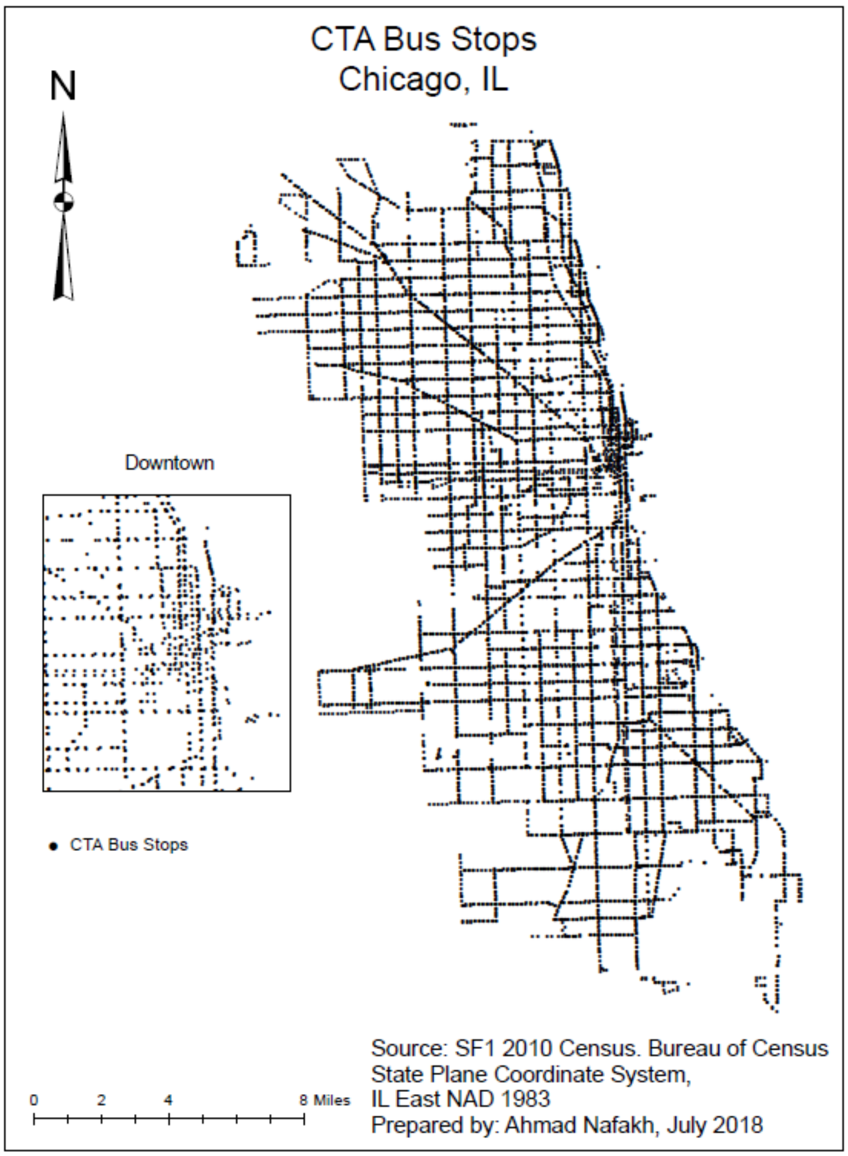

Figure 10. CTA Bus Stops - Chicago IL (CMAP 2010)

In this study, *BSDI* in a given census tract is defined as the total number of bus stops serviced by the CTA Bus System divided by the total area of census tract where they're located. The mathematical formulation of *BRDI* is defined as:

$$BSDI_i = \frac{\left(\frac{BS_i}{A_i}\right)}{max\left(\frac{BS_i}{A_i}\right)},\ 0 \leq BSDI_i \leq 1$$

In this study, the higher the *BSDI* the more accessible the *CTA* Bus System is, and the more access the roadway network provides to public transit the less likely that FMLM issue will arise deviating people from using the bus, as a result, using the system and walking to doing so. Similar to the previously described indices, *BSDI* has a direct and positive relationship with *PWI*.

4.2.7 Crime Rate per Area Density Index (CR_ADI)

Measurement of *CR_ADI* is a measure of number of crimes committed in a given zone divided by the area of that zone. This measure of crime rate per area is an important measure regarding how walkable a neighborhood or community may be. The display of physical disorder or misconduct in public areas provides for signs that have a potential to amplify residents' perception of crime and increase fears (Skogan and Maxfield 1981). This increased perception of insecurity or lack of safety is likely to discourage one from walking in such unwelcoming environments.

In this study, *CR_ADI* in a given census tract is calculated as an inverse to crime rate per unit area for each given census tract, and is computed using the following mathematical formulation:

$$CR\_ADI_i = 1 - \frac{\left(\frac{CR_i}{A_i}\right)}{max\left(\frac{CR_i}{A_i}\right)},\ 0 \leq CR\_ADI_i \leq 1$$

Here, CR_i is the number of crimes committed in zone i and A_i is the area of that given zone. In this study, measurement of crime rate per area is subtracted from one to represent a safety measure for each zone. For example, the higher the crime rate per unit area is for a given zone the lower the value of *CR_ADI*. Comparable to previously described indices, *CR_ADI* is concluded to have a direct and positive relationship with *PWI*.

4.2.8 Crime Rate per Capita Density Index (CR_CADI)

Measurement of *CR_CADI* is a measure of number of crimes committed in a given zone divided by the population of that zone. *CR_CADI* captures the rate of crime in zone as it relates to the number of people residing in that given zone. In a city like The City of Chicago, where population densities and corresponding census tract areas can vary drastically, *CR_CADI* is intended to compliment *CR_ADI* in assessing the safety of a given zone as it relates to others. This measure of crime rate per capita better captures the safety attributes in this context for such variation in population and zonal areas.

Similar to *CR_ADI*, *CR_CADI* is representation of safety in a community, and the safer the community the more walkable it may become. In this study, the mathematical formulation of *CR_ADI* is defined as:

$$CR\_CADI_i = 1 - \frac{\left(\frac{CR_i}{P_i}\right)}{max\left(\frac{CR_i}{P_i}\right)},\ 0 \leq CR\_CADI_i \leq 1$$

Where CR_i is number of crimes committed in zone i and P_i is the total population within that zone. In this study, and similar to *CR_ADI*, the higher crime rate per capita is the lower the value of *CR_CADI*; as a result, the les walkable that zone is. Once again, the denominator in both *CR_ADI* and *CR_CADI* is used a normalizing factor, i.e., ranging between zero and one, similar to other indices in this study providing for a region-specific indices better facilitating comparison. Moreover, *CR_CADI* is concluded to have a direct and negative relationship with *PWI*.

5. RESULTS

In this study, built environment characteristics, public transit serviceability attributes and public safety aspects that have previously shown association with physical activity level, i.e., walking, were identified and combined using spatial and statistical analysis leading to the development of the *PWI*. The *PWI* was then validated using Chicago Metropolitan Agency for Planning (CMAP) dataset. The resulting index showed a dose response relationship with all its characteristics leading to its development whereby areas exhibited high *PWI* values where reported by residents to have higher levels of physical activity, i.e., walking. The index also showed inverse relationship with crime related activities exhibited in neighborhoods.

As can be expected for The City of Chicago, by viewing the *LDI* map presented on Figure 11, higher values, darker color-coding, are exhibited in and near the downtown area, i.e., the Loop, in addition to relatively high values on the west side of the city as well. Mixed land-use in the city can be seen in many places, nevertheless, is concentrated in the commercial business district where many go to work and live in the high rises concentrated there. The West Loop area is similar in the mixture of land-use, except there aren't as many high rises. The West Loop area is vibrant with commercial and retail developments which attracts many form across the region.

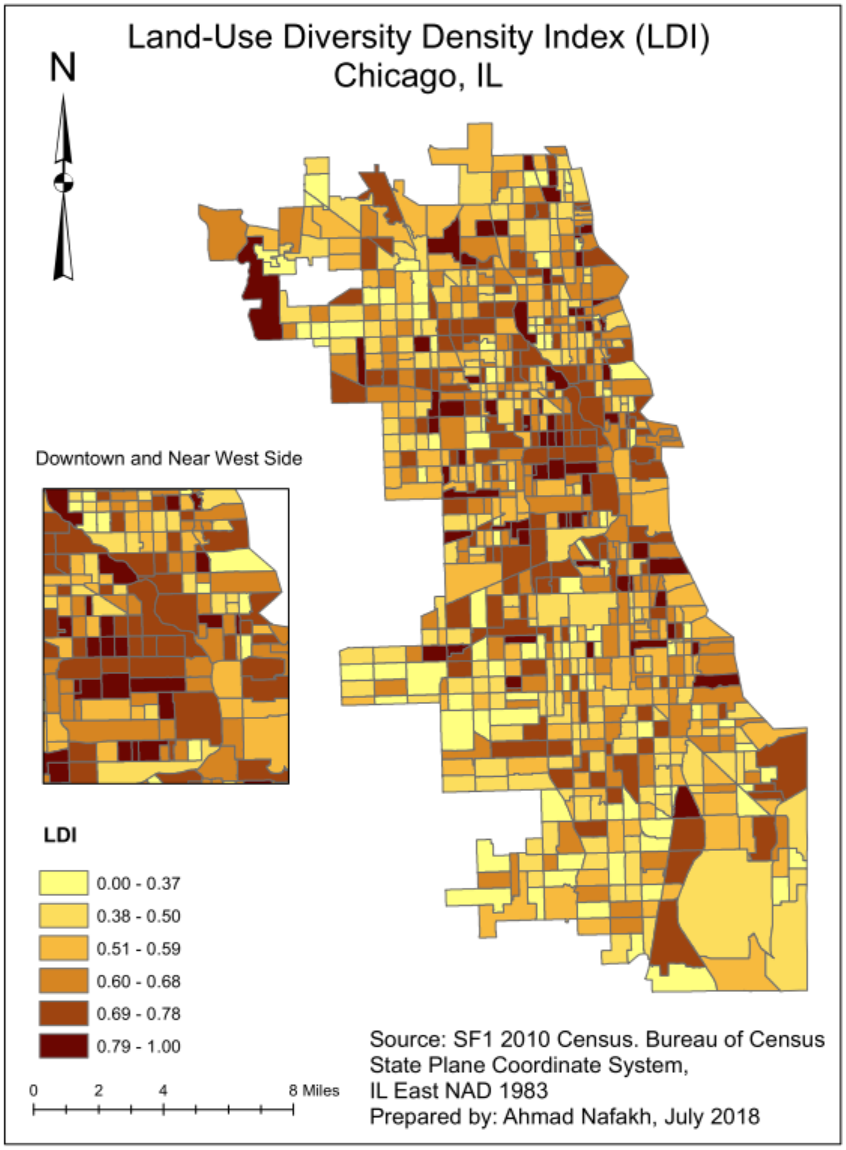

Figure 11. Land Use Diversity Index

The *PDI* map presented on Figure 12 shows higher values in the downtown area as well but more notable on the lakeshore northern edges of the city. This is mainly due to the existence of high-rise residential building along the shore line which leads to higher population densities, hence higher *PDI* values.

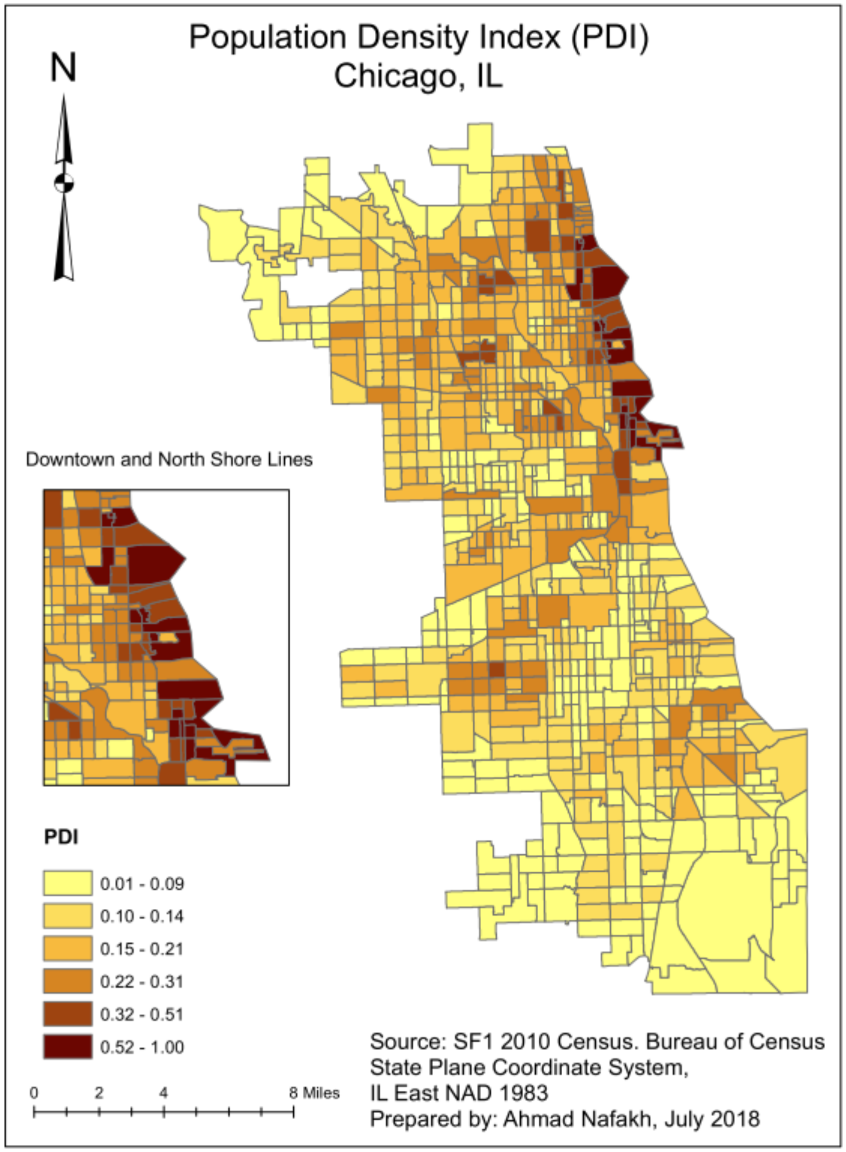

Figure 12. Population Density Index

With regards to the *CDI*, and as can be expected, the downtown area dominates in commercial developments, particularly that the *CDI* takes into account floor-count, or gross floor area, of commercial developments as opposed to building footprints only, therefore highest values with a considerable difference are seen. Figure 13 is a representation of the resulting map of the *CDI*.

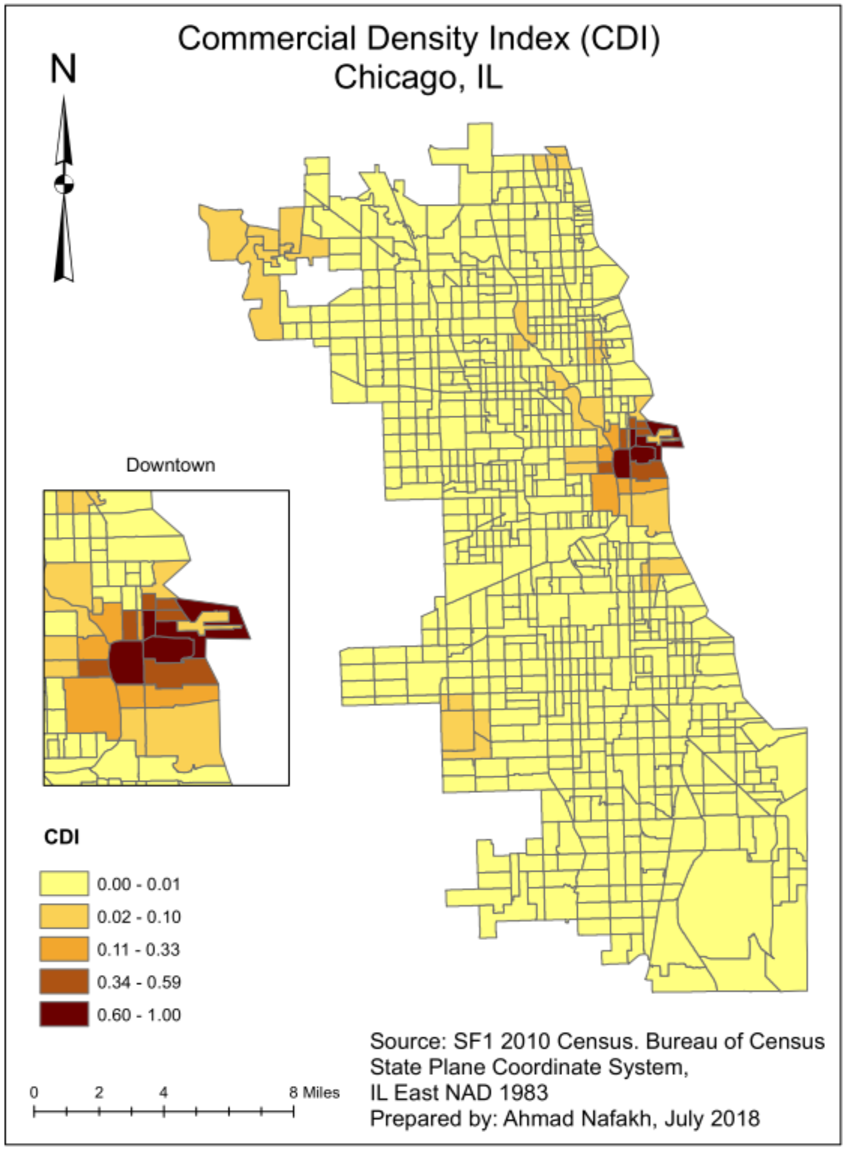

Figure 13. Commercial Density Index

Viewing the *NCI* map represented on Figure 14, it can be easily recognized that the downtown area is comprised of smaller city blocks that are more connected and has the tendency to decrease with distance from the downtown area. This explains the darker color-coding concentrated in the downtown area exhibited on the *NCI* map. Also, with the famous diagonal corridors that are six-legged, the higher NCI values are easily noticeable.

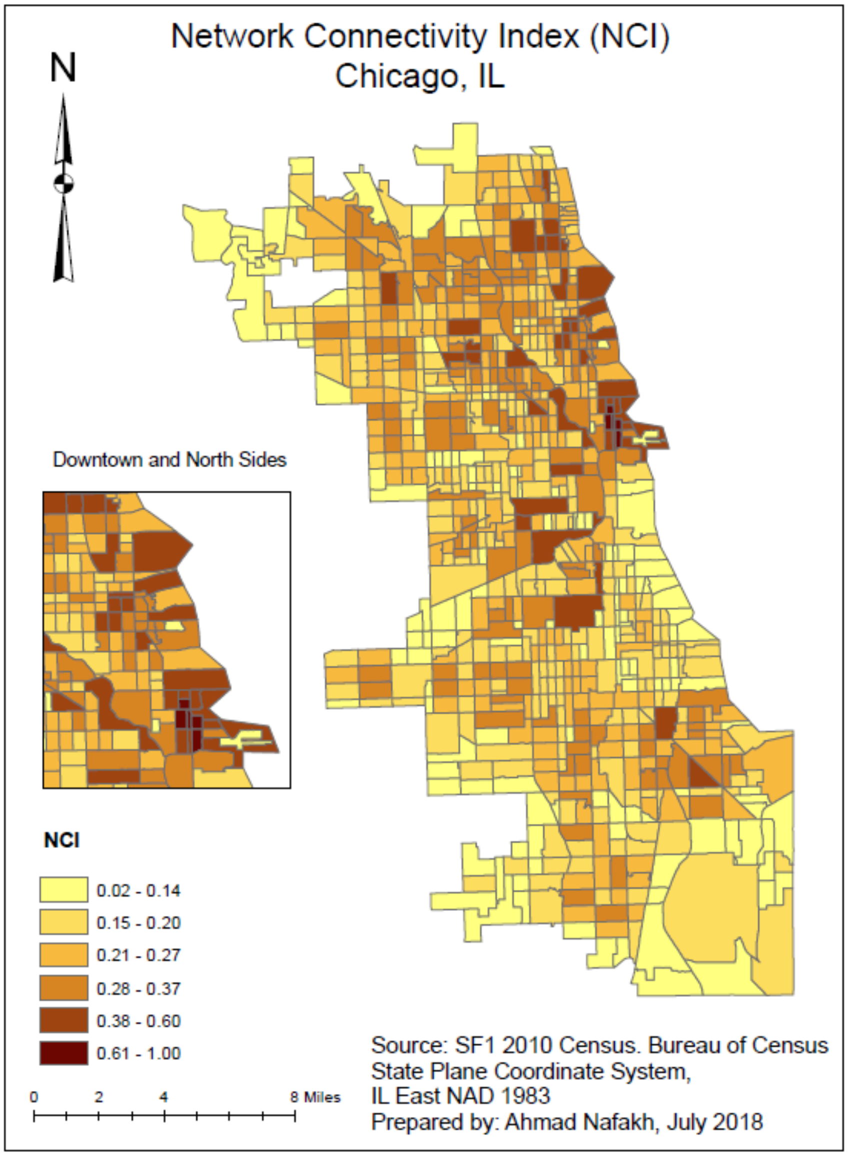

Figure 14. Network Connectivity Index

With the CTA Bus System serving 2,230 miles of route in the city, it's not surprising to see a wide spread of density variation concentrated in the downtown area and staying relatively dense along shore lines to then decrease with distance from it, as can be seen on the *BRDI* map Figure 15. This can be thought of as the level of service of the CTA Bus System.

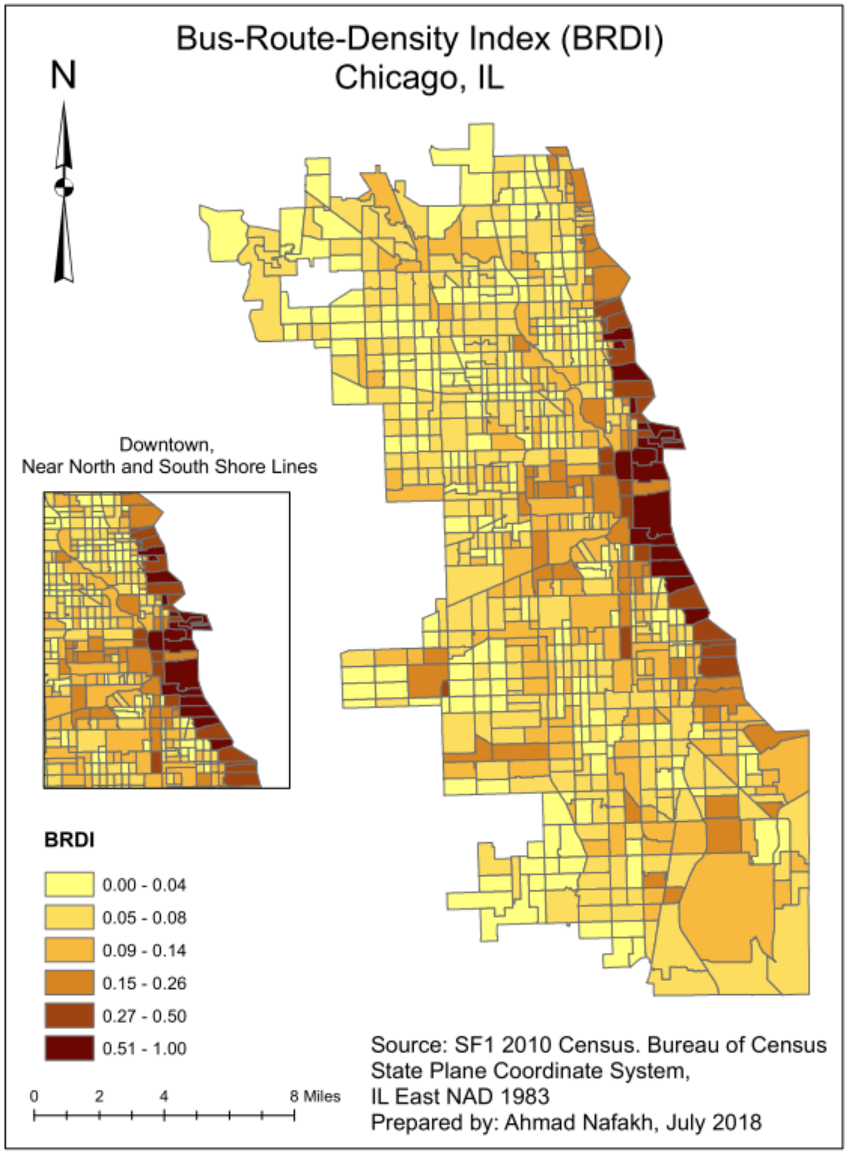

Figure 15. Bus Route Density Index

On the other hand, *BSDI* is, as expected, of higher concentration in the Loop area where much of the foot traffic can be exhibited and decreasing with distance from it. With smaller city blocks and higher commercial developments concentrated in the downtown area, it is not surprising that the CTA would locate a higher number of bus stops in that area serving both the population and the developments, hence higher *BSDI* values in the downtown areas as can be seen in Figure 16.

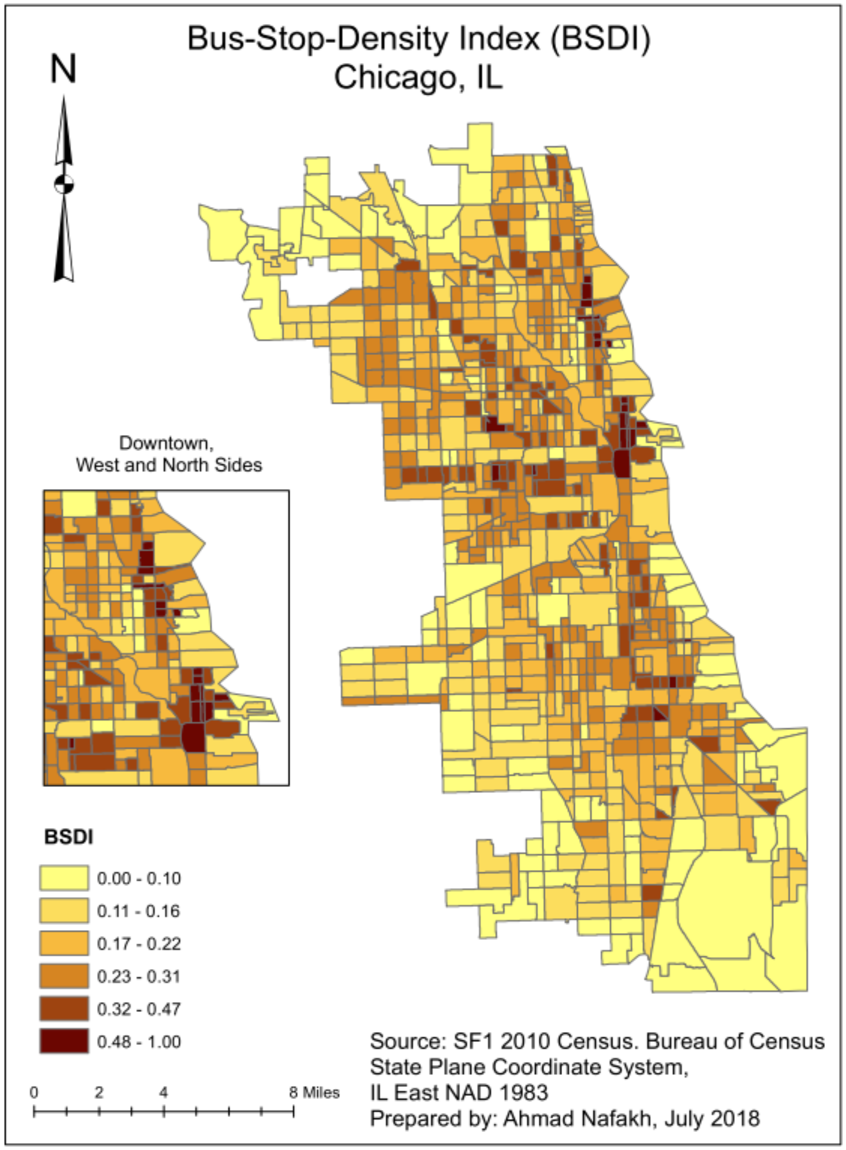

Figure 16. Bus Stop Density Index

Also, not surprisingly with the infamous reputation of Chicago's south and west sides, *CR_ADI* and *CR_CADI* show a higher concentration of crime rates in those respective areas that decreases with distance as can be seen in maps Figure 17 and Figure 18.

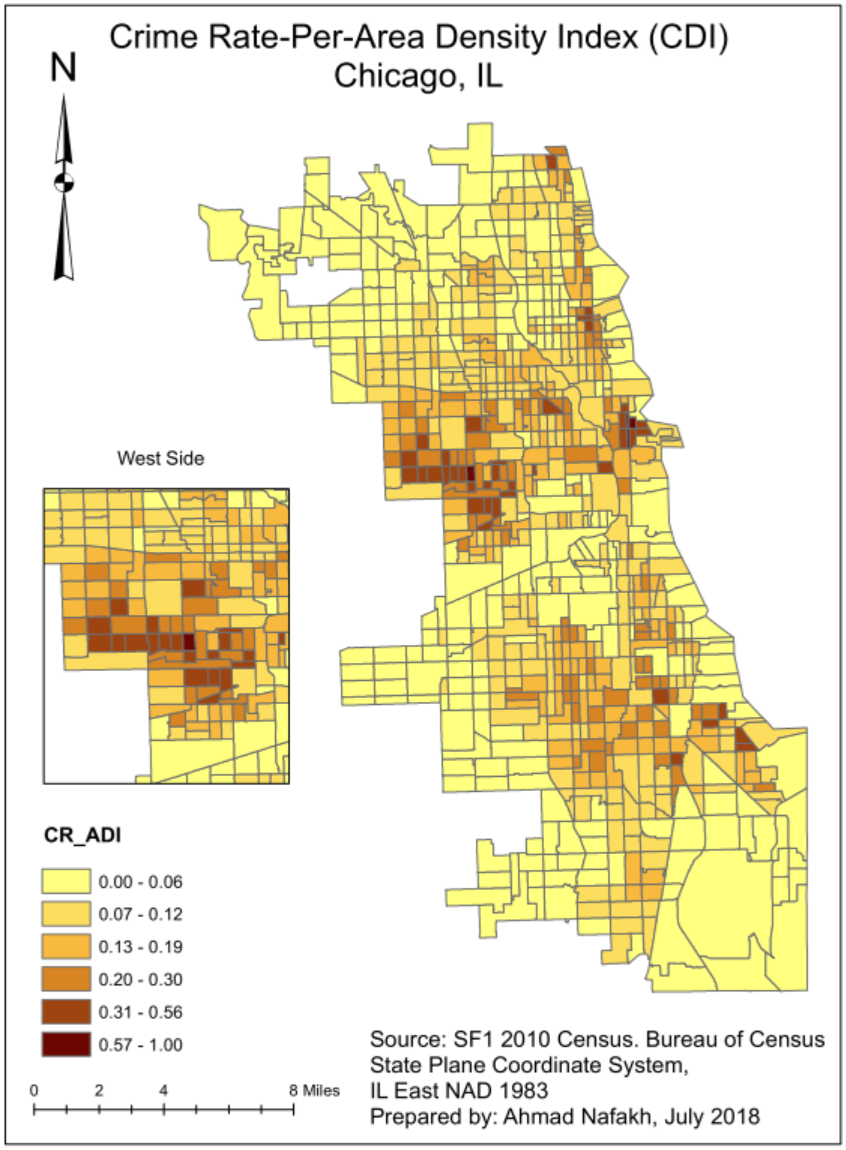

Figure 17. Crime Rate per Area Density Index

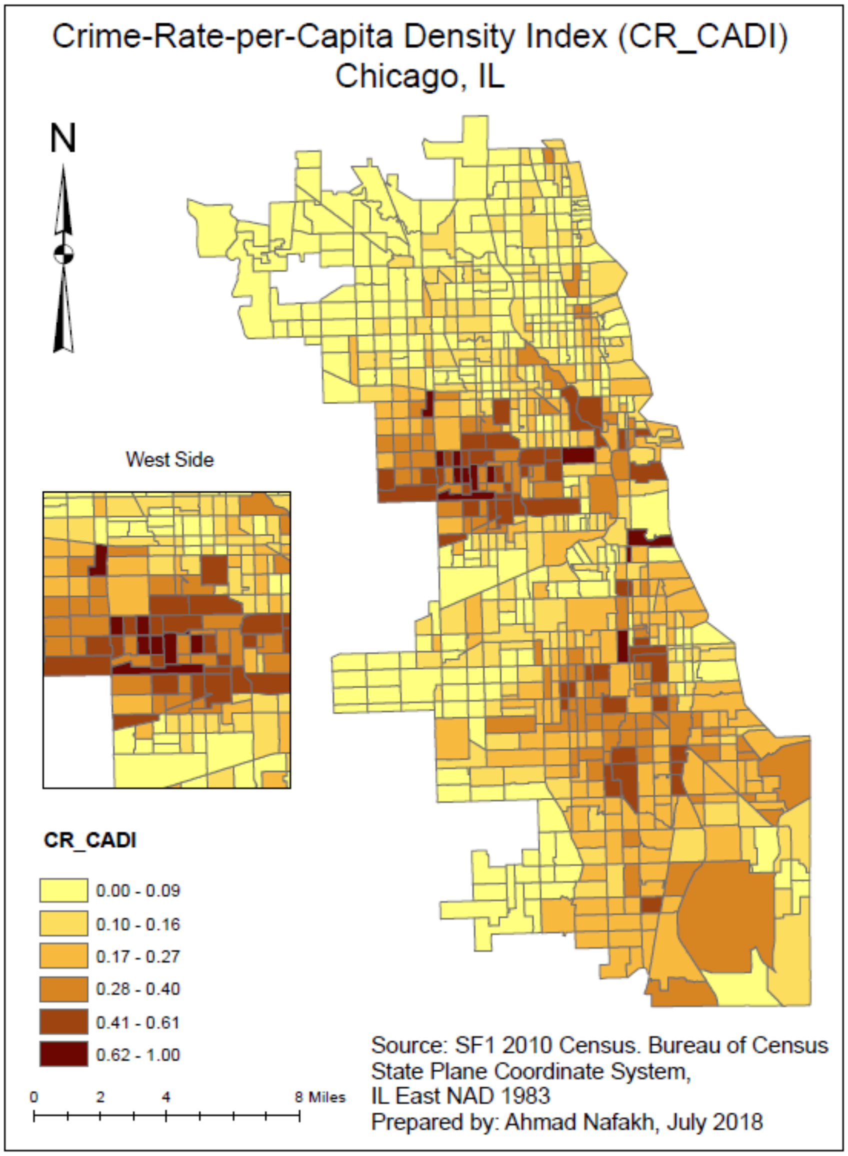

Figure 18. Crime Rate per Capita Density Index

5.1 Pedestrian Walkability Index (PWI)

As previously discussed, the *PWI* is the result of the combination of the eight sub-indices, i.e., *LDI, PDI, NCI, CDI, BRDI, BSDI, CR_ADI* and *CR_CADI*. Each one of those sub-indices captures important attributes that either promotes or inhibits walking in an urban community. The *PWI* was developed aimed at the assessment of built environment characteristics, public transit serviceability and safety aspects of communities. The final PWI for a given zone i.e., census tract, is mathematically defined as:

$$PWI_i = \frac{1}{256}[(1 + LDI_i) * (1 + PDI_i) * (1 + NCI_i) * (1 + CDI_i) * (1 + BRDI_i) * (1 + BSDI_i) * (1 + CR\_ADI_i) * (1 + CR\_CADI_i)] \quad 0 < PWI_i \leq 1$$

Where LDI_i is a measure of land-use diversity, PDI_i is a measure of population density, $NCDI_i$ is a measure of network connectivity, CDI_i is a measure of commercial density, $BRDI_i$ is a measure of bus route serviceability, i.e., level of service, $BSDI_i$ is a measure bus route accessibility, CR_ADI_i is an inverse measure of crime rate per area and CR_CADI_i is an inverse measure of crime rate per capita for zone i . The impact of each component of the PWI is combined by multiplication as opposed to summation. The reasoning behind this formulation is that attributes affecting pedestrian walkability in a giving urban environment have non-linear feedback impacts on one another. In other words, observing a change in one attribute results in the change in other attribute, i.e., cause-and-effect. For example, by enhancing or altering land-use to become more diverse, i.e., provide urban settings where work destinations, or the commercial business district, are in close proximity to or mixed with residential land-uses, more people will be encouraged to relocate residence locations to such area, hence increasing population density. As more people move into such more diverse land use areas, commercial developers may see business opportunities to have higher potential of attracting more customers; as a result, decide to be involved in commercially developing such areas leading to higher commercial densities.

Keeping the multiplication reasoning in mind, and for the purpose of avoiding a null value for *PWI* should any of the sub-indices yield a value of zero, a value of one has been added to every sub-index. Since a region-specific index is being developed at hand, relative values are important as opposed to absolute values. In such computation of the final index, the final result for the comparative analysis remains unchanged.

In the final formulation of the *PWI*, if each sub-index was to yield the highest possible value, the resulting *PWI* would yield 256, hence the use of a 1/256 coefficient is done to normalize the index keeping its value ranging between (0,1]. In accordance with definition provided above and the description of each sub-index, the higher the *PWI* value for a specific region, the more walkable and less car-dependent that region is as opposed to a low *PWI* value which indicates less walkability and higher car-dependency.

Finally, and as expected, *PWI* exhibits higher values in the downtown area, around the University of Illinois at Chicago's east campus and near Navy Pier areas by the lake front. Those results are compatible with expected performance of such areas designed and equipped with pedestrian-friendly environments. It's also worth noting the *PWI* exhibited relatively high values northeast of downtown, in particular, by the lake shores which is also supported by facts relating to walkability and pedestrian-friendliness in such areas as can be seen in Figure 19.

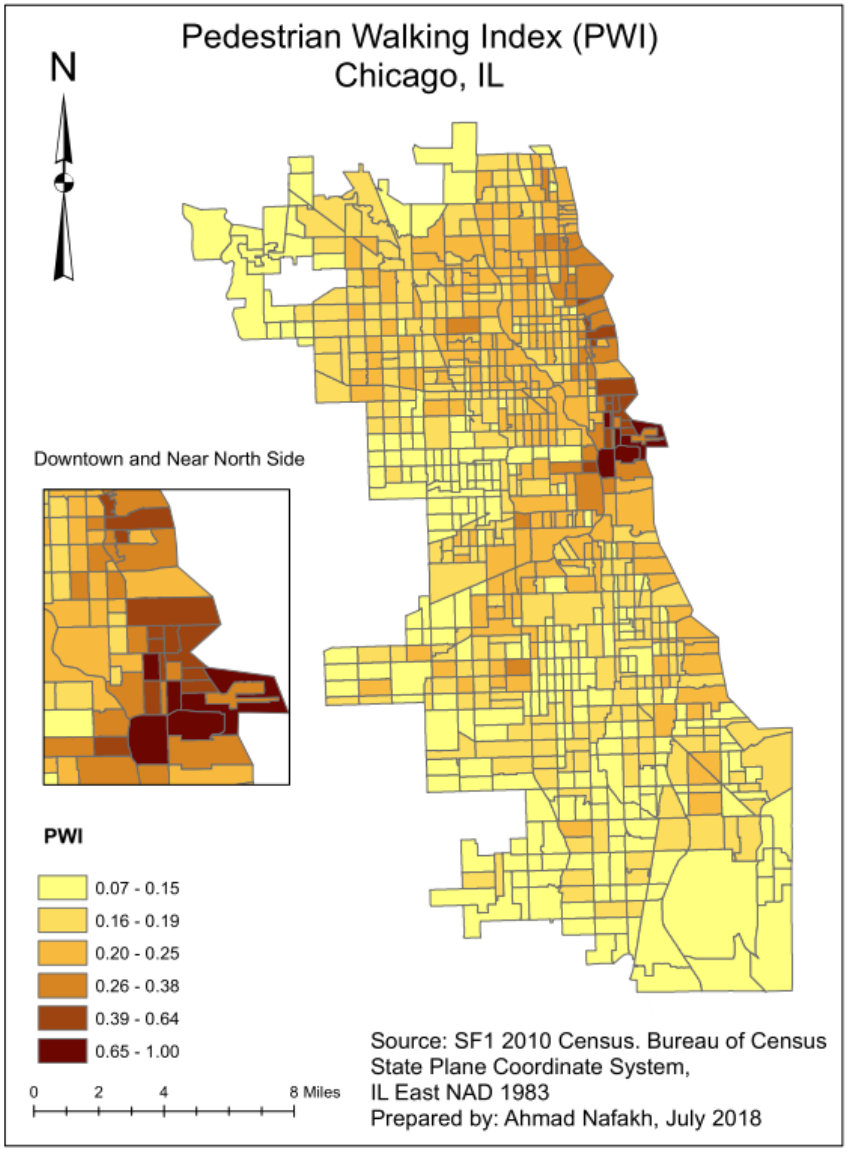

Figure 19. Pedestrian Walkability Index

This in turn leads to a partial validation of the *PWI*. In addition to the literature-supported evidence of the validity of the selected built environment characteristics, public transit serviceability and safety aspects as they relate to walkability, data from the CMAP database was utilized to provide for another validation approach. In this validation approach, number of walk trips, i.e., trips reported to have been conducted through a walk mode, was used for correlation with *PWI*. Through the correlation procedure, it was found that 66% of developed *PWI* values correlate with number of walk trips reported in the CMAP dataset, partially validating the developed index as can be seen in Appendix A. Figure 20 is a representation of the walk-mode trips reported through the CMAP survey.

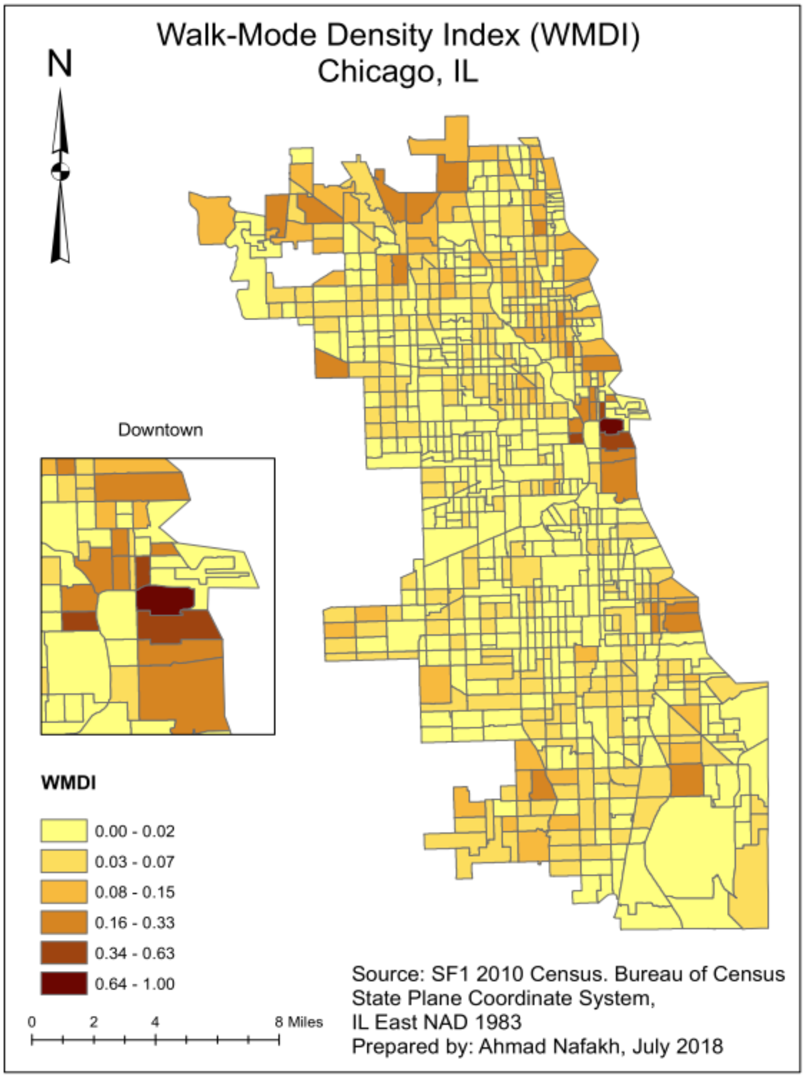

Figure 20. Walk-Mode Density Index (CMAP 2010)

5.2 Modeling Walkability

In this study, linear regression is used to model *PWI* for each of the 800 census tracts in The City of Chicago as an alternative method to the combination through multiplication method described previously. The variability in the response variable of the model is explained by built environment, public transit serviceability and safety related variables, i.e., the eight components of the *PWI*. Form all the gathered data used to generate the sub-indices, a subset of variables has been selected using Stepwise-Selection method. Moreover, chosen variables were narrowed down to eliminate multi-collinearity issues within the explanatory variables.

In the Stepwise-Selection method, 4 out of the total 8 explanatory variables were selected for the final model, resulting in the elimination of 4 variables. This selection was based on the variable's partial R-squared contribution to the overall model. Tables 5.1-A and 5.1-B present the results for the analysis of variance and selected variables used in the final model.

The parameter estimates were then tested at a 95% confidence interval two-tailed test with a 1.96 t-critical value. The parameter estimates of the walkability model were found statistically significant from zero. The overall model was also found to be significant from that with only the intercept, therefore the model is considered a statistically adequate model.

The model's goodness-of-fit was evaluated using the adjusted R-square statistic test. The adjusted R-square test is said to explain 75.28% of the variation in the response variable through the use of the final selected explanatory variables.

Table 16. Linear Regression Modeling - Analysis of Variance (A)

Analysis of Variance					
Source	DF	Sum of Squares	Mean of Squares	F Value	Pr>F
Model	4	2.22193	0.55548	330.37	<0.0001
Error	434	0.72973	0.00168		
Corrected Total	438	2.95166			

Table 17. Linear Regression Modeling - Analysis of Variance (B)

Variable	Parameter Estimates	Standard Error	Type II SS	F Value	Pr>F	Model R-Square
Intercept	-0.04303	0.01993	0.00784	4.66	0.0314	-
PDI	0.0955	0.01972	0.03942	23.45	<0.001	0.7010
CR_ADI	0.05293	0.02142	0.01026	6.1	0.0139	0.7385
NCI	0.75473	0.02866	1.16578	693.34	<0.0001	0.7493
BRDI	0.15369	0.02188	0.08295	49.33	<0.0001	0.7528

6. CONCLUSION

6.1 limitations

In this study, one of the limitations of the developed method used for walkability assessment is that there are arguably many other environmental characteristics that have an influential relationship with walkability but have not been used in the index developed in this study. Some of which may include, the existence of recreational facilities and public parks (Pikora, Bull, and Jamrozik 2002), the location, condition and continuity of pedestrian walkways (Handy et al. 2002; Cervero and Kockelman 1997), close proximity or access to destinations (Pikora, Bull, and Jamrozik 2002; Giles-Corti and Donovan 2003), other transit accessibility measures such as willingness-to-walk to train stations, attributes relating to natural landscapes objects and manmade or natural barriers (Rodriguez and Joo 2004); in addition to other urban design and safety related measures such the availability of street lighting, security cameras and building design characteristics. A comprehensively inclusive walkability index could include many or all of such attributes.

In addition to all the above described attributes, there exists evidence that perceived physical aspects of the built environment are to have an influence on walkability such as architectural designs and (N. Owen et al. 2004; Booth et al. 2000; Humple et al. 2004). The level and concentration at which parks along waterways, coastal beaches and parks are located within close proximity to residentially populated areas will have an influence on people's perception as being attractive and as a result be encouraged to be involved in recreational walking.

Another limitation of the used method was the availability of existing data for smaller geographic analysis levels, i.e., block-group level. In this study the geographic level utilized is census tract, which may not provide for the most accurate assessment of neighborhood walkability due to its large relative area which is comprised of multiple neighborhoods. Moreover, the availability of CMAP survey respondent data was available to only 400 of the 800 census tract in The City of Chicago which may have caused a skew in correlation used as a partially validating method to the developed index.

6.2 Discussion of Results

The walkability index in addition to its individual measures leading to its development in this study provides for a considerable policy-sensitive applied research. For instance, by geographically mapping diverse land use, residential and commercial densities and network connectivity across a city can aid decision maker in better allocating funds related to transportation infrastructure improvement programs that guides future growth and development. Through the covariations between the measures used to develop the walkability index, policy makers and practitioners can be better informed on where opportunities exist to promote physical activity through enhanced walkability. For example, communities that have high land use diversity but low network connectivity, i.e., larger block sizes, can be identified and investment can be directed towards the improvement and better design of such roadway network improving connectivity that in return promotes walkability and all the potential benefits that can be harvested as a result. One such investment could be allocated to better connect and complete pedestrian walkways. Moreover, communities that exhibit high diversity in land use in addition to high level of network connectivity can be identified and targeted for more residential development leading to an increased density.

The extent to which an individual perceives a community to be considered as a safe one is likely to have an influence on whether to involve in the behavior of walking in such a community or not. Safety here is viewed in terms of motorized density that could lead to causing harm or increasing risk of an injury if conflicted with a pedestrian; and as crime related safety that could expose the pedestrian to danger as result (Booth et al. 1997; Centers for Disease Control and Prevention 1996).

As funds for transportation infrastructure improvements increasingly become scares, the accurate identification and detection of areas of need for improvements that in return reduce automobile usage and fossil fuel dependency in addition to alleviating congestion and the environmental hazards resulting from it such as air pollution can be viewed as cost effective. To address modern-day public health and environmental issues, research in such trans-disciplinary approaches on the built environment and its quality of life is greatly needed (Frank et al. 2005).

6.3 Future Work

The eight sub-indices used in this study leading to the development of the *PWI* are a benchmark the built upon existing research strategies and a starting point aimed at providing for a more complete and better-informed measure to how walkable a neighborhood or a community is. It is obvious that there exist many other factors that are linked to walkability and walking behavior, some of which have been identified in this study and some that warrant further investigation and consideration. In the development of *PWI*, publicly available data resulting from surveys and built environment audits was utilized. For future continuation to the work described in this study, more comprehensive audits would be required. For example, sidewalk width and conditions, weather protected walkways and barrier protected walkways are likely to be influential in how pedestrian-friendly one location is compared to another.

The immense power of current GIS technologies in terms of capturing, storing, manipulating and analyzing different geographical attributes is relatively untapped in the context of physical activity and walkability research fields. The lack of availability of data on a smaller geographic level prevented the conduct of a more accurate and representable study for the neighborhood levels. Thus, the developed index in this study serves as a starting point for future work and development of and index that is more comprehensive capturing more of built environment characteristics, public transit serviceability characteristics and public safety related aspects related to walking.

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8. APPENDICES

8.1 Appendix A

PWI Values and CMAP "Number of Walk Trips" per Census Tract

Chicago Census Tracts	No. WLK TRIP (CMAP)	PWI
810400	0.022814	0.144627137
808002	0.011407	0.134092196
807600	0.022814	0.138929669
770700	0.030418	0.10669849
750600	0.019011	0.180704201
750500	0.049430	0.144316404
750300	0.019011	0.126405435
750100	0.015209	0.170243719
740300	0.019011	0.161846198
740200	0.019011	0.131835831
740100	0.007605	0.168242543
730700	0.003802	0.14006599
730600	0.007605	0.159238147
730500	0.030418	0.162848948
730400	0.038023	0.198473925
730300	0.019011	0.145460865
720700	0.015209	0.128824298
720600	0.007605	0.136448444
720500	0.003802	0.141782701
720400	0.049430	0.119402767
720300	0.019011	0.126076109
720200	0.144487	0.153713575
720100	0.015209	0.122639086
711400	0.011407	0.179408242
711200	0.019011	0.19299176
711100	0.019011	0.148900756
711000	0.011407	0.149526584
710900	0.007605	0.137756757
710800	0.015209	0.157280792
710700	0.030418	0.184752401
710600	0.030418	0.141562958
710500	0.034221	0.155382829
710400	0.003802	0.179671003
710300	0.011407	0.113120105
710200	0.011407	0.15608784
700200	0.011407	0.17656332
700100	0.003802	0.174550807
691500	0.019011	0.132199035
691400	0.011407	0.173333798
691200	0.011407	0.144964829
691100	0.015209	0.151023184
690900	0.019011	0.169354117
690500	0.072243	0.180013376
690400	0.030418	0.169894394
681400	0.007605	0.183211701
681300	0.030418	0.177829289
681200	0.026616	0.155523593
680900	0.041825	0.113770637
672000	0.003802	0.167223256
671800	0.003802	0.124848232
671600	0.011407	0.135908192
671500	0.034221	0.159631411
671400	0.007605	0.140903926
671300	0.030418	0.128343284
671100	0.057034	0.132082782
670900	0.015209	0.1526638
670800	0.019011	0.123872441
670700	0.026616	0.110628739
670600	0.007605	0.152817399
670500	0.022814	0.149192093
670100	0.003802	0.141631948
661000	0.003802	0.176907885
660800	0.015209	0.174264059
660700	0.015209	0.146205545
660400	0.011407	0.180059388
650500	0.011407	0.121185323
650400	0.034221	0.147170701
650100	0.041825	0.197884493
640800	0.003802	0.161548587
640700	0.011407	0.154473008
640600	0.011407	0.164251516
640500	0.007605	0.159669421
630900	0.003802	0.17889021
630800	0.030418	0.219255023
630500	0.095057	0.147907357
630400	0.041825	0.184634395
630300	0.019011	0.16780975
630100	0.007605	0.118398424
620400	0.007605	0.173643233

620300	0.015209	0.213741402
620200	0.019011	0.183448587
620100	0.003802	0.132805435
612100	0.038023	0.117592669
612000	0.007605	0.161705767
611900	0.003802	0.140385753
611800	0.015209	0.120229078
611700	0.022814	0.154688593
611400	0.026616	0.172500236
611300	0.106464	0.186432843
611200	0.007605	0.139353126
611100	0.003802	0.170433703
610400	0.011407	0.149693717
610300	0.060837	0.168374862
600400	0.019011	0.228575548
590700	0.015209	0.154719008
590600	0.026616	0.16161582
590500	0.007605	0.198237152
580700	0.015209	0.19663419
580600	0.007605	0.236424563
580400	0.049430	0.202848054
580200	0.003802	0.213396146
580100	0.007605	0.199042202
570500	0.007605	0.189606687
570400	0.007605	0.193357411
570300	0.030418	0.14476053
570200	0.007605	0.145475366
570100	0.007605	0.122234979
561100	0.045627	0.142514172
561000	0.022814	0.146357796
560900	0.015209	0.143469524
560800	0.019011	0.166732138
560700	0.053232	0.163806066
560200	0.015209	0.133690167
560100	0.003802	0.133417158
550200	0.007605	0.136172574
550100	0.003802	0.132870515
530600	0.003802	0.133795464
530400	0.034221	0.137692236
530300	0.053232	0.140092363
530200	0.026616	0.182931128

520500	0.015209	0.139358434
520400	0.003802	0.141603684
520300	0.003802	0.151139276
510300	0.038023	0.159935439
500200	0.022814	0.135895837
491400	0.011407	0.140708935
491300	0.015209	0.136271638
491000	0.007605	0.122940902
490800	0.007605	0.144578122
490700	0.003802	0.115567828
490600	0.011407	0.109324147
490500	0.015209	0.12158935
490400	0.011407	0.11933383
480500	0.011407	0.151011557
480400	0.003802	0.195907075
480300	0.022814	0.148866693
480200	0.003802	0.129103602
480100	0.007605	0.161110756
460700	0.030418	0.160016655
460500	0.041825	0.199709535
460400	0.011407	0.137812704
460200	0.007605	0.119436321
450300	0.030418	0.208789599
440900	0.003802	0.141350011
440800	0.003802	0.137798245
440700	0.007605	0.12777103
440600	0.003802	0.139817718
440300	0.015209	0.168484565
431400	0.003802	0.157718866
431200	0.045627	0.192332469
430800	0.049430	0.161890854
430700	0.003802	0.183240197
430600	0.068441	0.135649693
430500	0.087452	0.154228603
430400	0.030418	0.154215184
430300	0.007605	0.125708427
430200	0.011407	0.216575169
420800	0.003802	0.161557751
420700	0.026616	0.119788751
420600	0.019011	0.155164096
420500	0.007605	0.191160604

420400	0.038023	0.187501818
420200	0.015209	0.172683901
420100	0.007605	0.157682246
411200	0.304183	0.186351354
411100	0.133080	0.178883989
411000	0.167300	0.20582979
410900	0.182510	0.200934754
410800	0.053232	0.189783135
410700	0.186312	0.157368449
410600	0.102662	0.157613265
410500	0.030418	0.104995282
410100	0.106464	0.228656203
400800	0.007605	0.156711726
400500	0.003802	0.112211821
400400	0.022814	0.120918096
400300	0.041825	0.147028813
390700	0.098859	0.211554067
390600	0.083650	0.123054669
390500	0.015209	0.184801424
390400	0.007605	0.175363311
390300	0.003802	0.173720136
390200	0.007605	0.146562664
390100	0.011407	0.20376703
381900	0.007605	0.178048385
381800	0.007605	0.133439163
380200	0.003802	0.179775956
351400	0.003802	0.169389258
351100	0.015209	0.14256377
351000	0.007605	0.238559095
340600	0.022814	0.167562424
340500	0.007605	0.175290807
340400	0.007605	0.167413546
330200	0.034221	0.252731198
330100	0.114068	0.252932908
320600	0.190114	0.232704892
320400	0.733840	0.291752998
320100	1.000000	0.876591879
310900	0.030418	0.220724045
310800	0.064639	0.218963708
310700	0.007605	0.223945814
310600	0.068441	0.240095715

310500	0.034221	0.16638042
310400	0.011407	0.178949925
301600	0.030418	0.177869947
301200	0.045627	0.185043358
301100	0.038023	0.181822059
300900	0.022814	0.175058517
300800	0.022814	0.14745114
300700	0.007605	0.200954113
300600	0.007605	0.194174971
292500	0.057034	0.133400538
292400	0.007605	0.125375838
292200	0.015209	0.144939467
290900	0.015209	0.151859663
283800	0.034221	0.174715499
283200	0.011407	0.148975863
283100	0.041825	0.189420609
282800	0.007605	0.182662132
282700	0.011407	0.183071232
281900	0.703422	0.449956136
280900	0.015209	0.183693856
280100	0.365019	0.345795124
271800	0.003802	0.081726798
271300	0.003802	0.134195904
261000	0.003802	0.120095445
260700	0.022814	0.110769611
260600	0.034221	0.123561735
260500	0.007605	0.130055088
260300	0.007605	0.095980754
252000	0.003802	0.141973777
251900	0.026616	0.153118374
251800	0.068441	0.137045665
251700	0.003802	0.103971725
251600	0.007605	0.110096396
251500	0.026616	0.149428768
251400	0.003802	0.136889336
251200	0.026616	0.176933359
251100	0.026616	0.157098835
250800	0.022814	0.135587855
250700	0.003802	0.187714813
250600	0.003802	0.182482132
250500	0.068441	0.167252579

250400	0.003802	0.213168393
250300	0.015209	0.177656568
250200	0.007605	0.161709424
243500	0.045627	0.185386262
243400	0.022814	0.191659784
243300	0.019011	0.196481728
243200	0.007605	0.224542122
243100	0.064639	0.233879043
243000	0.038023	0.22369537
242900	0.007605	0.189982705
242800	0.007605	0.19107677
242600	0.041825	0.253411938
242500	0.049430	0.249448254
242400	0.003802	0.195209143
242300	0.022814	0.228693617
242200	0.026616	0.237222073
242100	0.057034	0.240367667
242000	0.022814	0.21672521
241500	0.022814	0.204800228
241400	0.110266	0.227180683
241300	0.003802	0.141887196
241200	0.007605	0.160579986
241100	0.011407	0.178375757
240900	0.022814	0.160043647
240700	0.007605	0.179374761
240300	0.022814	0.160054589
240200	0.007605	0.17235385
231500	0.007605	0.109722384
231200	0.011407	0.131021159
230900	0.038023	0.171843946
230800	0.007605	0.13802522
230700	0.034221	0.221329154
230600	0.003802	0.197063864
230500	0.030418	0.168281481
230400	0.015209	0.180712307
230200	0.015209	0.182200892
222900	0.003802	0.155731252
222800	0.015209	0.144029957
222700	0.038023	0.201594495
222200	0.007605	0.247253077
221500	0.019011	0.209424051

221400	0.022814	0.226759482
221100	0.011407	0.219284348
220500	0.053232	0.174838149
220400	0.011407	0.208764071
220300	0.041825	0.201470878
210900	0.038023	0.205750284
210700	0.030418	0.217186434
210400	0.022814	0.20530103
210100	0.038023	0.188769139
200100	0.030418	0.178379056
191200	0.007605	0.185439191
191100	0.030418	0.214720917
191000	0.007605	0.200684872
190300	0.003802	0.186035761
190200	0.038023	0.218234001
171100	0.022814	0.17172302
171000	0.022814	0.177255042
170900	0.007605	0.133765383
170800	0.007605	0.132645091
170600	0.003802	0.151147358
170400	0.003802	0.166067025
170300	0.003802	0.167692193
170200	0.045627	0.207269149
170100	0.015209	0.176958009
161300	0.015209	0.245760274
161200	0.030418	0.191811122
161100	0.011407	0.191078539
161000	0.030418	0.163749891
160900	0.053232	0.17713912
160800	0.022814	0.201316221
160700	0.019011	0.213482823
160400	0.140684	0.215671616
160300	0.015209	0.18602207
160200	0.057034	0.174317506
160100	0.015209	0.180438003
151200	0.026616	0.187258716
151100	0.011407	0.200873116
150800	0.041825	0.155142798
150700	0.015209	0.165672999
150600	0.045627	0.172219378
150300	0.079848	0.227889339

150200	0.076046	0.1884027
140800	0.038023	0.229474873
140500	0.022814	0.187834775
140400	0.049430	0.214340638
140100	0.007605	0.180983551
130300	0.011407	0.164588236
130200	0.015209	0.197464059
130100	0.034221	0.157318591
120400	0.057034	0.17083098
120300	0.045627	0.148161553
120200	0.026616	0.148619876
120100	0.007605	0.162902363
110400	0.022814	0.180546102
110300	0.015209	0.226460635
110100	0.030418	0.181255026
100700	0.011407	0.153881467
100600	0.015209	0.180920072
100500	0.015209	0.154546499
100400	0.034221	0.143242803
100300	0.041825	0.162253357
100200	0.038023	0.16795348
100100	0.072243	0.187101112
90300	0.011407	0.118061433
90200	0.011407	0.128760525
81900	0.022814	0.157853817
81800	0.201521	0.32584367
81700	0.174905	0.385813697
81600	0.064639	0.295572002
81500	0.501901	0.784405977
81300	0.395437	0.641674157
81100	0.064639	0.432291808
81000	0.133080	0.715144779
80400	0.019011	0.17474402
80300	0.117871	0.354973197
80100	0.106464	0.575810016
71800	0.030418	0.209156425
71700	0.038023	0.175620487
71600	0.076046	0.228361998
71500	0.163498	0.435843168
71400	0.152091	0.226411682
71300	0.015209	0.276192092
71200	0.159696	0.216881344
71100	0.095057	0.268712609
71000	0.003802	0.185991892
70700	0.015209	0.182228962
70600	0.015209	0.208007082
70500	0.030418	0.193283569
70400	0.064639	0.188866684
70300	0.125475	0.253811292
70200	0.041825	0.272844464
63400	0.159696	0.240051364
63200	0.091255	0.466235528
63100	0.095057	0.323910029
63000	0.167300	0.20216622
62900	0.038023	0.169094708
62800	0.041825	0.211098589
62700	0.022814	0.198242989
62600	0.068441	0.211769692
62500	0.049430	0.17910939
62400	0.026616	0.160884215
62300	0.011407	0.177024285
62200	0.026616	0.187971867
62100	0.057034	0.233641709
62000	0.019011	0.247904821
61800	0.026616	0.240724078
61500	0.030418	0.160974021
61200	0.053232	0.213046796
61100	0.057034	0.173982547
61000	0.026616	0.148308555
60900	0.091255	0.377632221
60800	0.019011	0.434129159
60500	0.026616	0.180364642
60400	0.072243	0.194610911
60300	0.019011	0.198482262
60200	0.019011	0.166875625
51300	0.019011	0.210005084
51200	0.007605	0.198528487
51100	0.041825	0.176063084
51000	0.019011	0.145838168
50800	0.049430	0.15534054
50700	0.015209	0.206033896
50600	0.041825	0.20490008

50500	0.015209	0.211806388
50200	0.057034	0.198115529
50100	0.022814	0.219534459
40900	0.030418	0.213930099
40800	0.030418	0.187579456
40700	0.049430	0.223504978
40600	0.045627	0.237978519
40300	0.007605	0.198866926
40100	0.011407	0.247850349
32100	0.060837	0.318697059
31900	0.007605	0.236877843
31800	0.022814	0.171344057
31700	0.019011	0.18938623
31400	0.030418	0.314280593
31300	0.114068	0.272692093
31200	0.038023	0.29874189
31100	0.045627	0.22662722
31000	0.026616	0.202018998
30900	0.034221	0.273444152
30800	0.193916	0.28849372
30500	0.053232	0.242082779
30400	0.003802	0.190005418
30300	0.015209	0.17186934
30200	0.114068	0.223052003
20500	0.007605	0.181400289
20400	0.026616	0.155893283
20200	0.022814	0.185932756
20100	0.022814	0.182743934
10600	0.167300	0.263833095
10400	0.117871	0.214780603
10300	0.049430	0.185234243
10100	0.041825	0.143471818

Correlation Between No. of Walk Trips and PWI		
	PWI	*No. Wlk Trips*
PWI	1	
No. Wlk Trips	0.658827936	1

Vita

Ahmad Jalal Nafakh

EDUCATION

2018	M.Sc. in Civil Engineering University of Illinois at Chicago, Chicago, IL Thesis: "Spatial Assessment of Walkability Index; A Case Study in Chicago"
2014	B.Sc. in Civil Engineering Purdue University Calumet, Hammond IN

EXPERIENCE

2017-present Civil Engineer I

Illinois Department of Transportation, Schaumburg, IL

- Assist Resident Engineer in performing tasks associated with layout, inspection and documentation for highway construction projects.

2015-2017 Project Engineer

TERRA Engineering Ltd, Chicago, IL

- Prepare and revise plan & profile sheets, maintenance of traffic plans drainage plans, cross sections and typical sections.
- Assessing the safety effects of geometric design and traffic control features at an existing interchange and adjacent roadway network
- Developing project schedules, cost estimates and quantity calculations. Developing Operation & Maintenance plans for Green Infrastructure Projects.

TRAINING

2018	Civil Engineer Trainee Illinois Department of Transportation, Schaumburg, IL
2014-2015	Engineering Intern TERRA Engineering Ltd, Chicago, IL
2014	Engineering Intern Town Council Office, Dyer, IN

CERTIFICATES

2018	Documentation of Contract Quantities Illinois Department of Transportation, Schaumburg, IL
2017	SAVE Approved Module I University of Illinois at Chicago, Chicago, IL

PUBLICATIONS

2015 Evaluation of Flashing Yellow Arrow Traffic Signals in Indiana / INDOT / Recommended Citation: Rescot, R. A., Qu, S., Noteboom, R., & Nafakh, A. (2015). Evaluation of flashing yellow arrow traffic signals in Indiana (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2015/08). West Lafayette, IN: Purdue University.

The evaluation of flashing yellow arrow signals for widespread implementation was evaluated. Through the collection of field driver performance data, survey data, crash data, at two test sites in the State, it was concluded that this is a worthwhile practice to be considered for a larger scale deployment. The return on investment includes both increased safety, and improved mobility. Given Indiana's widespread usage of span and catenary signal supports, installation could be simplified to place a larger four section flashing yellow head in a horizontal orientation while leaving adjacent through lane three section signal heads in a vertical alignment, and not decrease the standard of care provided to the public, given proper engineering judgment.

PROJECTS

2015-2018

ILLINOIS DEPARTMENT OF TRANSPORTATION – INTERSECTION IMPROVEMENT AND TRAFFIC SIGNAL MODERNIZATION / La Grange, IL / Inspector / Project includes pavement widening, hot-mix-asphalt surface removal, and resurfacing, traffic signal modernization, curb and gutter removal and replacement, pedestrian sidewalk ADA removal and replacement, drainage structure removal and replacement, pipe undertrains and storm sewer installation, placement of thermoplastic pavement markings and raised-reflectors, removal and replacement of detector loops, signing, fire hydrant removal and replacement and all incidental and collateral work necessary to complete the project. Ahmad's responsibilities include inspection of work to ensure contract compliance and documentation of work per IDOT guidelines.

ILLINOIS DEPARTMENT OF TRANSPORTATION – ROADWAY RESURFACING (3P) / Summit, IL / Inspector / Project includes roadway resurfacing and the work to be performed under the contract consists of pavement patching, hot-mix-asphalt pavement removal, resurfacing with polymerized leveling binder and hot-mix-asphalt surface course, pedestrian sidewalk ADA ramp removal and replacement, placement of thermoplastic pavement markings and incidental and collateral work necessary to complete the project. Ahmad's responsibilities include inspection of work to ensure contract compliance and documentation of work per IDOT guidelines.

ILLINOIS STATE TOLL HIGHWAY – SAFETY ANALYSIS / Various, IL / Project Engineer / Responsibilities include providing analysis conducted on I-294 using the AASHTO Highway Safety Manual (HSM) Predictive Method for Freeways and Interchanges described in the NCHRP Project 17-45. The Predictive Method is based on research quantifying the relationship between geometric design elements and average crash frequency. CDM Smith and TERRA Engineering have been using this tool as part of an Illinois Tollway Roadway Safety Analysis of I-294. The intention is to identify additional operational and safety issues in the corridor as an input to the master plan analysis that is just beginning.

ILLINOIS STATE TOLL HIGHWAY AUTHORITY – SPEED STUDY / Various, IL / Project Engineer / Project includes measuring and reviewing traffic speed data at 17 locations in nine (9) sections of the Reagan Memorial Tollway (I-88), Veterans Memorial Tollway (I-355), and Tri-State Tollway (I-94/294) before, one (1) month after, and (6) months after posted speed limits were variably increased. The purpose of this study is to review any variations in traveling behavior after increasing the posted speed limits. Parameters for traffic speed data review include: Average speed, median speed, standard deviation of speeds, maximum and minimum speed, 85th percentile speed, 10-miles-per-hour (mph) pace and frequency, and rate of violation (>70 mph). Ahmad's responsibilities include data collection, data analysis and report generation.

ILLINOIS STATE TOLL HIGHWAY AUTHORITY – ESTABLISHMENT AND POSTING OF SPEED LIMITS / Various, IL / Project Engineer / Project includes using IDOT's Policy on Establishing and Posting Speed Limits on the State Highway System for establishing and posting of speed limit along Interstate 90 (I-90). The policy provides a methodology for setting speed limits specific to interstate highways. The methodology compares three major components: determination of prevailing (average of 85th percentile speed, upper limit of 10-mph pace speed and average floatingcar run speed, application of prescribed adjustment factors, and final engineering analysis. Ahmad's responsibilities include data collection, data analysis and report generation.

ILLINOIS STATE TOLL HIGHWAY AUTHORITY – BUS-ON-SHOULDER OPERATIONAL CONSIDERATION / Various, IL / Project Engineer / Project includes providing a summary of several technical reports that were reviewed concerning Bus on Shoulder operations with the specific purpose of examining Bus on Shoulder speeds, and safe and efficient speed differentials between buses that operate on shoulders versus vehicles that travel in general use lanes during periods of traffic congestion. Ahmad's responsibilities include research and report generation.

BERWYN DEPOT DISTRICT/ Berwyn, Illinois / Project Engineer / Project includes streetscape design improvements along three roads and adjacent cross streets in downtown Berwyn's historic Depot District. The design includes utility relocation, drainage study, and ADA compliance. The final design will incorporate sustainable measures including permeable pavers, Silva Cell Systems, bioswales and other Best Management Practices (BMPs).

INSTALLATION OF BICECLE PARKING FACILITIES / Oak Park, Illinois / Project Engineer / TERRA is providing phase I and phase II engineering services for the installation of bicycle parking facilities at four separate locations throughout the Village of Oak Park. Streetscape improvements, pedestrian facilities, and resurfacing of two parking lots are included as well.

WEST SHORE PIPELINE CO. ROADSIDE BARIER WARRANT/DESIGN / Palos Heights, IL / Project Engineer / Project includes assessing the safety of West Shore Pipeline's existing fenced-in pipeline block valve.

The area of concern (AOC) was analyzed for application of a protecting concrete barrier. Ahmad's responsibilities include analysis, recommendation and plan preparation.

SOUTH BOULEVARD TRANSPORTATION, COMMUNITY, AND SYSTEM PRESERVATON (TCSP) PROGRAM / Oak Park, Illinois / Project Engineer / Responsibilities include involvement in developing detailed roadway and lighting improvement plans. TERRA is providing Phase I and Phase II engineering for a streetscape design on South Boulevard from Harlem Avenue to just west of Marion Street. The project includes upgrades of ADA pedestrian crossings and traffic signals at Harlem. Roadway design includes the reworking of the Harlem / South intersection adding a westbound to southbound left turn lane on South Boulevard. Lighting and utility work are also included.

U.S ROUTE 20 OVER WEST BRNCH DUPAGE RIVER / Hanover Park, Illinois / Project Engineer / Responsibilities include involvement in developing Phase II roadway plans and managing project schedule and budget. TERRA is replacing a culvert for IDOT District 1 over the West Branch of the DuPage River with a single-span bridge with a profile raise that meets hydraulic requirements. The bridge will accommodate three 12-foot lanes in each direction. Eastbound U.S. Route 20 east of the entrance east of Greenbrook Boulevard will have striping that provides a lane drop over the proposed bridge to match into the existing two lanes east of the river. The U.S. Route 20 westbound left turn lane to Ontarioville Road will be extended within the existing median to provide a maximum storage length of 400 feet. An additional westbound and northbound left turn lane will be provided in the existing medians at the intersection of U.S. Route 20 and Greenbrook Boulevard. Traffic signal upgrades will be performed at three intersections.

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