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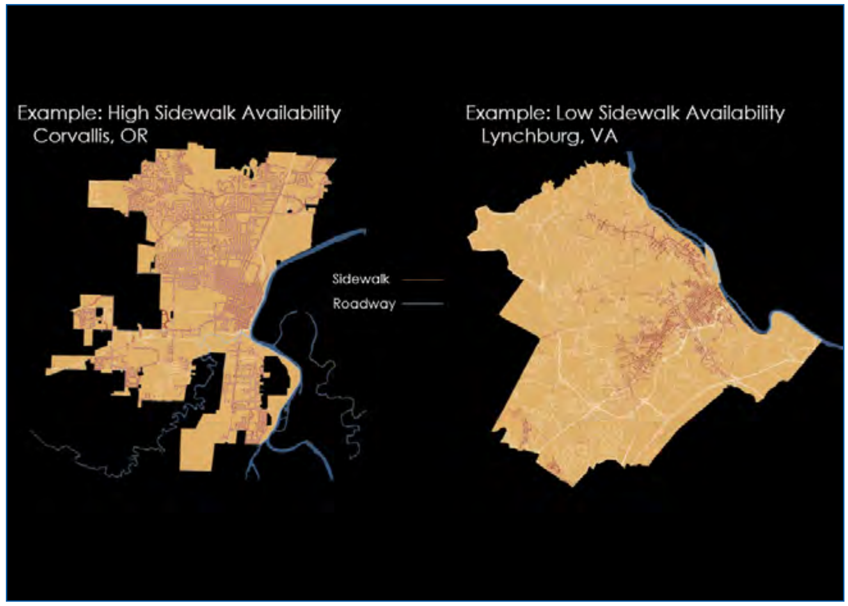
WHERE THE SIDEWALKS END: EVALUATING PEDESTRIAN INFRASTRUCTURE AND EQUALITY



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Academic literature has scant research on sidewalks, and some cities are lacking information to rectify an unprecedented backlog of deteriorating pedestrian infrastructure. A lack of data stymies efforts to understand sidewalks, how they may impact equity, and how cities can prioritize where to begin to rectify these issues. Remote sensing data are beginning to increase the prevalence and accuracy of sidewalk infrastructure data. In this report, we leverage these advances in remote sensing to bridge the data and research gap on pedestrian infrastructure in cities.

In Part 1, we analyze city-scale sidewalk availability, width, and land coverage calculated from spatial data from aerial imagery (planimetrics). In Part 2, we examine planimetric sidewalk data to evaluate relationships between the provision of sidewalk infrastructure and the socioeconomic status and sociodemographics of residents across sixteen cities. The Part 1 results show an overall deficiency of sidewalks and indicate that deriving sidewalk availability and average width are feasible at the city scale. In Part 2, we show that sidewalk availability had an inconsistent relationship to income, depending on the city. As for sociodemographics, non-white residents generally had wider sidewalks and greater availability.

With a growing interest in active modes of transportation, and cities facing limited resources, this research helps bridge a much-needed gap in sidewalk infrastructure research and planning.

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ABSTRACT

Academic literature has scant research on sidewalks, and some cities are lacking information to rectify an unprecedented backlog of deteriorating pedestrian infrastructure. A lack of data stymies efforts to understand sidewalks, how they may impact equity,and how cities can prioritize where to begin to rectify these issues. Remote sensing data are beginning to increase the prevalence and accuracy of sidewalk infrastructure data. In this report, we leverage these advances in remote sensing to bridge the data and research gap on pedestrian infrastructure in cities.

In Part 1, we analyze city-scale sidewalk availability, width, and land coverage calculated from spatial data from aerial imagery (planimetrics). In Part 2, we examine planimetric sidewalk data to evaluate relationships between the provision of sidewalk infrastructure and the socioeconomic status and sociodemographics of residents across 16 cities. The Part 1 results show an overall deficiency of sidewalks and indicate that deriving sidewalk availability and average width are feasible at the city scale. In Part 2, we show that sidewalk availability had an inconsistent relationship to income, depending on the city. As for sociodemographics, non-white residents generally had wider sidewalks and greater availability.

With a growing interest in active modes of transportation, and cities facing limited resources, this research helps bridge a much-needed gap in sidewalk infrastructure research and planning.

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PART 1: PLANIMETRIC SPATIAL DATA AND THE PROVISION OF SIDEWALK INFRASTRUCTURE IN CITIES

1. INTRODUCTION

Advances in remote sensing technologies continue to provide transportation agencies with efficient and accurate data from sophisticated systems and platforms. The results are beginning to afford the opportunity to shape smart cities and enhance traffic operations; however, amid this revolution, we should not forget about the sidewalk.

Advocacy groups across the United States (U.S.), and an increasing number of pedestrian plans in cities, indicate a renewed interest in walking (America Walks, 2008-2019; City of Boulder, 2019; City of Raleigh, 2012; City of Saint Paul, 2019; The National Center for Bicycling and Walking, 2002-2019; USDOT, 2019a; USDOT, 2019b; Walk Denver, 2018).

Efforts are underway, both nationwide and through local governments, to capitalize on advances in remote-sensing technologies that provide opportunities to enhance sidewalk research. Examples include the U.S. Geological Survey's (USGS) national three-dimensional elevation data program and the Denver Regional Council of Governments (DRCOG) embarking on bi-yearly aerial photography collection for the greater Denver metropolitan area (DRCOG, 2018; USGS, n.d.). These nationwide and local efforts are building extensive data repositories. In turn, this data must be converted into useful information and applied to enhance analysis and visualization for agencies.

DRCOG's Regional Planimetric Data Project, which collects high-resolution aerial imagery to extract various transportation infrastructure features into spatial datasets, highlights one such effort (DRCOG, 2018). As of 2018, this program facilitates spatial data acquisition for 28 partners including cities, counties, and other agencies in the greater Denver area through financing by partners, grants, and DRCOG (DRCOG, 2018). What can the use of this type of data tell us about sidewalk characteristics such as availability, width, and land coverage? Furthermore, what relationships exist between these sidewalk variables and city characteristics and policies, socio-demographic/socio-economic characteristics, and mode choice?

Utilizing planimetric and comparable data, we first describe the methods used to convert this data into usable sidewalk information. Planimetric data is defined here as a sub-type of land-based elements comprised of physical features on the ground (Montgomery & Schuch, 1993). This data is created from aerial imagery without elevation data and includes, but is not limited to, transportation infrastructure such as street edges, sidewalks, and trees (Montgomery & Schuch, 1993). The term "comparable data" is defined in this paper as transportation infrastructure data provided by municipalities that do not use the term "planimetric" in the title, website description, or metadata. We then analyze the results to learn more about the provision of sidewalk infrastructure in our 24 study cities. The intent is to increase our understanding of current city sidewalk characteristics, aspects influencing their development, and characteristics related to the people that live there. This may reveal economic or demographic inequalities in need of attention, insight into national trends, or assist in understanding the effects of city policy and planning. Moreover, this study adds to a deficient area of research incorporating high-resolution city sidewalk data.

2. LITERATURE REVIEW

Existing literature on sidewalk infrastructure has a long history, and as technologies have evolved, so has the scale and detail of the research. First, we considered smaller scale, audit-based sidewalk studies. Then, we focused on larger scale Geographic Information Systems (GIS) methods and concluded with research-related to the remote sensing of sidewalk spatial data for asset management.

A study in 2009 by Brownson et al. conducted extensive research on measurement of the built environment for physical activity using three categories: perceived measures (phone interview or questionnaire), observational measures (field audit), and archival datasets analyzed with GIS (Brownson et al., 2009). Our interests lie with objective data collection; therefore, we focused on observational measure and archival datasets. The authors described benefits, tradeoffs, and limitations to each of these methods with comprehensive research on prior studies.

The benefits of observational measures include the availability of researched and developed instruments, tools, and protocols. In addition, auditors can conduct direct observation of detailed physical environment characteristics. Some of the trade-offs include time consumption associated with field audits and the need to train and monitor assessors; moreover, concerns arise with inter-auditor reliability and subjectivity. GIS benefits included the ability to measure the built environment using less time and staff; moreover, the authors stated on page S112 that "Using GIS to characterize the built environment is the only feasible way to generate objective measures for studies involving individuals or neighborhoods dispersed across large areas" (Brownson et al., 2009). Trade-offs consisted of a need for knowledgeable personnel to work with GIS data and unknown time extent related to obtain, clean, and analyze data. In addition, there can sometimes be a cost associated with obtaining data, or it can be free for public use.

For both observational and GIS methods, the authors included a discussion on sidewalks. Although this study is a decade old and discussed approaches that are even older, there are still relevant issues. Presence, continuity, and width are listed as important field-based audit characteristics. The authors also mentioned the rarity of sidewalk data existing at the regional and county level and the poor resolution of aerial imagery to extract sidewalk details (Brownson et al., 2009). Herein lies the benefit to advanced sensing technologies, high accuracy imagery, and updated infrastructure data collected and provided by government agencies. However, in terms of methods to derive or apply sidewalk data from high accuracy imagery or other spatial data, limited research exists.

One study by Li et al. developed a method to create GIS sidewalk networks using roadway centerlines and parcel data (Li et al., 2018). The method presents a simplified approach to derive a sidewalk network including links and nodes and crosswalk links generated from intersections. This paper provides a simplistic method to create a connected sidewalk network, but many issues arise: i) the sidewalk network is theoretical; ii) it does not represent missing sidewalks; and iii) it does not mention spatial accuracy regarding whether the network follows where sidewalks exist. To attain this level of detail or additional descriptive attributes, we have noted the need for field-based collection to integrate into the data.

Research conducted by Kang et al. created an automated method using GIS to conflate sidewalk coverage along road segments into roadway data. To elaborate, the process Kang et al. created stores sidewalk information — absent, partial coverage, or full coverage (sidewalks on both sides of the road) — as information in the roadway data (Kang et al., 2015). The study provided a valuable method for data integration between sidewalks and roads, but polylines represented an approximation of sidewalk area locations lacking in spatial detail of edges, areas, and related calculations and analyses. The studies by Kang and Li provided uses of linear spatial data for sidewalks, but they still do not reach the threshold of what we would consider as incorporating high-resolution data.

A study by Jannsen and Rosu used ArcGIS and Google Earth to create a three-step method to measure sidewalk distances. Step 1 included measuring roadway distances for a chosen area of interest (i.e., a neighborhood) in ArcGIS and extracting the data for use in Google Earth. Step 2 included a manual review of all roads and deleting roadway segments without sidewalks. Roadway sections containing a sidewalk on one or both sides of the road were retained. Step 3 consisted of converting the data back for use in ArcGIS to measure the length of roadway containing sidewalks. Completing a manual analysis of sidewalks in Google Earth would be time consuming and labor intensive at a city scale. Regarding measurements in this research, the sidewalk distances are inaccurate because they do not indicate if sidewalks are present on one or both sides of the road. The final calculations are inaccurate, which may present unintended bias if multiple areas measurements are compared. Moreover, there is room for error since the data is being edited manually in Google Earth.

A study by Brezina et al. developed methods to estimate sidewalk widths utilizing a spatial database from the Vienna, Austria, road administration containing “public space surfaces” (Brezina et al., 2017). The Viennese streetscape surface database included polygon surface areas for sidewalk, driveway, and household walkway entrance. Utilizing this, the authors parsed spatial data to develop and evaluate three methods to calculate sidewalk width. Methods 1 and 2 looked at the minimum and maximum circle created within each surface type noted above. Although this provided valuable insight to GIS methods, this research limited the technique and evaluation of methods to a specific dataset structure. Method 3 evaluated the sidewalk data dissolved into a homogenous area, which provides a simpler approach for use. With this method, width is determined with the use of the roadway centerline length. We used a similar approach but with the creation and calculation using the sidewalk centerline. Although this presents valuable insight for methods to evaluate sidewalk width, it unearths bigger questions regarding how to use this information beyond infrastructure asset management.

Existing literature highlights the need for more sidewalk data, research on sidewalks, and the use of higher quality data. The research also suggests that using roadway data to approximate sidewalk characteristics does not provide reliable information and may lead to gross inaccuracies when studying the existence and/or need for sidewalks at all scales of analysis. However, the study by Brezina et al., used higher quality data and displayed the ability to extract sidewalk characteristics at the city scale. We took this a step further by quantifying sidewalk infrastructure for 24 U.S. cities and delving into how this data can be applied.

3. STUDY OVERVIEW

The goal of this paper is to analyze sidewalks using geographic information systems (GIS) planimetric or comparable data. The investigation included evaluating this data against ADA requirements, national and federal sidewalk recommendations, American Community Survey (ACS) five-year socio-economic and socio-demographic criteria, roadway coverage in the public right of way (ROW) and differing municipal policies. This study demonstrates the use of high accuracy data to unearth infrastructure characteristics and their relationship with the city, its people, and their chosen mode of transportation.

We initiated this by researching 769 cities in the United States for high accuracy sidewalk spatial polygon data. The initial search resulted in 36 cities with planimetric datasets from 2011 to 2019 and populations of 50,000 to 8.5 million. To retain geographic diversity and analyze cities with commonalities in chronology and population, we decided to focus on 24 cities. These locations included populations of approximately 50,000 to 900,000 from 2015 to 2019 with more than 400,000 sidewalk segments. The selected cities are listed in Table 3.2. Cities removed because of sidewalk data older than 2015 include: Sammamish and Kirkland, WA, and Salem, OR. Two cities — Los Angeles, CA, and Philadelphia, PA, — were removed due to population sizes of 3.4 and 1.6 million respectively. New York City, NY, had both a sidewalk dataset older than 2015 and a population of 8.4 million. White Plains, NY, was removed due to no response provided from the city to confirm the sidewalk maintenance policy. Cities removed because they did not provide planimetric or comparable roadway data include – Somerville, Boston, and Naperville, MA, Portland, OR; and Norman, OK.

This research included creating a comprehensive repository of sidewalk and roadway polygon and polyline spatial data for analysis. We used this data to evaluate sidewalks in the ROW against recommendations from national and federal publications and the ADA. In addition, three groups (city characteristics, socio-demographic/socio-economic characteristics, and mode of transportation to work) with multiple variables were generated from census, ACS five-year data, and city municipal policy to delve further into these relationships.

3.1 Municipal Policy, ADA Requirements, and National and Federal Recommendations

Municipal policy pertaining to sidewalk maintenance in the city ROW tends to take one of three approaches: i) placing the onus on city agencies; ii) placing the onus on the abutting property owner; iii) shared responsibility between city and property owner. These policies dictate responsibility for sidewalks in the public ROW; therefore, whether the responsibility lies with city, landowner, or both, the city maintains the ability to enforce management.

The ADA provides requirements for sidewalk design and the following publications provide recommendations in the United States: Federal Highway Administration (FHWA) Designing Sidewalks and Trails for Access, American Association of State Highway and Transportation Officials (AASHTO) Green Book, National Association of City Transportation Officials (NACTO) Urban Street Design Guide, and Congress for the New Urbanism (CNU) - Institute of Transportation Engineers (ITE) Designing Walkable Urban Thoroughfares. Regarding minimum sidewalk width, guidelines from each agency are listed in Table 3.1.

Regarding availability, we evaluated sidewalks with the theoretical understanding that for every urban roadway, a sidewalk could exist on both sides of the street. Therefore, when discussing sidewalk availability, this paper refers to complete availability as a 2:1 ratio (sidewalks: roadways) or better. NACTO emphasizes this by stating “Sidewalks should be provided on both sides of all streets in all urban areas," (NACTO, 2013). ITE states the same recommendation in Table 5.3 "Urban Thoroughfare Characteristics," but limits the suggestion to boulevards, multiway boulevards, avenues, and street thoroughfare types (ITE, 2010). FHWA provides greater detail, indicating sidewalk and curb requirement or preference on one or both sides of the street depending on road classification and land use in Table 4-2 "Guidelines for New Sidewalk Installation" (Kirschbaum et al., 2001).

Table 3.1 Minimum Sidewalk Width Guidelines

Agency	Document	Width
ADA	2010 ADA Standards for Accessible Design[1]	3 feet (0.9 meters)
	Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way[2]	4 feet (1.2 meters)
AASHTO	A Policy on Geometric Design of Highways and Streets[3]	
FHWA	Designing Sidewalks and Trails for Access[4]	5 feet (1.5 meters)
NACTO	Urban Street Design Guide[5]	
ITE & CNU	Design Parameters for Walkable Urban Thoroughfares[6]	6 feet (1.8 meters)

* *The 2010 ADA Standards for Accessible Design provide enforceable guidelines based on legislation; all other minimum sidewalk widths provided are recommendations from agencies.*
1 *(Mahoney, 2012)*
2 *(USAB, 2011b)*
3 *(AASHTO, 2018)*
4 *(Kirschbaum et al., 2001)*
5 *(NACTO, 2013)*
6 *(Daisa & ITE, 2010)*

The ADA, most recently revised in 2010, states that an accessible path of travel must be provided (Mahoney, 2012). This is defined as an unobstructed pedestrian passage for approach, entrance, exit, and connection on sidewalks (Mahoney, 2012). More specifically, ADA Standards for Accessible Design (Chapter 4) states a standard clear width for accessible routes is 36 inches (91.44 centimeters) (Mahoney, 2012). Please note that the 2011 U.S. Access Board proposed guidelines, which will be enforceable under title II of the ADA when approved by the Department of Justice, changes the continuous clear width to four feet (1.22 meters) (USAB, 2011a).

The FHWA Designing Sidewalks and Trails for Access section (4.1.2.3) on sidewalk corridors recommends a minimum width completely free of obstacles for pedestrian travel to be five foot (1.52 meters) wide (Kirschbaum et al., 2001). This research initially aimed to include additional sidewalk metrics such as ADA curb ramps, driveways, streetlights, signs, parking meters, and / or benches; however, no variable(s) existed in all cities to permit such an investigation. Therefore, the sidewalk data consists of a theoretical unobstructed pedestrian passage in all scenarios.

The AASHTO Green Book guidelines state a range in residential areas of 4–8 feet (1.22 meters to 2.44 meters) and approximately two feet (0.61 meters) wider when adjacent to the curb (NACTO, 2011). The overall minimum recommended width is four feet (1.22 meters). The NACTO Urban Street Design Guide has a slightly wider recommendation of an "absolute minimum of five feet" (1.52 meters) for all sidewalks stated on page 40 (NACTO, 2013); in addition, ranges are provided for residential and commercial of 5–7 feet (1.52 meters to 2.13 meters) and 8–12 feet (2.44–3.66 meters), respectively. The ITE Design Parameters for Walkable Urban Thoroughfares (Table 6.4) indicates a six-foot (1.83 meters) recommendation for all sidewalks (ITE, 2010).

Table 3.2 U.S. Cities with Sidewalk Geospatial Data, Annual Estimates of the Resident Population for Incorporated Places of 50,000 or More (Manson et al., 2018)

State	City	Population Estimate (as of July 1, 2017)
Colorado	Commerce City	52,905
	Boulder	106,271
	Centennial	108,448
	Lakewood	151,411
	Aurora	357,323
	Denver	678,467
Connecticut	Hartford	124,390
Florida	Weston	69,802
Illinois	Peoria	115,424
Iowa	Cedar Rapids	130,330
Minnesota	St. Paul	300,820
New York	Mount Vernon	68,671
	New Rochelle	79,877
	Yonkers	200,999
North Carolina	Huntersville	53,302
	Raleigh	449,477
Ohio	Cincinnati	298,957
Oregon	Corvallis	56,224
South Carolina	Charleston	131,204
Texas	Round Rock	116,369
	Austin	916,906
Virginia	Lynchburg	79,237
	Newport News	180,775
	Virginia Beach	450,057

With the ADA requirements, national and federal recommendations, and a spatial dataset for sidewalks and roadways, next steps included investigating census and ACS data and sidewalk municipal policy. These variables are broken up into two groups for analysis: city characteristics and socio-demographic/socio-economic characteristics, which we discuss further in the next subsections.

3.2 City Characteristics

This group includes average structure year, population, population density, and region. The average structure year originated from a table extracted from the National Historical Geographic Information System (NHGIS) containing 2017 ACS five-year data (2011-2017), which provided a metric to calculate the overall average age of the city (Manson et al., 2018). This approach is an adaptation of a prior research method created by James Spero and Tim Duane to analyze human settlement in a region of California and later adopted by Marshall and Garrick (2011) to estimate dates associated with road network development (Duane, 1996; Marshall & Garrick, 2010).

We obtained population data from an annual estimate for each Census Incorporated Place released by the ACS as of July 1, 2017. Dividing the population by the "Census Place" boundary area provided the density in people per square mile.

With a finalized selection of cities providing high accuracy spatial data and a baseline understanding of sidewalk guidelines, additional data and information obtained facilitated proper analysis.

3.3 Socio-Demographic/Socio-Economic Characteristics

This group includes resident age, per capita income, and race/ethnicity. ACS table data provides an extensive breakdown stating the number of people in age categories by sex, which were broken down and averaged.

Per capita income did not require any alteration. "Race/Ethnicity" included White, Black or African American, and Hispanic or Latino. We divided the totals of each group by the population total to determine the percent of each.

A finalized selection of cities, high accuracy spatial data, and an organized collection of variables facilitated proper analysis. An evaluation of details such as timeframes, geographic boundaries, extent of data, and policy details, to name a few, enabled next steps formulating methodology and extracting results.

4. METHODS

The design for this investigation initiated with reviewing 769 U.S. Census incorporated places for planimetric or comparable sidewalk datasets. This initial search focused on census places because planimetric data is scarce and researching a large number of cities increased the likelihood of results. In addition, the census provides standardized spatial datasets, and the ACS offers related demographic information. Based on the desire to investigate public transportation infrastructure and the scarcity of ROW spatial data, parcel boundaries were a necessary component to extract this information. Based on conversations with GIS departments in Portland, Denver, and Raleigh, areas outside of parcels denote the ROW.

4.1 Data Collection and Preparation

We obtained planimetric data (or comparable) and parcel spatial datasets from city, county, or regional government websites. Methods to acquire this data consisted of downloading from websites, email and/or phone requests, and submission of data release forms for access permission. We downloaded census road data from the Census Geography Data site and place boundaries and ACS tables from the NHGIS (USCB, 2018; Manson et al., 2018).

Data evaluation included parsing through sidewalk, roadway, and parcel datasets, in addition to their metadata and attributes. Information on agency websites and/or metadata often lacked critical information including relevant year pertaining to the data, frequency of updates, level of completeness, quality assurance and quality control measures, and attribute definitions. Due to the deficiency of detailed information, we retained and included datasets if at a minimum the metadata and/or agency provided information regarding a relevant year for the most recent updates to create new sidewalks to the dataset. However, cities often lacked information on the level of completeness.

This step revealed various data structures for sidewalks and road areas containing public and/or private features. In addition, some data was available as collective impervious surface datasets, which included sidewalks, roadways, medians, and intersections as an example. Geographic coverage included citywide, countywide, and select cities or towns within a greater metropolitan area.

Weston, Fla., was one exception that required manual data alteration. The city terminated data collection of impervious surfaces within the northern and western edge of the Census Place boundary along the interstate corridor; in turn, without sidewalk data for this area, we removed census interstate centerlines for comparable analyses.

4.2 GIS Analysis and Calculations

Using ArcGIS Pro software and Model Builder, we developed sequential spatial tasks to ensure consistency in analysis for each city. Next, all data was dissolved to create continuous multipart polyline and polygon spatial datasets. Please note that the sidewalk centerline was created by converting the sidewalk polygon to a centerline with the “Polygon to Centerline” ArcGIS tool.

The parcel data for each city enabled isolating all road and sidewalk data to within the ROW. Boundaries from the parcel data do not always align with the sidewalk or roadway polygons, which sometimes altered sections. This misalignment tended to impact some sidewalks due to their placement on the outside of the road and at times along the edge of the ROW.

After isolating the data to the ROW, the first step included dissolving the sidewalk and roadway centerlines for each city to provide a measurement for the entire length of each. This provided the values to calculate percent sidewalk availability — shown in equation 1 Table 4.1 — based on the previously mentioned theoretical understanding that a 2 to 1 ratio of sidewalk to roadway equates to 100% availability. The next step included using the “Multipart to Single part” tool in ArcGIS, which creates individual sidewalk segments with unique identification (ID) numbers. Figure 4.1 provides an example below. Next, the ArcGIS “Intersect” tool overlaps the sidewalk centerline with the segment area and copies the unique ID pairing them together. This enabled derivation of the sidewalk width for each sidewalk segment using equation 2 in Table 4.1. The final step included creating a dissolved sidewalk and roadway polygon per city. Figure 4.1 provides a detailed close-up example of the data below. This provided the values to calculate the percent sidewalk and roadway land coverage, which refers to the relative comparison of area occupied by each within the ROW — shown in Equations 3 and 4 of Table 4.1. Figure 4.1 provides an example for each analysis and calculation.

Table 4.1 Sidewalk and Roadway Equations

$$1. Percent\ sidewalk\ availability = \frac{\left(\frac{sidewalk\ length}{roadway\ length}\right)}{2}$$

$$2. Sidewalk\ width = \frac{sidewalk\ area}{sidewalk\ length}$$

$$3. Percent\ sidewalk\ land\ coverage = \frac{sidewalk\ area}{(sidewalk\ area + roadway\ area)}$$

$$4. Percent\ roadway\ land\ coverage = \frac{roadway\ area}{(sidewalk\ area + roadway\ area)}$$

Reviewing calculation results identified isolated narrow sidewalk areas intersecting the ROW. The FHWA identifies sidewalk widths to be a minimum of five feet (1.52 meters) for two people, which equates to 2.5 feet (.76 meters) for one person (FHWA, 2006). Therefore, leaving room for digitization and extraction errors in the original datasets, we conducted a manual review of sidewalks less than 1.5 feet (0.46 meters) wide. The result identified primarily portions of private sidewalk polygons and errors in original geometries. Based on the FHWA definition of sidewalk width and the manual review, we removed sidewalks 1.5 feet (0.46 meters) wide or narrower.

Additionally, the results identified outliers with larger sidewalk widths. The FHWA states that sidewalks can reach widths as great as 30 feet (9.14 meters) or more (FHWA, 2006); furthermore, areas of this size would typically resemble plazas or squares as opposed to sidewalks. Manual review of select segments validated this.

4.3 Statistical Tests

The Kruskal-Wallis Rank Sum Test was employed with RStudio software to evaluate whether at least two of the quartiles for each category (i.e., population, region, age) represent different populations (R Core Team, 2018; Sheskin, 1997). Tables 5.3 and 5.4 provide a column titled "H" to indicate if the test yielded a result indicating statistical significance. We used this test because it permits comparisons across more than two variables and does not require normal distributions (Sheskin, 1997).

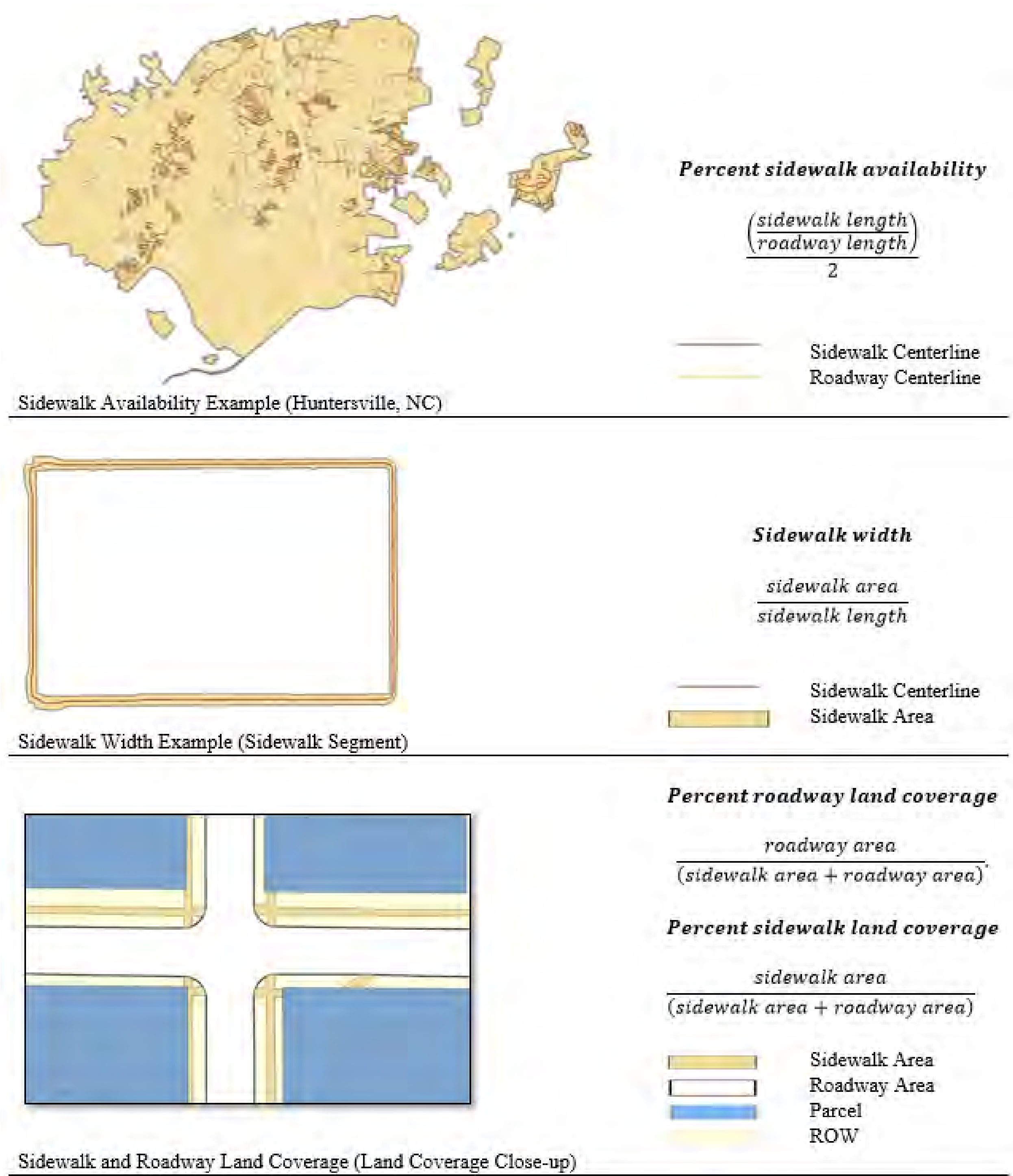


Figure 4.1 GIS Analysis and Calculation Examples

5. RESULTS

5.1 Planimetric Data

We were able to normalize planimetric data obtained from all 24 cities into sidewalk and roadway polygons and centerlines through GIS analysis within the ROW. This provided the core spatial data needed to calculate sidewalk characteristics (availability, width, and land coverage), which we will discuss next.

5.2 Sidewalk Characteristics (Availability, Width, and Land Coverage)

5.2.1 Sidewalk Availability

The average availability resulted in 47.5%, which equates to 0.95 miles (1.53 kilometers) of sidewalk for every two miles (3.22 kilometers) of roadway. Based on the 2 to 1 ratio of sidewalks to roadways recommended by NACTO, FHWA, and ITE, the results suggest less than half of full sidewalk availability is provided. Theoretically, this equates to less than one complete sidewalk segment alongside a roadway or half of the city roads with sidewalks on both sides and the other half without sidewalks. Individual results for each of the 24 cities showed 12 with less than 50% sidewalk availability and 12 with greater than 50% availability.

5.2.2 Sidewalk Width

The results for sidewalk width decreased for all cities in this study from three feet to six feet (0.91 meters to 1.83 meters), respectively. 89.2% of the sidewalks are at least three feet wide meeting the ADA three feet (0.91 meters) minimum requirement. Furthermore, 60.8% of the sidewalks are at least four feet (1.22 meters) wide, meeting the 2011 U.S. Access Board proposed guidelines. Regarding the NACTO and AASHTO recommendations only 28.8% of the sidewalks are at least five feet (1.52 meters) wide, and 13.5% of the sidewalks are at least six feet (1.83 meters) wide, meeting the ITE recommendation.

5.2.3 Sidewalk Land Coverage

Land coverage comparison, which is the relative comparison of area occupied by sidewalks and roadways within the ROW, shows disproportionate average percentages of 11.7% and 88.3% for sidewalks and roadways respectively. The results for each city slightly vary, with roads covering greater than 80% and sidewalks covering less than 20%. Analyzing land coverage with additional data from the census, ACS, and the sample cities begins to unravel more information. After reviewing the fundamental sidewalk characteristics, we probed deeper into their relationship with the city, its people, and their chosen mode of transportation. All results are provided in Table 5.2.

5.3 Relationships between Sidewalk and City Characteristics

5.3.1 City Characteristics

Of the city characteristics analyzed, average structure year reveals notable results indicating cities with the oldest average structures display the greatest sidewalk availability. Moreover, sidewalk availability decreases chronologically from older to newer cities. Regarding land coverage, the trend indicates that the older the average structure year in a city, sidewalk coverage increases, and roadway decreases.

Regarding population and population density, there is little indication of relationships with sidewalk availability, width, or land coverage. All city characteristic results are displayed in Tables 5.3 and 5.4 below.

5.3.2 Socio-Demographic/Socio-Economic Characteristics

Regarding race/ethnicity, the cities with white populations appear to be overrepresented with the "Lowest" quantile of 14.8% to 44.9% surpassing the "Medium-High" quantile for Black or African American and Hispanic or Latino at 15.3% to 26.9% and 10.4% to 30.6% respectively. Second, the greatest availability appears in the "Highest" White quantile and the "Lowest" Black or African American quantile.

In line with the availability results, the greatest percentage of sidewalks five feet (1.52 meters) or greater appears in the "Highest" White quantile and the "Lowest" Black or African American quantile. The Hispanic or Latino category does not reveal any noticeable results for either availability or width.

Age and per capita income do not indicate relationships with sidewalk availability, width, or land coverage. However, it is worth noting that cities with the youngest residents, on average, show the greatest availability. Breaking down this category to look at age based on employment or looking at families may be more revealing. All socio-economic and socio-demographic characteristic results are displayed in Tables 5.3 and 5.4.

Table 5.1 Sidewalk Availability and Width Results

State	City	Availability	Width			
		Percent (%)	≥ 6 feet (1.8 meters)	≥ 5 feet (1.5 meters)	≥ 4 feet (1.2 meters)	≥ 3 feet (0.9 meters)
SC	Charleston	12	25.3	40	62.6	85.5
VA	Newport News	21	14	24.1	53.6	83.5
VA	Lynchburg	22	4.8	12.3	37	76.2
VA	Virginia Beach	25	10.6	20.3	47.2	84.6
TX	Austin	30	4.6	13.2	43.5	84.5
NY	New Rochelle	32	16.7	28.1	63.8	92.3
NC	Raleigh	34	11	34.3	70.1	89.7
NC	Huntersville	37	6.8	34.8	74.5	90.4
NY	Yonkers	40	18	25.6	52.3	94.8
TX	Round Rock	42	10.2	24.7	61.9	96.5
IA	Cedar Rapids	48	6.2	12.6	31	86.3
IL	Peoria	48	16.3	47.6	87	97.1
CO	Commerce City	51	16	30.3	60.4	89.8
FL	Weston	53	32.4	70.1	84.8	91.5
CO	Lakewood	54	16.4	29.7	52.7	79.7
OH	Cincinnati	55	11.7	19.2	46.5	89.8
CO	Boulder	63	20.4	34.6	68.9	89.7
CT	Hartford	63	7.4	18	57.5	96.5
NY	Mount Vernon	64	13.3	17	50.1	92
CO	Denver	65	14.2	26.1	57.5	83.8
MN	St. Paul	65	9.1	25.3	69.8	91.6
CO	Aurora	66	17.5	35.7	70.2	89.7
CO	Centennial	74	8.6	25.4	68	88.3
OR	Corvallis	75	13.4	42	89.3	96.3
Minimum		12	4.6	12.3	31	76.2
Maximum		75	32.4	70.1	89.3	97.1
Median		49.5	13.4	25.9	61.2	89.8
Mean		47.5	13.5	28.8	60.8	89.2

Table 5.2 Land Coverage Results

State	City	Road	Sidewalk
		Percent (%)	
NY	Mount Vernon	81.6	18.4
OR	Corvallis	81.6	18.4
MN	St. Paul	83.6	16.4
OH	Cincinnati	84.3	15.7
CO	Boulder	85.0	15.0
CT	Hartford	85.0	15.0
CO	Centennial	86.5	13.5
CO	Aurora	86.6	13.4
CO	Denver	87.3	12.7
IL	Peoria	87.4	12.6
NY	Yonkers	87.4	12.6
FL	Weston	88.7	11.3
IA	Cedar Rapids	88.8	11.2
NC	Huntersville	88.9	11.1
CO	Lakewood	89.0	11.0
CO	Commerce City	89.3	10.7
NY	New Rochelle	90.0	10.0
TX	Round Rock	90.1	9.9
NC	Raleigh	91.0	9.0
VA	Lynchburg	93.2	6.8
TX	Austin	93.4	6.6
VA	Newport News	93.4	6.6
VA	Virginia Beach	93.4	6.6
SC	Charleston	94.7	5.3
Minimum		81.6	5.3
Maximum		94.7	18.4
Median		88.8	11.3
Average		88.3	11.7

Table 5.3 Sidewalk Availability and Width

		City										
		Quartile †	Availability		Width							
				H	≥ 6 feet (1.8 meters)	H	≥ 5 feet (1.5 meters)	H	≥ 4 feet (1.2 meters)	H	≥ 3 feet (0.9 meters)	H
Average Structure Year	Newest	1984 - 1997	41.2%		13.5%		34.6%		65.9%		90.4%	
	-	1976 - 1984	45.5%		14.9%		31.2%		65.2%		88.0%	*
	-	1962 - 1976	50.0%		13.0%		27.1%		55.7%		85.5%	
	Oldest	1951 - 1962	53.2%		12.7%		22.2%		56.7%		92.8%	
Population	Highest	299,423 - 916,906	47.5%		11.2%		25.8%		59.7%		87.3%	
	Medium-High	127,360 - 299,423	38.3%		15.3%		25.2%		49.8%		86.6%	*
	Medium-Low	79,717 - 127,360	53.7%		13.3%		29.7%		67.8%		93.4%	
	Lowest	52,905 - 79,717	50.3%		14.5%		34.4%		66.0%		89.4%	
Population Density	Highest	4,178 - 15,599	54.8%		13.1%		23.4%		58.5%		91.8%	
	Medium-High	3,146 - 4,178	60.5%	***	13.4%		29.3%		64.6%		90.0%	
	Medium-Low	2,169 - 3,146	42.0%		16.0%		37.5%		68.2%		89.3%	
	Lowest	1,161 - 2,169	32.5%		11.6%		25.0%		52.1%		85.5%	
Municipal Policy	City *(n=14)*		41.9%		13.4%		30.0%		61.2%		87.2%	
	Landowner *(n=9)*		56.1%		13.5%		24.8%		57.4%		91.3%	*
	Shared *(n=1)*		48.0%		16.3%		47.6%		87.0%		97.1%	
Socio-Demographic/Socio-Economic Characteristics												
Age	Oldest	38 - 40	46.0%		16.4%		27.6%		58.2%		88.8%	
	-	36 - 38	49.0%		15.2%		32.6%		59.0%		88.8%	
	-	35 - 36	40.5%		12.4%		29.3%		62.4%		86.5%	
	Youngest	31 - 35	54.3%		10.1%		25.6%		63.7%		92.5%	
Per Capita Income	Highest	$38,342 - $45,358	54.0%		16.5%		36.5%		69.6%		89.3%	
	Medium-High	$32,183 - $38,342	32.5%		14.3%		27.2%		54.7%		86.5%	*
	Medium-Low	$28,109 - $32,183	57.0%		11.4%		28.2%		64.8%		93.3%	
	Lowest	$19,220 - $28,109	46.3%		11.9%		23.3%		54.2%		87.6%	
Race (White)	Highest	70.5% - 83.6%	51.5%		13.4%		31.6%		65.7%		89.4%	
	Medium-High	52.8% - 70.5%	41.3%		12.2%		28.4%		58.6%		85.2%	
	Medium-Low	44.9% - 52.8%	48.3%		11.6%		24.4%		59.3%		90.7%	
	Lowest	14.8% - .44.9%	48.7%		16.8%		30.8%		59.8%		91.4%	
Race (Black or African American)	Highest	26.9% - 64.3%	43.2%		10.4%		20.8%		52.5%		88.0%	
	Medium-High	15.3% - 26.9%	41.3%		15.9%	*	32.8%	**	66.8%	*	90.1%	
	Medium-Low	5.7% - 15.3%	43.7%		10.0%		22.8%		53.4%		89.4%	
	Lowest	1% - 5.7%	61.7%		17.9%		38.7%		70.7%		89.2%	
Ethnicity (Hispanic or Latino)	Highest	30.6% - 51.8%	46.5%		14.8%		30.3%		60.1%		92.3%	
	Medium-High	10.4% - 30.6%	52.5%		14.8%		28.5%		60.7%		87.9%	
	Medium-Low	7.5% - 10.4%	53.8%		12.7%		28.6%		66.1%		89.0%	
	Lowest	2.9% - 7.5%	37.0%		11.9%		27.7%		56.4%		87.6%	

Table 5.4 Land Coverage

		City			
		Quartile †	Land Coverage Comparison		
			Roadway	Sidewalk	*H*
Average Structure Year	Newest	1984 - 1997	90.2%	9.8%	**
	-	1976 - 1984	89.5%	10.5%	
	-	1962 - 1976	88.3%	11.7%	
	Oldest	1951 - 1962	85.3%	14.7%	
Population	Highest	299,423 - 916,906	89.2%	10.8%	
	Medium-High	127,360 - 299,423	89.5%	10.5%	
	Medium-Low	79,717 - 127,360	87.3%	12.7%	
	Lowest	52,905 - 79,717	87.3%	12.7%	
Population Density (People/mi²)	Highest	4,178 - 15,599	86.0%	14.0%	***
	Medium-High	3,146 - 4,178	86.0%	14.0%	
	Medium-Low	2,169 - 3,146	91.8%	8.2%	
	Lowest	1,161 - 2,169	86.6%	13.4%	
Municipal Policy	City *(n = 14)*		90.1%	9.9%	**
	Landowner *(n = 9)*		85.7%	14.3%	
	Shared *(n = 1)*		87.0%	13.0%	
		Socio-Demographic/Socio-Economic Characteristics			
Age	Oldest	38 - 40	88.3%	11.7%	
	-	36 - 38	88.2%	11.8%	
	-	35 - 36	89.7%	10.3%	
	Youngest	31 - 35	87.2%	12.8%	
Per Capita Income	Highest	$38,342 - $45,358	87.8%	12.2%	*
	Medium-High	$32,183 - $38,342	91.3%	8.7%	
	Medium-Low	$28,109 - $32,183	85.7%	14.3%	
	Lowest	$19,220 - $28,109	88.5%	11.5%	
Race (White)	Highest	70.5% - 83.6%	87.8%	12.2%	
	Medium-High	52.8% - 70.5%	90.0%	10.0%	
	Medium-Low	44.9% - 52.8%	88.0%	12.0%	
	Lowest	14.8% - .44.9%	87.5%	12.5%	
Race (Black or African	Highest	26.9% - 64.3%	88.0%	12.0%	
	Medium-High	15.3% - 26.9%	89.3%	10.7%	
	Medium-Low	5.7% - 15.3%	89.2%	10.8%	
	Lowest	1% - 5.7%	86.8%	13.2%	
Ethnicity (Hispanic or Latino)	Highest	30.6% - 51.8%	88.8%	11.2%	
	Medium-High	10.4% - 30.6%	87.7%	12.3%	
	Medium-Low	7.5% - 10.4%	87.3%	12.7%	
	Lowest	2.9% - 7.5%	89.5%	10.5%	

Quartile † n = 6 per quartile
*Kruskal-Wallis Test Statistical Significance * p < .10; ** p < .05; *** p < .01*

6. CONCLUSIONS

This research displays the benefit provided by new developments in remote-sensing technologies, and it introduces planimetric data for evaluating sidewalks in cities. We identified the capability to collect field-based audit characteristics (sidewalk presence, continuity, and width) noted by Brownson et al. with the use of high accuracy spatial data and GIS (Brownson et al., 2009). These results exhibit how to apply the use of higher quality data and analysis to expand on prior research not only in transportation infrastructure and data analysis but also into demographics and policy.

Sidewalk availability reveals a considerable deficit with 24 sample cities averaging 47.5%, which equates to 0.95 sidewalk miles (1.53 kilometers) for every two roadway miles (3.22 kilometers). This does not consider other areas that could potentially be more revealing, such as identifying obstructions or connectivity barriers hindering paths to and from destinations. GIS provides capabilities for network analyses on these subjects, so the potential exists to delve deeper.

Analyzing sidewalk availability compared to roadways using linear data only tells part of the story. Land coverage, which is the relative comparison of area occupied by sidewalks and roadways within the ROW, reveals a greater imbalance of 11.7% sidewalk versus 88.3% roadway area. Considering the increase in demand to live in cities globally, the ROW provides valuable and desirable public space, and this information affords ways to measure this. Furthermore, an evaluation of maintenance or new development costs could benefit from this data and shed light on allocation of funds by cities.

Regarding width, the data displays that an average of 89.2% of sidewalk segments meet the three feet (0.91 meters) minimum ADA requirement; however, this number represents a minimum standard. Of greater concern, only 60.8% of existing sidewalks meet the 2011 U.S. Access Board proposed guidelines minimum of four feet (1.22 meters) (USAB, 2011a). The ADA and all national and federal recommendations define these widths as routes free and clear of impediments such as utility poles, street furniture, and fire hydrants. Considering select cities collect this type of data, the potential exists for more in-depth analysis; however, this does not account for other factors of quality including broken, uneven, or sloping sidewalks.

Relationships between sidewalk and city characteristics revealed older cities tended to provide greater sidewalk availability; in addition, there is greater land coverage of sidewalks in comparison to roadways in the ROW. Regarding municipal policy for maintenance, the outcome indicates landowner responsibility was associated with greater availability but narrower sidewalks than cities that take responsibility for the sidewalks themselves. The results also suggest racial disparities regarding both sidewalk availability and width.

Sidewalk data availability remains scarce, as we identified that only 5% (36 out of 769) of U.S. cities currently provide planimetric-quality sidewalk data. Moreover, a critical component to the quality of data and documentation provided through metadata is warranted. Investment into high-resolution imagery and data extraction would enable a greater understanding for various disciplines to discover deficiencies or disparities and possibly comprehend the effectiveness of policies and plans. Furthermore, this study reaffirms that expanding on this data availability would promote research into demographics or transportation infrastructure that would greatly benefit various industries, government agencies, and the public.

Beyond the data collection, greater documentation on methods, quality, and revisions of sidewalk data would benefit not only the agencies providing high accuracy data but also users. The metadata provides a critical component to any spatial dataset. Without this information, it diminishes the value and introduces many potential issues in utilizing this data in asset management, analysis, or any additional intended use.

The National Cooperative Highway Research Program (NCHRP) Synthesis 371 highlights the need for additional sidewalk data and research. NCHRP 371 surveyed infrastructure asset agencies at the state, provincial, county, and city levels from across the United States about their management policies (Markow et al., 2007). Results indicated that agencies lack information regarding sidewalk inventory, location, condition, and understanding of codes and practices related to maintenance responsibility (Markow et al., 2007). The interest to fill this void in sidewalk research and evaluation is evident with legislation, policies, projects, and programs from the federal government and advocacy groups aiming to increase support and awareness (America Walks, 2008-2019; The National Center for Bicycling and Walking, 2002-2019; USDOT, 2019a; USDOT, 2019b; Walk Denver, 2018). The results presented in this paper not only reaffirm this deficiency but also present how data from remote sensing technologies can help fulfill these needs.

PART 2: THE (UN)EQUAL DISTRIBUTION OF SIDEWALK INFRASTRUCTURE ACROSS 16 U.S. CITIES

7. INTRODUCTION

Walking helps provide access to work, transit, businesses, leisure activities, and even to and from parking lots. Yet, the fundamental infrastructure generally necessary for walking in urban areas — sidewalks — is rarely provided uniformly. Such inconsistencies beg the question: which populations are most impacted by lacking or inadequate sidewalks?

Cities are increasingly concerned with equity in pedestrian planning, and some cities are zeroing in on the topic of sidewalks (Berg & Newmark, 2020). Understanding the equality of sidewalk distribution, which refers to all neighborhoods receiving the similar levels of infrastructure, provides insight to equity for different populations by demographic. The city of Milwaukee, WI, for instance, highlights the negative impact that variable sidewalk accessibility (equality) can have on different populations (equity) (City of Milwaukee, 2019). Yet, Milwaukee also acknowledges that a lack of sidewalk data hinders their ability to make progress on this issue, or even to know where they currently stand.

This problem is not unique to Milwaukee. A deficiency of sidewalk data has long stood in the way of properly understanding the provision of sidewalk infrastructure. In fact, of the academic sidewalk-related research that does exist, most papers focus on a single small city or a relatively small portion of a larger city due to a general lack of comprehensive sidewalk data (FHWA, 2006, 2015, 2018; Park et al., 2015; Zhang & Zhang, 2019). With recent advances in remote sensing technology, however, we are beginning to reach the point where we can close the sidewalk data gap. Planimetric data, for example, identifies physical features on the ground using aerial imagery (Montgomery & Schuch, 1993). Today, many cities use planimetric data to calculate stormwater management fees; however, it is often possible to extract detailed sidewalk data as from planimetric data well (Coppola & Marshall, 2019, 2020).

For this study, we canvased every city in the United States by city, county, and state websites seeking out planimetric data. This effort resulted in 16 viable cities with the potential to extract sidewalk data. We then quantified sidewalk availability and width measures for the entirety of these 16 cities and compared those results against the sociodemographic and socioeconomic characteristics of the people that live there. Studying these issues across this many cities fills a major gap in the academic sidewalk and equality literature. This research also helps provide cities a methodology to understanding their own sidewalk equality situation.

The next section reviews the existing literature related to sidewalks and equality. We then describe the steps required to obtain and prepare the spatial data and our methods for converting this data into usable sidewalk information. Finally, we discuss what we learned regarding sidewalk infrastructure and disparities across sociodemographic and socioeconomic characteristics in our study cities.

8. LITERATURE REVIEW

The existing literature on sidewalks and equality is scarce. One reason for this is a lack of sidewalk spatial data needed to objectively analyze sidewalks, especially at the city scale or lager (Bolten et al., 2017; Brownson et al., 2009). In fact, sidewalk research, in general, has been hindered by a lack of sidewalk data (Bise et al., 2018; Bolten et al., 2017). Using advancements in spatial data for sidewalks, we aim to help fill the research gap. In this section, we discuss the prior research by focusing on: i) sidewalk data collection methods; ii) sidewalk characteristics and measurement; and iii) outcomes with regard to race, poverty, and income.

First, in terms of data collection methods, the four prior studies that we identified with a focus on sidewalks and equality all relied entirely upon manual, field-based data collection. While such data collection efforts can be time intensive and expensive, they can also constrain the geographic area that researchers can cover. For example, del Pilar Rodriguez and Rowangould assessed the sidewalks within 50 meters of 100 intersections in Albuquerque, NM. (del Pilar Rodriguez & Rowangould, 2017). Given that Albuquerque has over 22,000 intersections, this represents less than 1% of the city. Kelly et al. trained field auditors to collect sidewalk data for 25% of street segments within 210 St. Louis, MO, block groups (Kelly et al., 2007). This still results in less than 4.4% of street segment coverage. Lowe was able to consider all of New Orleans, LA, but focused only on the sidewalks near bus stops (Lowe, 2016). The largest data collection effort of the four prior studies covered the entirety of Starkville, MS, which is a city of approximately 25,000 people (Bise et al., 2018). To collect data for this large of an area, Bise et al. visually inspected sidewalks from a car as they drove along every street for the entirety of the city. Their methods consisted of manually noting sidewalks on topographic maps that they later manually converted to spatial GIS data. Although Bise et al. could collect sidewalk data for a full city, their manual methods introduced a high potential for human error and are not easily replicable in other locations, particularly in larger cities or regions. Moreover, the only useful sidewalk measures that can seemingly be derived from driving around the city is whether the sidewalk exists and perhaps, how connected the network may be. Measures, such as sidewalk width, seem difficult to obtain with adequate accuracy.

With respect to quantifying sidewalk characteristics, the existing literature typically relied upon ordinal — or even binary — measures with relatively subjective ranking thresholds. Defining sidewalk data in this manner omits measurable, objective details such as width and introduces interrater reliability issues. Lowe, for example, employed a binary variable as to whether the sidewalk was continuous or not. Simplifying sidewalk continuity to this extent omits many important details such as: i) where the discontinuity exists; ii) the percentage of missing sidewalks; and/or iii) the number of gaps in the sidewalk segment. Additionally, Lowe's study only considered the sidewalks between bus stops and the nearest roadway intersection; this left a considerable portion of the city sidewalk system unevaluated. Kelly et al. used a dichotomous measure for the presence or absence of sidewalks with "a lot" or "some/none" for sidewalk characteristics. This omits information such as: i) details pertaining to sidewalk location (e.g. which side of the street, length, and continuity); and ii) what "a lot" or "some" represent. Del Pilar Rodriguez and Rowangould provided definitions with greater detail by listing quantitative sidewalk measurements such as "cross slope should be a maximum of 2%," but the data was then reduced into a binary pass/fail measure. Bise et al. broadened their approach to an ordinal measure for sidewalk connectivity and ADA compliance using a scale of "poor" to "excellent" and "very poor" to "excellent," respectively. However, this system still fails to provide potentially useful quantitative information. For example, the ADA compliance definition of "very poor" states "too narrow" (not ADA compliant) and excellent is "more than 1.83 meters (six feet)" (Bise et al., 2018); yet, the term "too narrow" is not specifically defined, and 1.83 meters (six feet) is double the ADA minimum sidewalk width requirement of 0.91 meters (three feet) (USDOJ, 2010). Given the time consuming and manual nature of their data collection efforts, these authors made considerable strides. However, the lack of quantifiable measures leaves us unable to map basic sidewalk characteristics such as width, which remain critical for ADA compliance and to truly understand issues of sidewalk infrastructure and equality.

In terms of equality outcomes, the existing literature focused on the relationships of sidewalk infrastructure to race, poverty, and income. Looking first at race, three of the prior studies identified disparities for minority populations versus: sidewalk presence (or absence), quality, and continuity (Bise et al., 2018; Kelly et al., 2007; Lowe, 2016). Bise et al. identified a greater association of "excellent" sidewalks to White populations and a significant correlation between the Black or African American populations and "poor" sidewalks (Bise et al., 2018). Kelly et al. identified a greater association of predominantly Black or African American populations with sidewalk unevenness, obstructions, and physical disorders (Kelly et al., 2007). Lowe identified an association with worse sidewalk connectivity and both minority populations and poverty (Lowe, 2016). However, Kelly et al. did not find any significant association between poverty and sidewalk walkability (unevenness and obstruction) (Kelly et al., 2007). Regarding income, del Pilar did not find evidence of disparities with respect to sidewalks and ADA compliance (del Pilar Rodriguez & Rowangould, 2017). Results suggest that inequities exist, but the prior research also lacks quantitative metrics and usually only covers a limited portion of a city or a smaller single city. Still, research by Berg and Newmark reveals that municipal pedestrian plans rarely include race as a factor (Berg & Newmark, 2020). Our paper seeks to build upon the prior literature and support city planning efforts by using higher quality sidewalk data, covering larger and complete geographic scale (multiple cities), and including quantitative information.

9. STUDY OVERVIEW

The goal of this paper is to use planimetric data to map and quantify sidewalk infrastructure in terms of availability and width and to compare those characteristics against socio-economic and socio-demographic data. Prior research has shown sporadic availability of planimetric data in U.S. cities, but first we needed to determine which planimetric data sets could lead to viable sidewalk data, and in turn, which cities to focus on for this study (Coppola & Marshall, 2019, 2020).

9.1 City Selection

We initially researched state, county, city, and other municipal websites in the United States. Within these websites, we searched not only for sidewalks, but also for terms including impervious, transportation, and infrastructure. This is because sidewalk data is often a component of larger data sets. For example, Mecklenburg County, NC, provides a spatial data set called "Impervious – Edge of Pavement." Within this data set is a field titled "subtheme" where sidewalks can be identified.

Next, we tabulated all cities with available sidewalk data, contacted the data originator (e.g., city GIS department), and requested verification of the year when the data was collected and if the data set included coverage for the entire city. Based on these assessments, we focused on the 16 cities shown in Table 9.1, which included populations of approximately 58,000–380,000 and data sets from 2015–2020. We then created a comprehensive repository of sidewalk polygon spatial data to quantify sidewalk availability and width measures.

Table 9.1 U.S. Cities with Sidewalk Polygon Geospatial Data

State	City	Population Estimate (2019)
Colorado	Commerce City	60,336
	Boulder	105,673
	Centennial	110,937
	Lakewood	157,935
	Aurora	379,289
Connecticut	Hartford	122,105
Illinois	Peoria	110,417
Iowa	Cedar Rapids	133,562
New York	Mount Vernon	67,345
	New Rochelle	78,557
	Yonkers	200,370
North Carolina	Huntersville	58,098
Ohio	Cincinnati	303,940
Oregon	Corvallis	58,856
Texas	Round Rock	133,372
Virginia	Lynchburg	82,168

9.2 Sidewalk Standards and Guidelines

The ADA provides legal standards for sidewalks, and the following publications represent a sample of the various guidelines found in the United States that include recommendations for sidewalks:

- Federal Highway Administration's (FHWA) Designing Sidewalks and Trails for Access (2001)
- American Association of State Highway and Transportation Officials' (AASHTO) A Policy on Geometric Design of Highways and Streets (2018)
- National Association of City Transportation Officials' (NACTO) Urban Street Design Guide (2013)
- Institute of Transportation Engineers (ITE)/Congress for the New Urbanism's (CNU) Designing Walkable Urban Thoroughfares: A Context-Sensitive Approach (2010)

These documents typically refer to the ADA when discussing their own recommendations. Furthermore, states and municipalities also reference the ADA and one or more of these guidebooks when developing their pedestrian plans and sidewalk designs.

Regarding minimum sidewalk width, Table 9.2 lists the guidelines from each agency. At present, the ADA stipulates a three feet (0.91 meters) minimum sidewalk width requirement, but this measurement is exclusive of the width of the curb (USDOJ, 2010). Given that curb width varies depending on several factors (AASHTO, 2018), and the fact that we were unable to discern curb width via planimetric data, the sidewalks widths we focus on in this paper include the curb width. The U.S. Access Board is also currently proposing an increase of the minimum sidewalk width to four feet (1.22 meters) (USAB, 2011a).

The FHWA Designing Sidewalks and Trails for Access section (4.1.2.3) on sidewalk corridors recommends a minimum width completely free of obstacles for pedestrian travel to be five feet (1.52 meters) wide (Kirschbaum et al., 2001). The AASHTO Green Book guidelines state a range in residential areas of 4–8 feet (1.21–2.44 meters) and approximately two feet (0.61 meters) wider when adjacent to the curb (AASHTO, 2018). The overall minimum recommended width is four feet (1.21 meters). The NACTO Urban Street Design Guide has a slightly wider recommendation of an "absolute minimum of five feet" (1.52 meters) for all sidewalks (NACTO, 2013); in addition, ranges are provided for residential and commercial of 5–7 feet (1.52–2.13 meters) and 8–12 feet (2.44–3.66 meters), respectively. The ITE Design Parameters for Walkable Urban Thoroughfares (Table 6.4) indicates a six-foot (1.83 meter) recommendation for all sidewalks (ITE, 2010).

While we initially aimed to include sidewalk metrics such as ADA curb ramps, streetlights, signs, parking meters, and/or benches, such data is not readily available. Therefore, we focused on sidewalk availability and width, which we can derive from planimetric data.

Table 9.2 Sidewalk Minimum Width Standards and Guidelines

Agency	Document	Width
ADA	2010 ADA Standards for Accessible Design[1]	3 feet (0.9 meters)
	Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way[2]	4 feet (1.2 meters)
AASHTO	A Policy on Geometric Design of Highways and Streets[3]	
FHWA	Designing Sidewalks and Trails for Access[4]	5 feet (1.5 meters)
NACTO	Urban Street Design Guide[5]	
ITE & CNU	Design Parameters for Walkable Urban Thoroughfares[6]	6 feet (1.8 meters)

[1] *(Mahoney, 2012)*
[2] *(USAB, 2011b)*
[3] *(AASHTO, 2018)*
[4] *(Kirschbaum et al., 2001)*
[5] *(NACTO, 2013)*
[6] *(Daisa & ITE, 2010)*

9.2.1 Sidewalk Availability

Sidewalk availability refers to the presence (or absence) of sidewalks alongside a roadway. Sidewalks provide safety and a conduit for all pedestrians to reach destinations. Moreover, providing sidewalks along both sides of roadways is highlighted in the ADA and all the other guidelines. In turn, we calculated sidewalk availability as a comparison of roadway and sidewalk length in cities.

9.2.2 Sidewalk Average Width

Sidewalk availability merely denotes the existence of sidewalks. Width is also an important characteristic for cities to understand their sidewalk infrastructure. Accordingly, we first measured the sidewalk average width for each sidewalk polygon.

9.2.3 Sidewalk Minimum Width

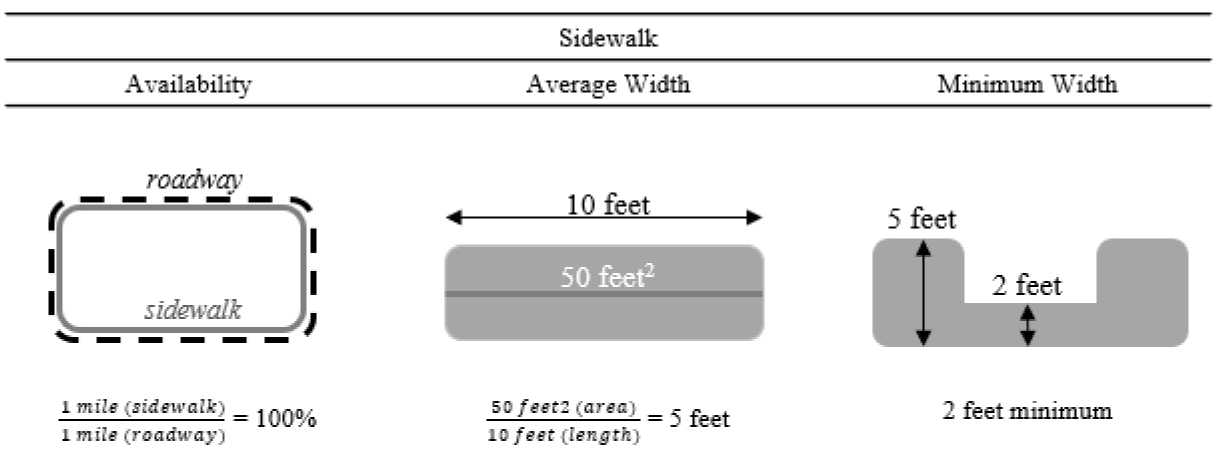
Understanding average sidewalk width is important, but this measurement does not always represent or convey the usefulness of a sidewalk. For many pedestrians, a sidewalk is only as good as its narrowest point. For example, if a person in a wheelchair is on a sidewalk that begins at six feet wide but narrows to one foot, it may no longer be traversable. As a result, we also measured the minimum width for each sidewalk polygon. This measure corresponds with how the ADA defines the physical dimensions of the sidewalk for persons with disabilities.

10. DATA AND METHODS

We first obtained planimetric data for each of the cities shown in Table 9.1 from their respective city, county, or regional council of government websites. Next, we obtained census city boundaries, block group boundaries, and roadways data via the software package R and the Tigris and Tidycensus U.S. Census interfaces (Walker, 2020a, 2020b). When evaluating data for our 16 study cities, we found that most sidewalks were in the public right of way (ROW), but some were on private land. To limit the analysis to public land, we used parcel data to isolate sidewalks and roadways in the public ROW. This effort also required conversations with GIS departments in Portland, OR, Denver, CO, and Raleigh, NC, to confirm that areas outside of parcels denote the public ROW. The remainder of this section overviews the steps taken to turn these data sets into usable sidewalk infrastructure measures.

10.1 Sidewalk Availability

For sidewalk availability, our intent is to compare the length of the sidewalk to the length of the roadway at the census block group geography. As discussed in the study overview section, a sidewalk should theoretically exist on both sides of a roadway. In turn, we can approach sidewalk availability in one of two ways. First, we can consider one mile of roadway with two miles of sidewalk to equal 100% sidewalk availability. However, roadway centerlines often delineate census block group boundaries in GIS data. This places the sidewalks on either side of the road in different block groups, and a confounding situation where the sidewalks will be attributed to only the associated roadway block group. Thus, we can also view sidewalk availability from the standpoint that a roadway should theoretically exist on one side of the sidewalk. As a result, we chose this method, which evaluates the sidewalk independently in each block group. From this approach, we can consider one mile of sidewalk with one mile of roadway to have 100% sidewalk availability. For example, as displayed on the left side of Figure 10.1, if one mile (1.61 kilometers) of sidewalk paralleled one mile (1.61 kilometers) of roadway, this would equate to 100% sidewalk availability.



To calculate the sidewalk length, we converted the sidewalk polygon data to centerlines. Before creating the sidewalk centerline; however, we needed to make sure that the sidewalk polygons included connecting driveways — some cities treated driveways as a separate entity from the sidewalks, which would result in unwarranted discontinuities. The top portion of Figure 10.1 provides examples of sidewalk polygons missing driveways and the steps taken to remedy this. This included using the parcel data to isolate the sidewalk polygons to the right-of-way and then, converting sidewalk polygons to centerlines. We also removed small lines unassociated with the public sidewalk before calculating sidewalks lengths from the centerline data.

To calculate the corresponding roadway lengths, as shown in the bottom portion of Figure 2, we first removed interstates. We then combined all roadway lines to ensure overlapping roads were only measured once. To account for roadway lines that coincide with census block group boundary lines, we identified such roads and created roadways parallel to the boundary. We then removed roadways outside of the public ROW and calculated the roadway length.

To calculate sidewalk availability, we joined the sidewalk and roadway length to the corresponding census block group and divided the sidewalk by the roadway length to calculate the sidewalk availability.

10.2 Sidewalk Average Width

The intent of an average sidewalk width measure is to calculate an overall mean width for a sidewalk segment. To do so, we divided the area measurements catalogued for each sidewalk polygon by the centerline lengths, as depicted in the center of Figure 10.1.

We also conducted a review of anomalies in sidewalk measurements of less than one foot (0.30 meters) and greater than 30 feet (9.14 meters) width measurements. The manual review of sidewalks less than one foot primarily included residual narrow areas of private sidewalk polygons resulting from clipping these polygons at the parcel boundary. The review of sidewalks greater than 30 feet (9.14 meters) identified primarily areas representing plazas or squares. For the sake of our study on sidewalk infrastructure, we removed sidewalk polygons one foot (0.30 meters) wide or narrower and 30 feet (9.14 meters) wide or greater.

10.3 Sidewalk Minimum Width

To calculate the minimum sidewalk width, the idea is to isolate the narrowest width measurement of each sidewalk polygon. This first required creating a sidewalk centerline and a unique identification attribute matching each sidewalk polygon and the corresponding sidewalk centerline. Then, we converted the sidewalk polygon to a polyline and measured the distance from the centerline to the sidewalk boundary edge. To measure this distance, we created points along the centerline at three feet (0.91 meters) intervals, starting 10 feet (3.05 meters) from the beginning and terminating 10 feet (3.05 meters) from the end. The spacing at the end points was needed because otherwise, the resulting width would be zero feet due to the centerlines touching the sidewalk boundary. Figure 10.3 depicts this process.

We tested these dimensions with Lynchburg, VA, and Commerce City, CO. Creating points along the centerline at two feet (0.61 meters) intervals considerably increased processing time, and the resulting difference in measurements were negligible at approximately 0.04 feet (1.22 centimeters) for Commerce City, and 0.01 feet (0.31 centimeters) for Lynchburg, on average. We tested the 10 feet (3.05 meters) dimension by also creating centerline points at three feet intervals, starting at nine feet and 11 feet (3.35 meters) from the beginning and end. We continuously conducted manual reviews focusing on sidewalk polygons producing abnormally narrow widths at the beginning or end of sidewalk polygons (e.g. less than one foot). At nine feet (2.74 meters), we identified incorrect narrow width measurements for sidewalk polygons due to centerlines deviating off-center. The results at 10 feet (3.05 meters) alleviated the errors identified at nine feet, and 11 feet (3.35 meters) indicated little to no difference from 10 feet (3.05 meters).

After joining the sidewalk polygon's unique ID with each point, we created a line from each centerline point to the nearest sidewalk boundary edge. Since the distance only accounts for half the width, we doubled the number to estimate the full sidewalk width. We then stored the full width measurement as an attribute with each centerline point, which allowed us to identify the minimum width for each sidewalk polygon.

10.4 Combined Availability/Width Sidewalk Infrastructure Thresholds

Sidewalk availability and width provide useful quantitative metrics, but they must be combined to give us a better understanding of overall sidewalk infrastructure. For example, if an area contains 100% sidewalk availability, but all the sidewalks are less two feet wide, it is not particularly useful. On the other hand, if an area contains sidewalks that are all six feet (1.83 meters) wide or greater, but there is only 25% sidewalk availability, that is also not very useful.

To account for such discrepancies, we created a combined availability/width sidewalk infrastructure threshold, which indicates how complete and compliant the sidewalk infrastructure from zero to 100% at various average width levels. For instance, sidewalk infrastructure with 100% at the three feet (0.91 meters) width level threshold would mean 100% sidewalk availability and all those sidewalks are at least three feet (0.91 meters) wide. If the same block group was 25% at the four feet (1.22 meters) width threshold, that would suggest that three-quarters of those sidewalks are less than four feet (1.22 meters) wide. While this measure is useful for considering compliance with ADA-standards or the various other guidelines, it is also useful to compare results across different widths. Doing so provides better insight into the sidewalk system as a network.

To calculate this, we multiplied the percent of sidewalk availability by the percent of sidewalk polygons that meet each width guideline in each block group. The left column of Figure 10.4, for example, displays a census block group that contains two miles (3.22 kilometers) of sidewalks and four miles (6.44 kilometers) of roadways. This equates to 50% sidewalk availability. The center column of Figure 10.4 displays the same census block group where one of the two sidewalk polygons meets the three feet (0.91 meters) minimum sidewalk average width. This equates to 50% of the existing sidewalks meeting that three-foot (0.91 meters) width guideline. Last, the right column of Figure 10.4 displays the resulting sidewalk infrastructure at the three feet (0.91 meters) threshold, which equates to 25%. This means that 25% of the sidewalk network is at least three feet (0.91 meters) wide or more, on average; the rest is either narrower or non-existent.

When reviewing the sidewalk infrastructure thresholds using the average and minimum widths, we generally found similar trends emerging. In turn, we focus on average width because it provides an overall representation of the sidewalk as opposed to solely focusing on the narrowest point.

10.5 Data Analysis

The intent of this paper is to evaluate income and race data against sidewalk characteristics to identify any trends showing populations impacted by lacking or narrow sidewalks not conforming to guidelines. We selected the census block group as the unit of analysis since it is the smallest geographic extent that provides the necessary socioeconomic and sociodemographic data. We used median household income in 2018 dollars to represent the relative wealth of residents. In terms of race/ethnicity variables, we initially conducted these analyses separately based on the relative percentage of White, Black, and Hispanic residents. The results were all highly correlated with one another, so we focused on the relative percentage of non-White residents. We then categorized both our income and race variables into quantiles and examined the relationships against the sidewalk infrastructure measures.

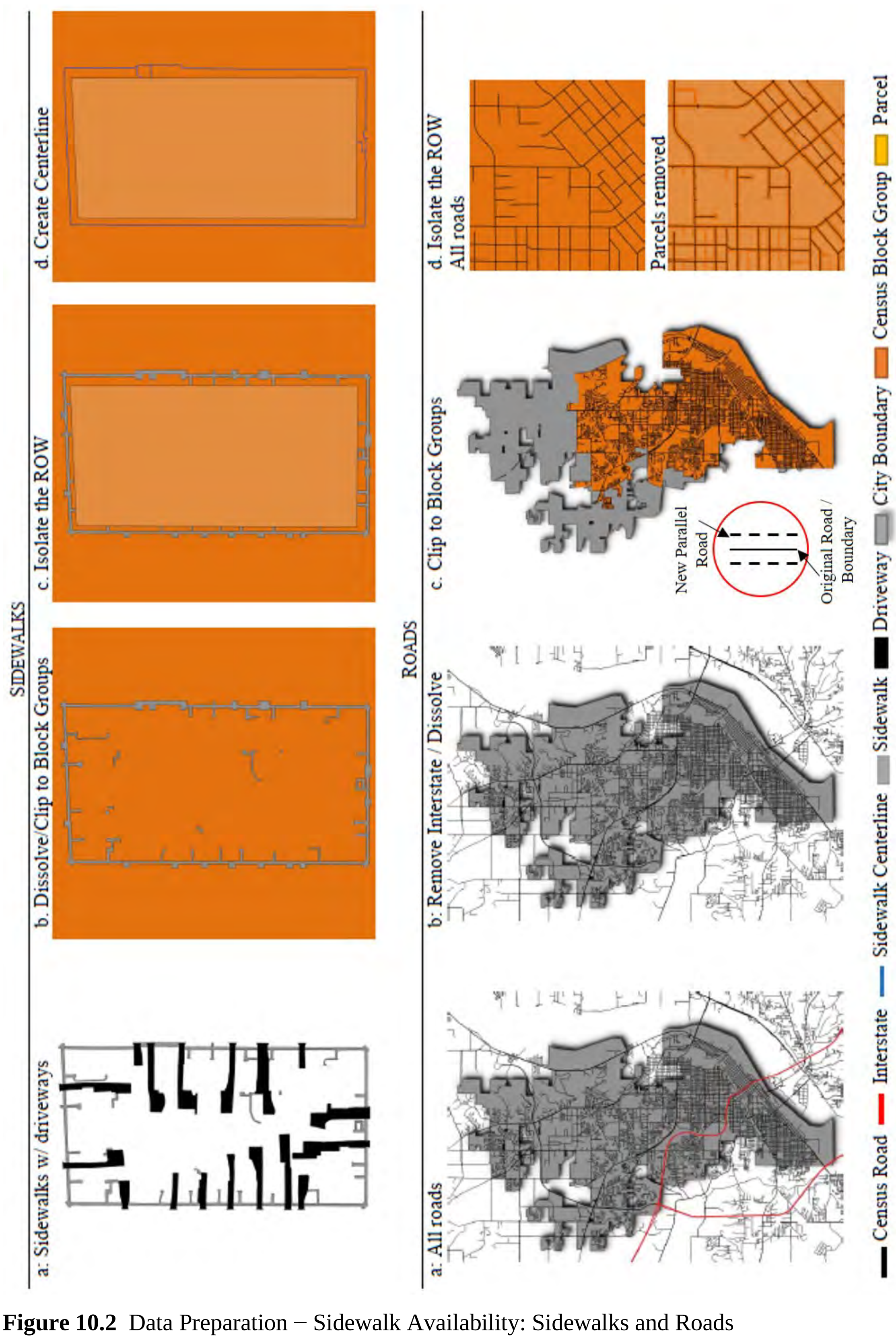
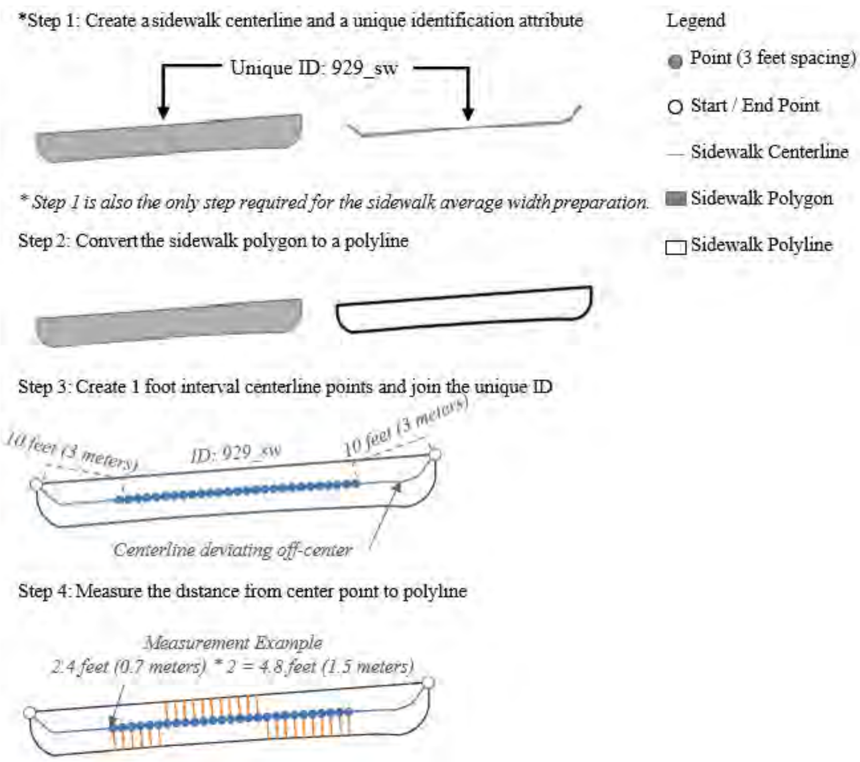


Figure 10.2 Data Preparation − Sidewalk Availability: Sidewalks and Roads



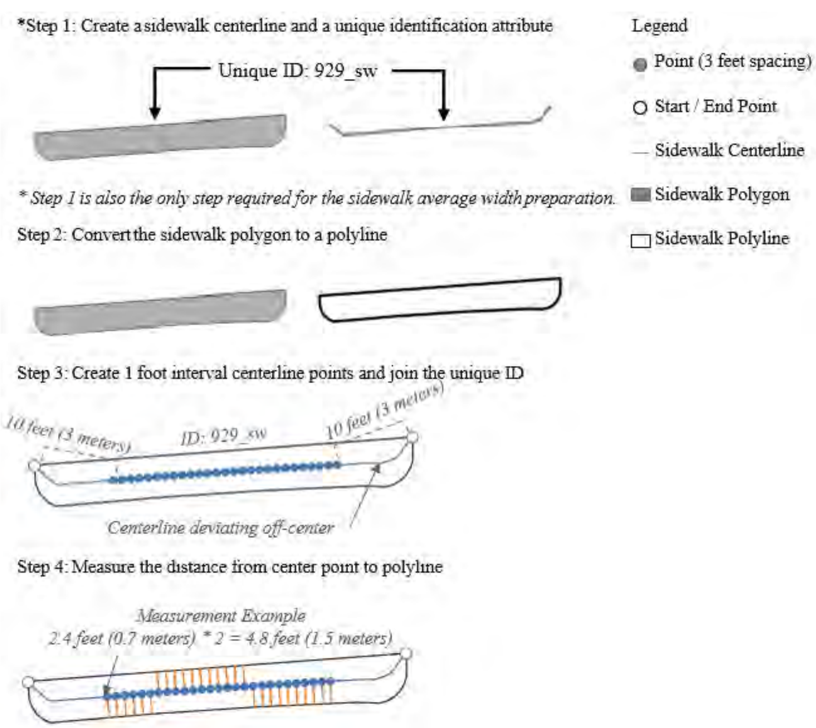
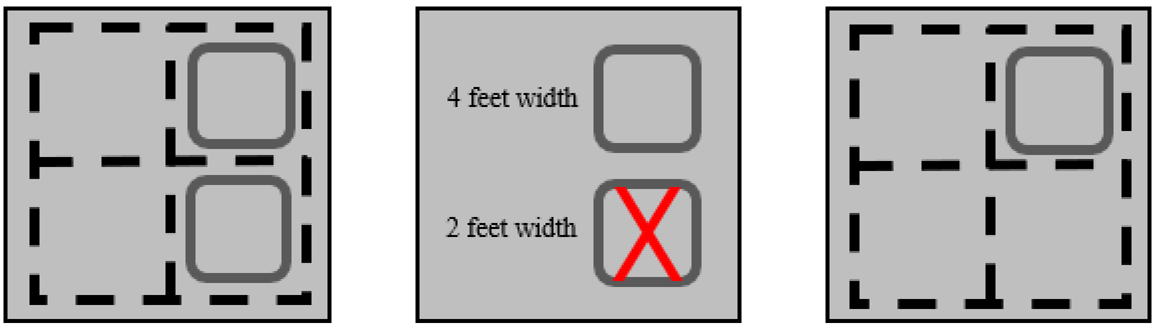


Figure 10.3 Data Preparation − Sidewalk Minimum Width

Sidewalk Formulas		
Availability	Average Width	Infrastructure Threshold *(3 feet average width)*
$\frac{sidewalk\ length}{roadway\ length}$	$\frac{\#\ sidewalks\ \geq\ width}{total\ \#\ sidewalks}$	$availability\ \times width$

Example

$avg. width \geq 3\ feet\ (0.9\ meters)$



$\frac{2}{4} = 0.5\ (50\%)$	$\frac{1}{2} = 0.5\ (50\%)$	$0.5 \times 0.5 = 0.25\ (25\%)$

Census block group; 1 mile (1.6 kilometers) of roadway; 1 mile (1.6 kilometers) of sidewalk

Note: Figure is not to scale

Figure 10.4 Sidewalk Infrastructure Threshold Example

11. RESULTS

We first discuss median household income with respect to each sidewalk characteristic: availability, width, and the availability/width infrastructure thresholds. Next, we discuss the same relationship with respect to non-White population quartiles. Lastly, we discuss the combination of median household income and race with respect to each sidewalk characteristic.

11.1 Median Household Income

11.1.1 Sidewalk Availability

When aggregating our cities with respect to median household income and sidewalk availability, as shown in Table 11.1, we generally found those living in block groups with higher median household incomes with lesser sidewalk availability and those living in lower income areas with greater sidewalk availability. For example, sidewalk availability in the lowest income quartile was 74.3% but only 68.5% in the highest income quartile.

Table 11.1 Aggregated City Results

Sidewalk		Median Household Income				Non-White Population			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Availability		Percent (%)				Percent (%)			
		74.3	70.0	71.5	68.5	64.8	65.5	72.8	81.0
Width		U.S. feet				U.S. feet			
Average		5.2	4.9	4.8	4.8	4.7	4.9	5.0	5.2
Minimum		4.4	4.1	3.9	3.8	3.8	4.0	4.1	4.4
Threshold		Percent (%)				Percent (%)			
Average	3 feet	70.3	65.3	66.8	65.7	60.3	62.1	69.1	76.6
Width	4 feet	50.7	44.9	45.3	47.6	42.0	46.0	47.7	52.8
	5 feet	31.0	24.7	21.0	17.8	19.1	21.6	25.3	29.3
	6 feet	17.7	13.8	11.2	8.6	9.3	10.5	13.8	18.9

Looking more closely at individual cities, however, we noticed that this trend was not consistent. In other words, there were six cities where those living in block groups with higher median household incomes tended to have better sidewalk availability, but we also had six cities where this relationship flips, and lower income block groups had better sidewalk availability. Moreover, there were four cities where this relationship had no clear trend. Table 11.2 displays these grouped results and is a stark contrast to the fully aggregated results in Table 11.1. For example, we now see one group where sidewalk availability in the lowest income quartile was 69.7% but 81.3% in the highest income quartile block groups. We also have one group where sidewalk availability in the lowest income quartile was also 69.7% but only 50.5% in the highest income quartile.

These dissimilarities helped us realize that simply aggregating our results may conceal important trends. Accordingly, for the remainder of the analysis, we aggregated the cities into the following three groups:

- Group 1 (cities with greater sidewalk availability in higher income block groups)
- Group 2 (cities with greater sidewalk availability in lower income block groups)
- Group 3 (cities with no apparent trend between sidewalk availability and income)

More specifically, Group 1 (Cities with Greater Sidewalk Availability in Higher Income Areas) includes: (Colorado) Aurora, Centennial, Commerce City, and Lakewood; (North Carolina) Huntersville; and (Texas) Round Rock. Group 2 (Cities with Greater Sidewalk Availability in Lower Income Areas) includes: (Iowa) Cedar Rapids; (Illinois) Peoria; (New York) Mount Vernon, New Rochelle, and Yonkers; and (Virginia) Lynchburg. Group 3 (Cities with No Trend between Sidewalk Availability and Income): includes (Colorado) Boulder; (Connecticut) Hartford; (Ohio) Cincinnati; and (Oregon) Corvallis.

Table 11.2 Grouped Cities Results

Sidewalk		Median Household Income											
		Group 1 Higher Income- Greater Availability [1]				Group 2 Lower Income- Greater Availability [2]				Group 3 No Trend [3]			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Availability		Percent (%)											
		69.7	73.3	77.1	81.3	69.7	62.2	65.3	50.5	77.4	74.2	80.0	77.0
Width		U.S. feet											
Average		5.3	5.2	4.8	4.7	5.4	4.9	4.6	4.5	5.1	4.8	4.5	5.0
Minimum		4.1	3.9	3.6	3.4	4.6	4.2	4.1	4.1	4.3	4.1	4.0	4.1
Threshold		Percent (%)											
Average Width	3 feet	65.8	70.3	73.0	79.5	66.1	57.5	60.5	47.2	73.1	69.3	74.2	72.6
	4 feet	51.5	55.1	58.7	64.6	54.5	40.1	36.9	25.0	48.8	42.1	42.9	49.5
	5 feet	34.4	32.4	23.2	20.5	36.1	23.3	16.5	10.1	28.0	21.1	17.3	21.6
	6 feet	17.5	17.3	11.5	7.4	21.9	15.3	9.5	5.9	16.3	10.8	8.6	11.5
Sidewalk		Non-White Population											
		Group 1 Higher Income- Greater Availability 1				Group 2 Lower Income- Greater Availability 2				Group 3 No Trend 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Availability		Percent (%)											
		75.3	74.4	73.7	76.8	48.9	49.6	69.6	81.3	72.2	76.1	75.9	82.8
Width		U.S. feet											
Average		4.8	5.1	5.1	5.1	4.2	4.6	5.1	5.9	5.3	5.1	4.7	4.6
Minimum		3.5	3.7	4.0	3.9	3.7	4.0	4.4	5.1	4.1	4.2	4.2	4.1
Threshold		Percent (%)											
Average Width	3 feet	71.9	72.3	71.4	72.0	42.2	45.9	66.3	78.8	68.8	71.1	70.7	77.2
	4 feet	55.0	61.5	60.8	51.4	21.5	27.2	45.5	64.4	51.7	46.8	40.2	44.7
	5 feet	22.4	26.6	29.4	31.6	9.4	11.8	26.4	40.7	26.3	25.8	18.5	18.4
	6 feet	9.6	13.5	14.1	16.4	4.5	5.4	14.8	30.2	13.9	13.6	11.7	9.5

[1] *six cities - block groups with a higher median household income and greater sidewalk availability*
[2] *six cities - block groups with a lower median household income and greater sidewalk availability*
[3] *four cities – block groups with no trend in terms of median household income and sidewalk availability*

11.1.2 Sidewalk Width

Regarding median household income and sidewalk width, we generally found wider average and minimum width measurements in the lower income areas and narrower average widths in the higher income areas. For example, when aggregating all cities as shown in Table 11.1, average sidewalk widths reach 5.2 feet (0.61 meters) in the lowest income quartile, gradually dropping to 4.8 feet (1.46 meters) in the highest income quartile. The minimum width measurements starts at 4.4 feet (1.34 meters) in in the lowest income quartile and again gradually drops to 3.8 feet (1.16 meters) in the highest income quartile.

In looking at the grouped cities, shown in Table 11.2, we see similar trends almost across the board. For example, the Group 1 (Higher Income – Greater Availability Cities) average width shows 5.3 feet (1.62 meters) in the lowest income quantile but 4.7 feet (1.43 meters) in the highest income quantile. In addition, the Group 1 (Higher Income – Greater Availability Cities) minimum width shows 4.1 feet (1.25 meters) in the lowest income quartile but 3.4 feet (1.04 meters) in the highest income quantile. The results are similar in Group 2 (Lower Income – Greater Availability Cities), but a bit less so in Group 3 (no trend). The difference between the average width and the minimum is 1.2 feet (0.37 meters) or greater in the higher income/greater availability and only 0.7 feet (0.21 meters) or greater in the lower income/greater availability. This may indicate that the cities with higher income/greater availability may have more variability in their sidewalk segment widths and cities with lower income/greater availability may have more regularity in their widths.

11.1.3 Sidewalk Infrastructure Thresholds

With respect to median household income and the sidewalk infrastructure thresholds, we generally found no trends when focused on three feet (0.91 meters) or four feet (1.22 meters) sidewalks. However, when we focus on five feet (1.52 meters) or six feet (1.83 meters) sidewalks, we tended to find a higher sidewalk infrastructure threshold in lower income areas. When aggregating all cities, as shown in Table 11.1, 31% of the sidewalk network in the lowest income quartile is at least five feet (1.52 meters) wide or more, on average. Yet in the highest income quartile, only 18% of the sidewalk network meets that same width threshold. Given that the sidewalk infrastructure threshold at the four feet (1.22 meters) level is about the same in each of those income quartiles, this suggests a sharper decline in sidewalk width for the highest income quartile.

Interestingly, the results are similar for the five feet (1.52 meters) and 6 feet (1.83) results when we look at the grouped cities in Table 11.2, even though we would expect Group 1 (Higher Income – Greater Availability Cities) to result in a higher sidewalk infrastructure threshold in wealthier areas. For instance, in Group 1 (Higher Income – Greater Availability Cities), 34% of the sidewalk network in the lowest income quartile is at least five feet (1.52 meters) wide or more, on average, but this drops down to 21% in the highest income quartile. Given the greater sidewalk availability in the higher income areas, this discrepancy can mainly be attributed to differences in width. The trend is remarkably similar in Group 2 (Lower Income – Greater Availability Cities) where percent of the sidewalk network is that at least five feet (1.52 meters) wide goes from 36% to 10% (lowest income quartile to highest income quartile). The trend is a bit less drastic in Group 3 (No Trend Cities), but it still drops from 28% to 22%.

11.2 Race

11.2.1 Sidewalk Availability

Regarding race and sidewalk availability, we generally found that areas with a greater percentage of non-White residents shows greater sidewalk availability. For example, when aggregating all cities, as displayed in Table 11.1, the lowest percentage of sidewalk availability (65%) comes in the block groups with the highest White population. As the percent of the non-White population increases, there is a parallel increase in sidewalk availability, eventually reaching 81% in the highest quantile.

Looking at the grouped cities in Table 11.2, that trend does not hold for Group 1 (Higher Income – Greater Availability Cities) where we see results hovering between 73 and 77% across all four quantiles. Group 2 (Lower Income – Greater Availability Cities), however, exhibits a stark difference in sidewalk availability between the lower and higher quantiles of non-White population. In the lowest two quantile categories, there is less than 50% sidewalk availability. This increases to nearly 70% in the third quantile and over 80% in the highest quantile of percent of non-White residents. Group 3 (No Trend Cities) exhibits a similar trend to the overall results but not quite as drastic of a difference.

11.2.2 Sidewalk Width

Regarding race and sidewalk width, we generally found that areas with a greater percentage of non-White residents also show slightly wider sidewalk measurements.

When aggregating all cities, as shown in Table 11.1, we found an average sidewalk width of 4.7 feet (1.43 meters) in the quartile with the smallest percentage of non-White results. Average sidewalk widths gradually increased as the percent of non-White residents increases, eventually reaching 5.2 feet (1.58 meters) wide on average in the highest quartile. Minimum sidewalk widths increased from 3.8 feet (1.16 meters) to 4.4 feet (1.34 meters) across this same spectrum.

For the grouped cities, shown in Table 11.2, this width trend is almost non-existent in Group 1 (Higher Income – Greater Availability Cities) but exacerbated in Group 2 (Lower Income – Greater Availability Cities). In Group 2, the average sidewalk width is only 4.2 feet (1.28 meters), and the minimum sidewalk width is 3.7 feet (1.13 meters) in the quartile with the lowest percentage of non-White residents. These numbers jump to an average width of 5.9 feet (1.80 meters) and a minimum width of 5.1 feet (1.55 meters) in the quartile with the highest percentage of non-White results. Interestingly, the average width trend flips in Group 3 (No Trend Cities) where average sidewalk width is 5.3 feet (1.62 meters) in areas with a higher percentage of White residents, dropping down to 4.6 feet (1.40 meters) wide in the quartile with the highest percentage of non-White results. There was no apparent trend for Group 3 with respect to minimum sidewalk width.

11.2.3 Sidewalk Infrastructure Thresholds

Regarding race and the sidewalk infrastructure thresholds, we generally found higher percentages in areas with the highest percentage of non-White residents. In terms of the aggregated city results shown in Table 11.1, as the percentage of non-White residents increase, so does the percentage for infrastructure thresholds. In addition, the percent difference between the least and most non-White populated areas gradually increases, with greater differences at the five feet (1.52 meters) and six feet (1.83 meters) sidewalks. In fact, the percentage more than doubles from 9% to 19% at the six feet (1.83 meters) width threshold. This may indicate that the wider sidewalks, such as five feet (1.52 meters) and six feet (1.83 meters), begin to highlight greater racial differences in sidewalk infrastructure in our cities.

When looking at the grouped city results shown in Table 11.2, these trends hold for Group 1 (Higher Income – Greater Availability Cities) and Group 2 (Lower Income – Greater Availability Cities), but with less and more dramatic difference respectively. For example, the sidewalk network increases from 22% to nearly 32% at the five feet threshold across the non-White resident quartiles for Group 1, and it more than quadruples from 9% to 41% for Group 2. Group 3 (No Trends Cities), however, finds opposing trends at the five feet (1.52 meters) and six feet (1.83 meters) level. In other words, these cites tend to find lower percentages for sidewalk infrastructure thresholds as the percentage of non-White residents increases.

12. CONCLUSION

With recent advances in remote-sensing technologies and spatial data, this research shows that deriving sidewalk availability and average and minimum widths to analyze sidewalk equality is feasible at the city scale. In terms of sidewalk availability, we found six cities with greater sidewalk availability in wealthier areas, six cities with greater sidewalk availability in lower income areas, and four cities with no trend. While some cities saw no apparent trend, we also generally found greater sidewalk availability in parts of our cities with a greater percentage of non-White residents. With respect to sidewalk width, lower income areas and those with a greater percentage of non-White residents tended to have wider sidewalks; however, it is worth keeping in mind that this data does not necessarily speak to sidewalk quality. We also created the sidewalk infrastructure thresholds that combine sidewalk availability and average sidewalk width to indicate how complete and compliant the sidewalk infrastructure is at various average width levels. When focused on narrower sidewalks, there were no apparent trends with respect to income. However, at widths greater than five feet (1.52 meters), we found better sidewalk infrastructure in lower income areas. Surprisingly, this also turned out to be the case in our cities where higher income areas had greater sidewalk availability. In general, we also found higher percentages for complete and compliant sidewalk infrastructure in areas with a higher percentage of non-White residents; yet, this relationship unfortunately flipped in one group of cities where we found lower percentages for complete and compliant sidewalk infrastructure as the percentage of non-White residents increases.

While these results suggest economic and racial sidewalk infrastructure disparities that should be considered more closely, they could also be representative of lower income and/or non-White populations living closer to commercial land uses or along arterial roadways where wider sidewalks are recommended in guidelines (AASHTO, 2018; ITE, 2010). It is also worth noting that this result does not control for sidewalk quality, annual average daily traffic (AADT), speed limit, or roadway classification. In other words, the pedestrian infrastructure in a neighborhood with many wide, high traffic, fast arterials that happen to have five feet (1.52 meters) wide sidewalks is not necessarily better than a neighborhood with slow, low traffic, residential streets with four feet (1.22 meters) wide sidewalks. Future research should account for these issues. Future research may also want to control for land use, the location of the central business district, and the age of housing as well as look to combine income and race variables to uncover additional trends. Moreover, including sidewalk obstruction spatial data when measuring sidewalk width in future research would provide a more accurate clear width measurement and indication of sidewalk width compliance with the ADA as well as national and federal guidelines (Coppola & Marshall, 2021).

When we dig deeper into the cities themselves, it is interesting to note that three study cities from the state of New York all resulted in greater sidewalk availability in areas with lower incomes. Also, four out of the five study cities in Colorado suggested greater sidewalk availability in areas with higher incomes. These results warrant future research and could be indicative of city or county policies that may impact sidewalk availability. Some cities, for example, take responsibility for the maintenance of sidewalk infrastructure while others put that onus on the adjacent property owners. Thus, one might expect that Group 1 (Higher Income – Greater Availability Cities) would be more likely to place that responsibility on the adjacent property owner; yet five out of the six cities in Colorado seem to take on that responsibility. One might also expect that Group 2 (Lower Income – Greater Availability Cities) would be less likely to put that one on the property owner, but four of the six cities in New York and Illinois mostly do so (Peoria, IL, takes on 80% of that responsibility). These trends suggest that lower income areas tend to have more sidewalk availability when it is their responsibility and that greater sidewalk availability in higher income areas does not seem to be a function of cities placing that burden onto lower income folks. Even for Group 3 (No Trend Cities), it would make sense for them to be mostly municipal responsibility, but three out of four cities put most of the onus on the adjacent property owner (although Hartford, CT, has recently changed to municipal responsibility). Either way, sidewalk infrastructure policies regarding municipal versus adjacent property owner responsibility is an area worthy of future research.

This paper presents the use of remotely sensed spatial data as a supplement or alternative to field-based data collection of sidewalk characteristics, particularly with respect to collecting sidewalk availability and average/minimum width measures at a city scale or larger. This work also contributes to the massive data gap in sidewalk research and will assist city pedestrian planning efforts pertaining to sidewalk infrastructure and equality.

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