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# Equity Evaluation of Residents' *Transit+Walk* Accessibility to Sacramento Healthcare Facilities

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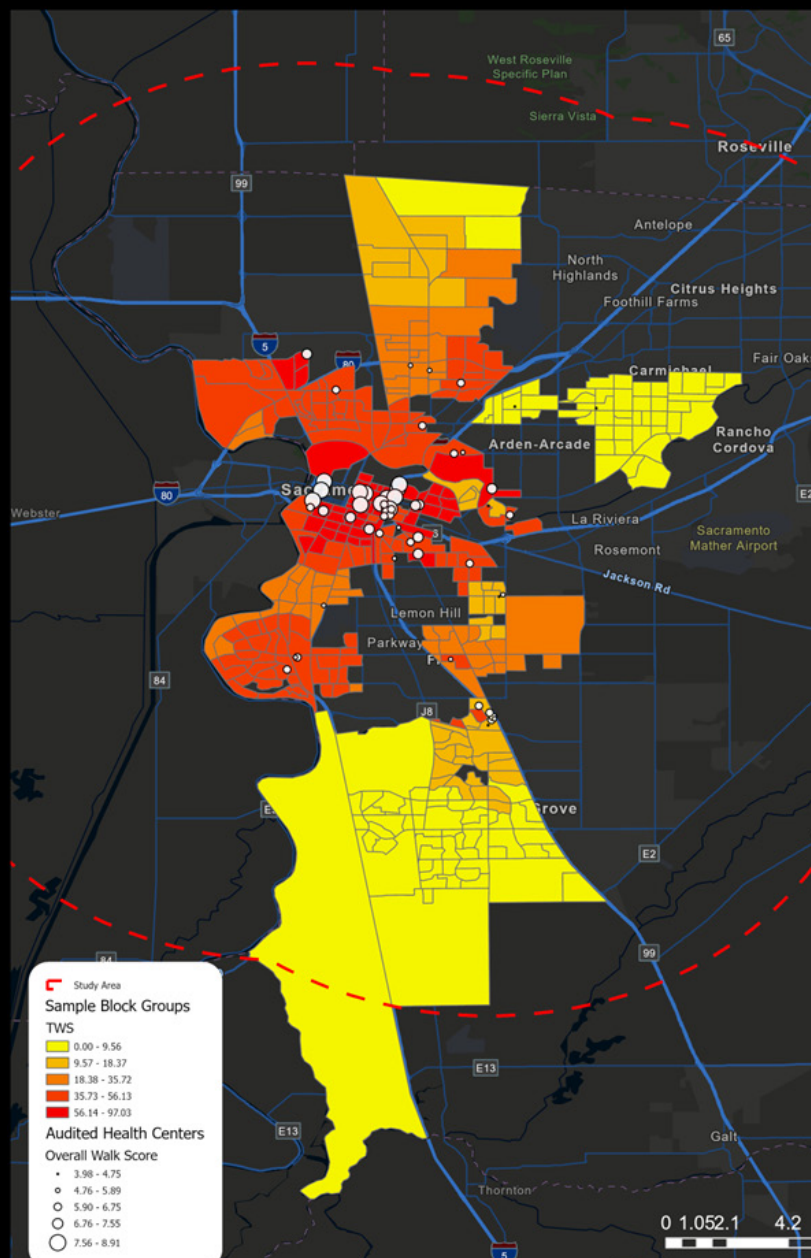


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**16. Abstract**
Access to healthcare is a key component of public health equity, yet many U.S. communities remain dependent on private vehicles for medical travel. This study introduces an integrated framework, the *Transit+Walk Score* (*TWS*), to evaluate how effectively residents of Sacramento, California, can reach healthcare facilities via public transit and how safely, comfortably, and conveniently they can walk from transit stops to those facilities. The research aims to inform planners, transit agencies, and policymakers in designing equitable and multimodal transportation systems. The research team combined geospatial network modeling and field-based walkability audits to assess 123 healthcare facilities across Sacramento, with 56 sites selected for detailed evaluation using the Pedestrian Environment Data Scan (PEDS) tool. The *TWS* integrated modeled transit travel times with on-the-ground walkability data to identify areas of high and low accessibility. Findings revealed that Downtown, Midtown, and East Sacramento exhibited the highest multimodal accessibility, while northern Arden-Arcade and outer suburban areas demonstrated the lowest. Educational attainment emerged as the strongest predictor of accessibility, highlighting structural inequities in pedestrian and transit infrastructure. The study concludes that equitable healthcare access requires both reliable transit and safe, continuous pedestrian networks. The *TWS* offers a scalable, data-driven tool to guide future investments that advance health equity, sustainable transportation, and inclusive community design.


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# Executive Summary

This study presents the first comprehensive assessment of walkability and transit accessibility to healthcare facilities in Sacramento, California. It introduces an integrated framework, the *Transit+Walk Score* (*TWS*), to evaluate how efficiently residents can reach healthcare centers via public transit and how safely, comfortably, and conveniently they can navigate the final walking segment from transit stops to these facilities. The research addresses critical equity and mobility questions by combining spatial modeling, field-based audits, and socioeconomic analysis.

The study analyzed 123 healthcare facilities across Sacramento and conducted detailed walkability audits at 56 representative sites using the Pedestrian Environment Data Scan (PEDS) tool. Transit accessibility was modeled using open-source geospatial methods (OSMnx, GTFS, and NetworkX), enabling precise calculation of travel times and pedestrian network conditions. These data were combined into the *TWS* composite index, a 0–100 scale integrating transit efficiency and pedestrian environment quality, to identify areas of high and low multimodal accessibility.

The walkability audit results show moderate overall scores (average 6.66/10), with safety/security being the most critical challenge. While sidewalks and crossings are generally present, the lack of lighting, landscape buffers, and pedestrian amenities diminishes comfort and perceived safety/security. Many healthcare facilities require walking through parking lots rather than offering street-facing entrances, underscoring persistent car-oriented development patterns.

Combining walkability and transit access results reveals apparent spatial clustering in accessibility. The highest *TWS* values are concentrated in Downtown, Midtown, East Sacramento, Oak Park, and Land Park, where dense transit networks, connected street grids, and compact land uses foster multimodal travel. In contrast, northern Arden-Arcade, South Sacramento, Natomas, and peripheral suburban and rural communities exhibit substantially lower scores due to longer transit travel times, fragmented sidewalks, and automobile-oriented design.

Socioeconomic analysis using Random Forest regression indicates that educational attainment is the strongest predictor of walkability and *TWS*, followed by income and ethnicity. Areas with higher education and income levels tend to have better multimodal access, while neighborhoods with larger Hispanic populations often face lower accessibility, highlighting structural inequities in urban infrastructure distribution.

From a policy perspective, the *TWS* framework offers a replicable, evidence-based tool to guide equitable investment. State and local agencies can use these findings to prioritize improvements in lighting, sidewalk continuity, crosswalk safety/security, and last-mile connections, especially in underserved communities. Integrating this framework into state initiatives, such as the Sustainable Communities Strategies (SB 375) and Active Transportation Program (ATP), can ensure that transportation and health equity objectives advance together.

Ultimately, this research demonstrates that transit connectivity and walkability must be planned as an integrated system. The *TWS* provides a scalable approach to assess and enhance multimodal access to essential services, supporting California's broader goals for sustainability, equity, and public health.

# 1. Introduction

## 1.1 Background

A visit to nearly any healthcare facility in the United States reveals a defining feature of the American built environment: expansive parking lots. These large paved spaces are not merely incidental; they are foundational to how such facilities are planned, accessed, and experienced. This observation reflects an underlying transportation reality: The overwhelming majority of healthcare-related trips in the U.S. are made by private automobiles. For example, a recent study suggested this number to be as high as 94% (Labban et al., 2023). However, as Owen et al. (1999) argue, this auto-centric model raises an important contradiction: if healthcare institutions exist to promote health and well-being, should we not also consider the health implications of the ways in which people reach them? Specifically, what if the act of accessing healthcare itself could support healthier behavior, such as walking, even for short segments of the trip? Framing healthcare access not solely as a logistical challenge but also as a public health opportunity invites a broader, more proactive approach to how mobility and health intersect (Frank et al., 2005; Sallis et al., 2012).

Another important concern is the situation of individuals who lack access to, or are unable to use, personal vehicles to reach healthcare facilities for their routine medical needs. The U.S. Department of Transportation identifies "expanding access" as one of the four key focus areas in its 2022 Equity Action Plan (U.S. Department of Transportation, 2022). "Expanding access" aims to enhance social and economic opportunities for disadvantaged and underserved communities by providing affordable, multimodal transportation options. One major challenge highlighted in this focus area is the lack of access to key destinations, including healthcare centers, for transportation-disadvantaged individuals. Evidence shows that populations such as low-income individuals, people with disabilities, older adults, and communities of color face substantial difficulties in securing reliable transportation for essential mobility needs, including healthcare access. For instance, a recent study found that 5.8 million people in the U.S. delayed medical care due to transportation issues (Wolfe et al., 2020). The study noted that Hispanic individuals, those living below the poverty line, Medicaid recipients, and people with functional limitations were more likely to encounter transportation-related barriers (Wolfe et al., 2020). Additionally, a meta-study reviewing 61 studies on this topic confirmed that transportation barriers significantly hinder healthcare access, particularly for individuals with lower incomes or inadequate insurance coverage (Syed et al., 2013).

While public transit could serve as a reliable option for disadvantaged communities, particularly in rural areas and small towns, these populations often face challenges such as outdated infrastructure, irregular service, and routes that do not adequately connect them to essential services, including healthcare centers (Mattson & Molina, 2022). As a result, these populations bear a disproportionately high cost of travel. Data show that the lowest-income households spend, on average, 37% of their after-tax income on transportation, compared to 19% for middle-income and

11% for high-income households (U.S. DOT Equity Action Plan, 2022). Therefore, an equitable "expanding access" strategy must account for the specific factors influencing a community's ability to access public transit and connect to essential services, such as healthcare.

By understanding the transportation needs of transportation-disadvantaged individuals, policymakers can better assess and implement the necessary interventions to create a transportation network that is truly equitable and accessible for all populations. However, as explained earlier, accessibility to public transit is just one component of a multi-modal mobility framework. Public transit and active transportation modes, such as walking, are often complementary, as walking typically makes up the first and last segments of any transit trip (Malekafzali, 2009). Therefore, while public transit accessibility is crucial for promoting equitable access, it must be considered alongside the quality of walking infrastructure. The accessibility and walkability of the areas surrounding transit stops are essential factors in determining whether individuals, especially those from disadvantaged communities, can effectively access necessary services, especially healthcare.

Enhancing both transit coverage and the pedestrian environment can significantly impact healthcare access decisions for disadvantaged communities. Therefore, the current project contributes to equitable "expanding access" planning by (1) analyzing the spatial accessibility of residential areas in Sacramento, CA, to public transit routes that connect to healthcare centers, and (2) auditing the walkability from transit stations to these healthcare facilities.

### 1.2 Project Objectives

The current project focuses on developing a first-of-its-kind multimodal accessibility score, combining residents' transit access to a transit stop of the nearest healthcare facility and the walkability of the stop to the healthcare facility. This score, called *Transit+Walk Score* (*TWS*) hereafter, then allows us to evaluate the multimodal accessibility of healthcare facilities through the non-auto options of public transit and pedestrian connecting routes in Sacramento, CA.

The following research questions (RQs) guide this study:

- RQ #1: How walkable are the Sacramento healthcare centers' surrounding areas (i.e., including a physical buffer to the nearest mass transit station)?
- RQ #2: Is there any significant spatial inequity/disparity regarding RQ #1 walkability with respect to socioeconomic attributes?
- RQ #3: How accessible are healthcare centers via public transit?
- RQ #4: How accessible are healthcare centers when combining transit accessibility (RQ #3) and walkability (RQ #2)?

- RQ #5: Is *Transit+Walk* accessibility (RQ #4) equitable for transit-dependent and non-transit dependent populations and residents living in urban areas vs. those in rural areas?

Although this study concentrated on healthcare facilities within the City of Sacramento, the analysis of transit accessibility was expanded to include the entire Sacramento County. This broader scope allows for a more comprehensive evaluation of travel suitability to various healthcare facilities, especially for residents in suburban areas.

# 2. Literature Review

This chapter examines the intersection of transportation and healthcare access, with a particular focus on how mobility constraints influence health outcomes. It synthesizes existing research on transportation barriers to healthcare, the role of public transit and last-mile connectivity, the influence of walkability and the built environment, and the implications of equity and environmental justice in mobility. By critically examining these strands of literature, the review highlights both the progress made in understanding transportation-related healthcare access and the persistent gaps that motivate the present study.

## 2.1 Transportation and Healthcare Access

While transportation is not typically at the forefront of discussions regarding healthcare, it plays a significant role in accessing healthcare and achieving positive health outcomes. As mentioned in the Introduction, a national survey conducted in 2017 in the United States found that 5.8 million people delayed getting medical care due to a lack of transportation (Wolfe et al., 2020). As a result, a key focus for many studies has been access to healthcare without a personal vehicle. Not owning a personal vehicle leaves few common options such as bicycling, walking, and taking public transportation.

Public transportation is an important mode to consider, as it allows someone to travel larger distances than walking or bicycling with little to no effort. This is a key consideration for someone who is physically impaired or elderly and may have mobility issues. A study examining the relationship between public transportation and healthcare accessibility found that individuals in more vulnerable census tracts had less access to healthcare facilities via public transportation (Alam et al., 2023). This study highlights the need not only for public transportation to exist, but also for it to be equitably accessible.

Even when a public transportation system is present, other challenges may still exist in last-mile connectivity. Last-mile connectivity refers to the walk from the origin point to the transit stop and the walk from the transit stop to the destination. A 2022 study specifically examined the prevalence of challenge in last-mile connectivity in suburban contexts. It found that many barriers exist to improving the last-mile connectivity, including a lack of funding to create sidewalks and paths, coordination issues with the various jurisdictions, and automobile-oriented planning and sprawl (Braun et al., 2022). The main conclusions showed that while many agencies are aware of the issue of last-mile connectivity, it is still a very persistent issue that pedestrians are actively facing.

While several studies have explored the importance of healthcare accessibility through public transit and the lack of last-mile connectivity often associated with public transit, there appears to be no current research that ties these concepts together. Last-mile connectivity to healthcare is critically important, as barriers within this last mile can be the difference between someone receiving critical healthcare or not.

## 2.2 Walking and the Built Environment

Walkability is a term associated with the conditions present at and surrounding the pedestrian environment. Many studies on the topic emphasize the inherent complexities of measuring walkability. One study sought to narrow it down to what it called the "DMA," or density, mix, and access of a region (Dovey & Pafka, 2020). The authors argued that having many people together with a variety of locations to visit and good access conditions led to a more walkable place. While this gives a broader view of walkability, the purpose of the present study is to focus most on the "access" category of walkability, specifically to healthcare facilities.

It is well established that the quality of the paths surrounding an area has a large influence on its walkability (Lam et al., 2022). The built environment of suburban regions is most notable for discouraging walking in favor of driving, typically alone (Ewing & Cervero, 2001). This can further reduce the walkability of an environment, as pedestrian-vehicle interactions are among the most stressful for pedestrians to navigate (Suarez-Balcazar et al., 2020).

It is also important to establish objective and subjective measures of walkability, as one study found that 32.1% of residents in objectively highly walkable areas perceived walkability as low, and 32.7% of residents in objectively low walkable areas perceived walkability as high (Gebel et al., 2009). Some commonly used objective measures of sidewalk walkability include the presence of obstacles, sidewalk width, types and presence of crossing facilities, protective buffers, shading, seating, vehicle volume, and diversity of the streetscape (Gao et al., 2022). The presence and quality of these different variables can be combined to form an overall walkability score. The Pedestrian Environment Data Scan (PEDS) tool is one example that provides a framework for this scoring (Clifton et al., 2007). PEDS is further discussed in the Methodology chapter.

## 2.3 Equity and Environmental Justice in Mobility

An emerging focus of walkability is its relationship to equity. A 2024 study examined the changes in walkability for a region over time, as well as their correlation with equity and social justice. This study concluded that "increased racial and social justice disparities were observed in access to more walkable infrastructure by marginalized populations" (Frank & Wali, 2024, p. 1). The study also observed heterogeneity within the distribution of walkability relative to similar sociodemographic factors. This ties into larger themes about transportation equity, as seen in a study from 2021 which discussed the unequal distribution of transportation systems as well as what should be guiding principles for building a more equitable future (Pereira & Karner, 2021).

## 2.4 Conclusion

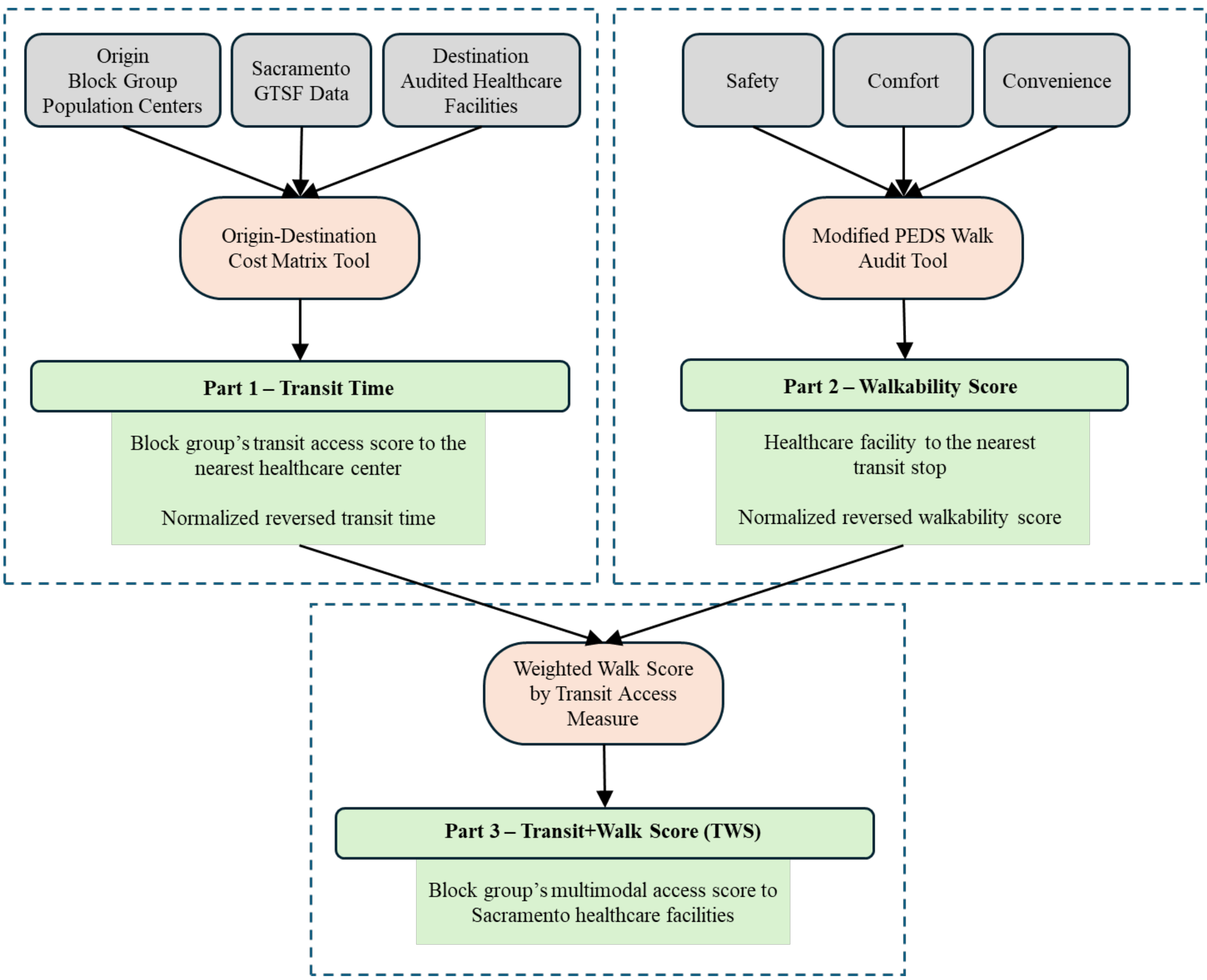
As explained in the literature review, there is much existing research into the connection between transportation and healthcare. When people are unable to access healthcare, they lose the opportunity to participate in it and, consequently, experience worse health outcomes. This affects those who do not own a personal vehicle and are required to utilize alternative modes of transportation. Public transit accessibility and walkability are key considerations for this group. While these issues have been studied in isolation, no study has sought to find the direct connection between public transit and walkability to access healthcare facilities. This study seeks to address the existing gap in knowledge at the intersection of transportation and healthcare.

# 3. Methodology

## 3.1 Methodological Framework

Our method consists of three major components (as shown in Figure 1) for developing a *Transit+Walk Score* (*TWS*) to the nearest healthcare facilities within the study area.

Figure 1. Methodological Framework for Developing a Multimodal *Transit+Walk Score* (*TWS*) to Healthcare Facilities




## 3.2 Study Area and Case Selection

Sacramento is the capital of California and home to a diverse population. According to the U.S. Census Bureau, 29.4% of Sacramento's population identifies as Hispanic or Latino, 19.5% as Asian, and 12.6% as Black or African American. Additionally, 14.8% of the city's population lives in poverty ("U.S. Census Bureau," n.d.). The National Equity Atlas ranks Sacramento 114th among the 150 largest U.S. metropolitan areas, indicating significant racial disparities ("National

Equity Atlas," 2024). Choosing Sacramento as a case study allowed us to investigate the current conditions faced by transportation-disadvantaged populations. Additionally, Sacramento's diverse landscape facilitated a comparison of public transit accessibility in both urban and rural areas, as the region includes significant urban and rural zones ("California Department of Finance," n.d.).

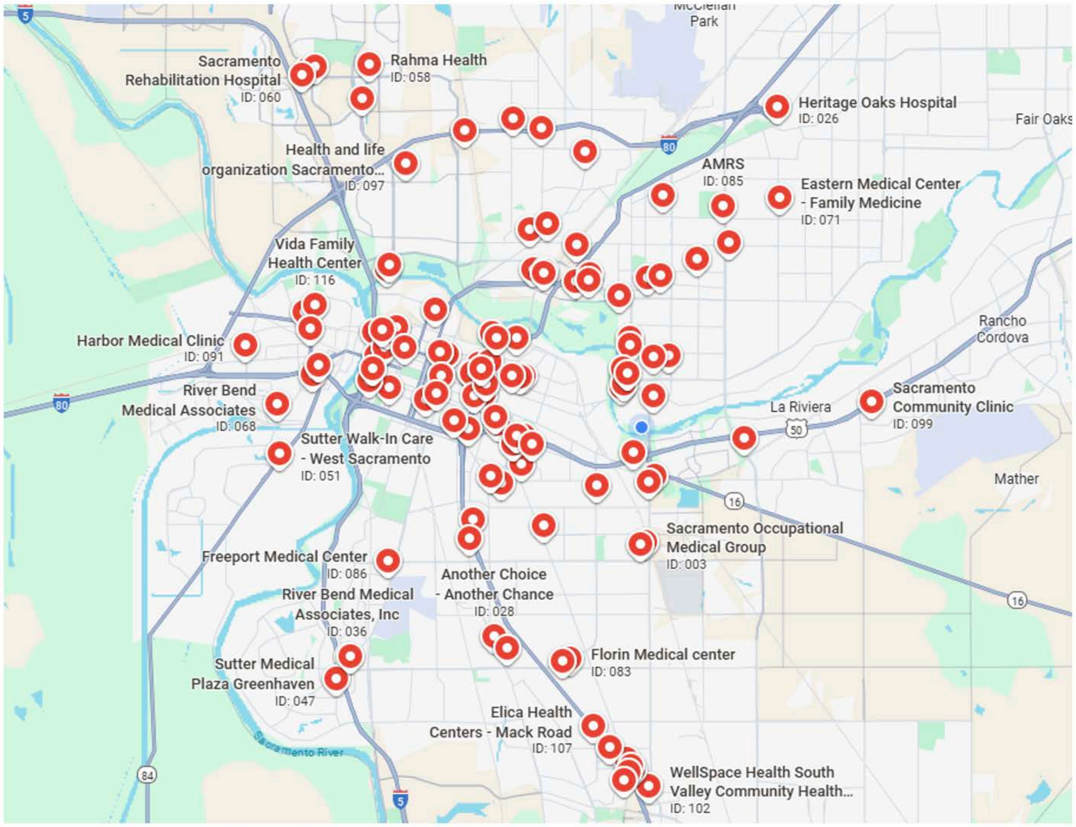
After choosing Sacramento as the study area, a stepwise approach was employed to identify relevant healthcare facilities. Initially, a comprehensive dataset was obtained using ESRI's Business Analyst tool, which provides premium data accessible to ESRI subscribers (ESRI, 2023). For the purposes of this study, we included only hospitals classified by ESRI as either General Medical and Surgical Hospitals or other Specialty Hospitals, within an expanded study area. This preliminary dataset included slightly more than 200 healthcare facilities.

Subsequently, we conducted a manual verification process using an online search to assess the operational status and public transit accessibility of each facility. Facilities that did not provide general healthcare services, such as those exclusively offering orthopedic surgical procedures (e.g., arthroplasty) or podiatry, urgent care facilities, elderly residential housing, or fitness centers, were excluded from the analysis. Additionally, when multiple healthcare services operated within the same building, only one instance of the facility was recorded to avoid duplication. This refinement reduced the dataset to 69 distinct locations.

To ensure the dataset's comprehensiveness, a supplementary round of facility identification was conducted using online searches. This effort aimed to capture any relevant healthcare destinations that may not have been included in the original ESRI dataset. Following this verification and augmentation process, the final dataset comprised 123 healthcare facilities within the study area (Figure 2). Each facility was assigned a unique identification number, and the corresponding address, website (if available), type of services offered, and the nearest public transit station were documented for each location.

We developed a comprehensive database of healthcare facilities to further support this analysis. The dataset includes each facility's name, address, website (where available), type of services offered, a unique Google Maps link, and information on the nearest transit station. This compilation, provided in the Appendix, serves as a reference for future studies and planning efforts aimed at improving healthcare accessibility and multimodal transportation connectivity across the Sacramento region. A Google Maps library containing all selected healthcare facilities was also created and is accessible via the QR code embedded in Figure 2.

Figure 2. Study Area and Selected Healthcare Facilities




Given the complex and time-intensive nature of conducting field-based walkability audits, the dataset was filtered to produce a smaller yet representative sample of healthcare facilities. Of the 123 identified healthcare facilities, 56 were selected for the walkability audit using a two-stage selection procedure. First, facilities were stratified by type of healthcare service to ensure that the audit sample was representative of the range of services present in the study area. Second, facilities were selected within each category to achieve a balanced geographical distribution across the study area, avoiding spatial clustering. Prior to conducting the walkability audits, in-person site visits were carried out to confirm that each selected facility was operational and to verify the location of the nearest public transit station used as the audit origin point.

Table 1. Summary Table of Healthcare Centers

| Type | Sample Size | Selected for Walkability Audit |
|---|---|---|
| Hospital[a] | 13 | 6 |
| Primary Care Clinic[b] | 16 | 7 |
| Specialty Medical Clinic[c] | 45 | 20 |
| Outpatient Medical Center (Primary and Specialty)[d] | 10 | 5 |
| Community Health Center[e] | 39 | 18 |
| Total | 123 | 56 |

[a] A hospital is a licensed healthcare facility that provides a wide range of diagnostic, therapeutic, and surgical services, including inpatient and emergency care. Hospitals typically offer 24/7 acute care for individuals with serious or life-threatening conditions and may include specialty departments such as surgery, intensive care, and maternity services.

[b] A primary care clinic is an outpatient facility that serves as the first point of contact for patients seeking routine medical care. These clinics typically provide services such as annual physicals, preventive screenings, chronic disease management, and treatment for common illnesses and injuries. Providers often include family physicians, internists, pediatricians, and nurse practitioners.

[c] A specialty medical clinic focuses on the diagnosis, treatment, and management of specific health conditions or medical fields, such as cardiology, dermatology, oncology, or orthopedics. These clinics are typically staffed by physicians and healthcare professionals with advanced training in a particular specialty and offer outpatient care tailored to that area of expertise.

[d] An outpatient medical center offers a variety of healthcare services, including primary care, specialty care, diagnostic imaging, and minor procedures, without requiring an overnight stay. These centers are designed for convenient, coordinated care and may house multiple providers and services under one roof.

[e] A community health center is a nonprofit, patient-centered facility that provides comprehensive primary and preventive care, often including behavioral health, dental, and specialty services, to medically underserved populations. Many are Federally Qualified Health Centers (FQHCs), offering care regardless of a patient's ability to pay.

## 3.3 Transit Access

This study employed an integrated geospatial and network-based methodology to evaluate accessibility between population centers and healthcare centers in Sacramento, CA. The analysis was conducted in Python, leveraging a suite of open-source libraries designed for spatial data processing and multimodal network modeling.

OpenStreetMap (via OSMnx) served as the foundation for constructing the pedestrian street network, enabling the representation of realistic walking connections that constitute the first-mile access to the transit system. This ensured that population centers were appropriately linked to the nearest points of entry into the regional public transport network. Public transit data were incorporated through the General Transit Feed Specification (GTFS), which was processed using

Partridge to extract valid weekday service schedules and stop-to-stop connections. Transit stops consisted of light rail and bus stops, and the analysis included only fixed-route transit services, excluding alternatives such as paratransit and microtransit. These data were used to construct a directed transit graph in which travel times were derived from scheduled arrival and departure information. The integration of OSM-based pedestrian infrastructure and GTFS-based transit services allowed us to capture both walking and in-vehicle mobility components within a unified analytical framework.

The multimodal network was operationalized in NetworkX, where different edge types reflected the corresponding travel modes: Walking edges were weighted by distance-based travel times, and transit edges were captured in-vehicle travel times. GeoPandas was used to manage and spatially align the input data, including population center and hospital locations. Once the network was assembled, Dijkstra's shortest-path algorithm, a graph-based method for finding the fastest route between nodes, was applied to calculate the minimum travel times from each population center to the nearest healthcare center, subject to a defined time threshold. Results were subsequently disaggregated into first-mile access times (walking to transit) and total transit travel times, providing a detailed evaluation of transit level of service and access quality.

### 3.4 Walkability Audit

In line with the study's objectives, we utilized the Pedestrian Environment Data Scan (PEDS), a peer-reviewed and validated audit tool developed by Clifton et al. (2007). PEDS is designed to assess walkability by capturing various aspects of the built, social, and natural environment related to non-motorized activity. The audit includes questions grouped into four sections: (a) Environment (macroscale), (b) Pedestrian Facility, (c) Road Attributes, and (d) Walking/Cycling Environment (microscale). The PEDS audit tool also includes a subjective evaluation of the attractiveness and safety/security of street segments. There are several advantages to using PEDS. It is a free tool, and the developers have provided a comprehensive implementation protocol, which was invaluable for training auditors to conduct consistent reviews. Additionally, PEDS has been widely adopted in recent literature, allowing us to benefit from extensive prior experience in this field (Rigolon et al., 2018).

Data collection began with a comprehensive training session that reviewed the questions presented within the PEDS tool. This training session gave clear and concise direction on some of the more subjective questions within the audit tool, such as path condition and tree cover (see Section 4.2 for a complete list of questions). While the very best and worst condition paths were easy to categorize, it was important to ensure there were standards for deriving what a "fair" condition path was and how it was differentiated from a path in "poor" condition. This training gave clear examples of each of these to remove any subjectivity from the observations.

Field data collection began within a week of the training, starting with a pilot day to ensure that the audit was being conducted in an objective manner. This provided an opportunity to further identify any potential issues with the audit that may arise in the field. One issue that arose quickly was how to handle parking lots during the audit. The PEDS audit tool covers only general characteristics of a corridor, but access to a particular building was important for this study. To assess the potential impact of parking lots on pedestrian accessibility to healthcare facilities, four additional questions were incorporated at the end of the walkability audit. These questions were designed to capture key aspects of parking lot design and visibility that may influence walkability. Specifically, the questions addressed the following:

- Whether a pedestrian must walk through a parking lot to access the facility (Yes/No)
- Whether the facility is visible from the sidewalk (Yes/No)
- The primary mode of access through the parking lot (Pedestrian Path/Roadway/Trail/Not Applicable)
- The condition of the access route through the parking lot (Poor/Fair/Good/Not Applicable)

Following the completion of the training and audit design, data collection was carried out over a six-week period from May 20, 2025, to July 6, 2025. Each walking route was traversed twice: the first pass was used to become familiar with the route and to video record the environment for potential verification or secondary analysis, while the second pass was dedicated to conducting the walkability audit.

Routes were divided into segments based on changes in the roads walked. Specifically, each time the auditor turned onto a different road, a new segment was defined to reflect the significant change in the built environment, such as transitioning from a high-volume arterial road to a local collector. In contrast, if the auditor crossed the road but continued walking along the same roadway, this was treated as a continuation of the same segment. This approach was adopted because road crossings generally did not produce substantial environmental variation, and longer routes often allowed multiple crossing points. Counting each road as a single segment ensured greater consistency and minimized variability in segment delineation.

## 3.5. Composite Index

### 3.5.1 Study Area and Selection Criteria

The analysis focused on census block groups located within the transit-accessible areas of the audited health centers. To delineate this region, block groups were selected based on transit travel distance from each health center. This study defines a 10-mile transit accessibility threshold, representing a typical 30-to-45-minute transit trip under average urban transit speeds of 10–20 mph. This benchmark aligns with established research on metropolitan transit accessibility and built environment relationships (Cervero & Guerra, 2011; Ewing & Cervero, 2010; Tomer, 2012) and reflects the practical reach of most bus and light-rail systems in U.S. metropolitan regions.

Block groups located within this 10-mile transit travel range from any audited health center were considered transit-accessible and therefore included in the study. From this subset, we further refined the sample by including only those block groups whose nearest destination in the transit-based origin–destination (OD) matrix corresponded to one of the audited healthcare centers. This criterion ensures that the modeled travel time (*Transit Time*) and the pedestrian environment variable (*Walkability Scores*) both correspond to the same real-world facility, preserving spatial consistency between transit accessibility and destination walkability.

### 3.5.2 Data and Variables

The analysis utilized a geodatabase feature class containing modeled transit travel times and walk audit data for each census block group within the study area. Two key variables were used to construct the *Transit+Walk Score* (*TWS*):

1. *Walkability Score*: a built-environment index representing the quality, safety/security, and walkability of the pedestrian environment surrounding each audited healthcare center.

2. *Transit Time*: the modeled public transit travel time (in minutes) from each block group centroid to its nearest health center, derived from a transit-based OD matrix.

Together, these two variables capture both how efficiently a destination can be reached by transit and how walkable the environment is upon arrival.

### 3.5.3 Normalization of the Walk Audit Measure

To standardize the scale of the walk audit scores and facilitate combination with other variables, the *Walkability Score* was normalized to a 0–100 scale using min–max normalization:

$$WalkAudit_{100,i} = (x_i - \min(x) \,/\, \max(x) - \min(x)) \times 100$$

Where $x_i$ is the overall walkability audit value for feature $i$, and $\min(x)$ and $\max(x)$ represent the minimum and maximum observed values in the dataset. This transformation expresses each healthcare center's pedestrian environment quality as a relative percentage of the observed range, where higher values indicate better safety/security, comfort, and convenience conditions.

### 3.5.4 Normalization and Reversal of Transit Travel Time

The *Transit Time* variable was standardized using min–max normalization and reversed so that higher scores represent greater accessibility (shorter travel times):

$$TransitAccess_{inv01,i} = 1 - \frac{(t_i - \min(t))}{\max(t) - \min(t)}$$

Where $t_i$ denotes the modeled travel time for block group $i$, and $\min(t)$ and $\max(t)$ correspond to the minimum and maximum observed travel times (0.690 and 207.490 minutes, respectively). This reversal ensures directional consistency with accessibility measures, such that values near 1.0 represent high accessibility, while values near 0.0 indicate low accessibility.

### 3.5.5 Construction of the *Transit+Walk Score* (*TWS*)

The *Transit+Walk Score* (*TWS*) was developed by integrating the normalized pedestrian environment score and the reversed transit accessibility score into a single composite measure. In this formulation, transit accessibility functions as a weighting factor for the walk audit score, ensuring that areas with shorter travel times exert greater influence on the final score. In other words, block groups with shorter transit times (high accessibility) receive weights approaching 1, while those with longer transit times (low accessibility) receive weights approaching 0, effectively reducing the contribution of walkability in locations that are difficult to reach by transit.

The *TWS* score was calculated as follows:

$$TWS_i = WalkAudit_{100,i} \times TransitAccess_{inv01,i}$$

This multiplicative structure results in a 0–100 scale index, where higher values indicate block groups that are both transit-accessible and characterized by strong pedestrian environments surrounding the healthcare center. The resulting composite measure was stored as *TransitWalkScore* in the project geodatabase.

### 3.5.6 Interpretation

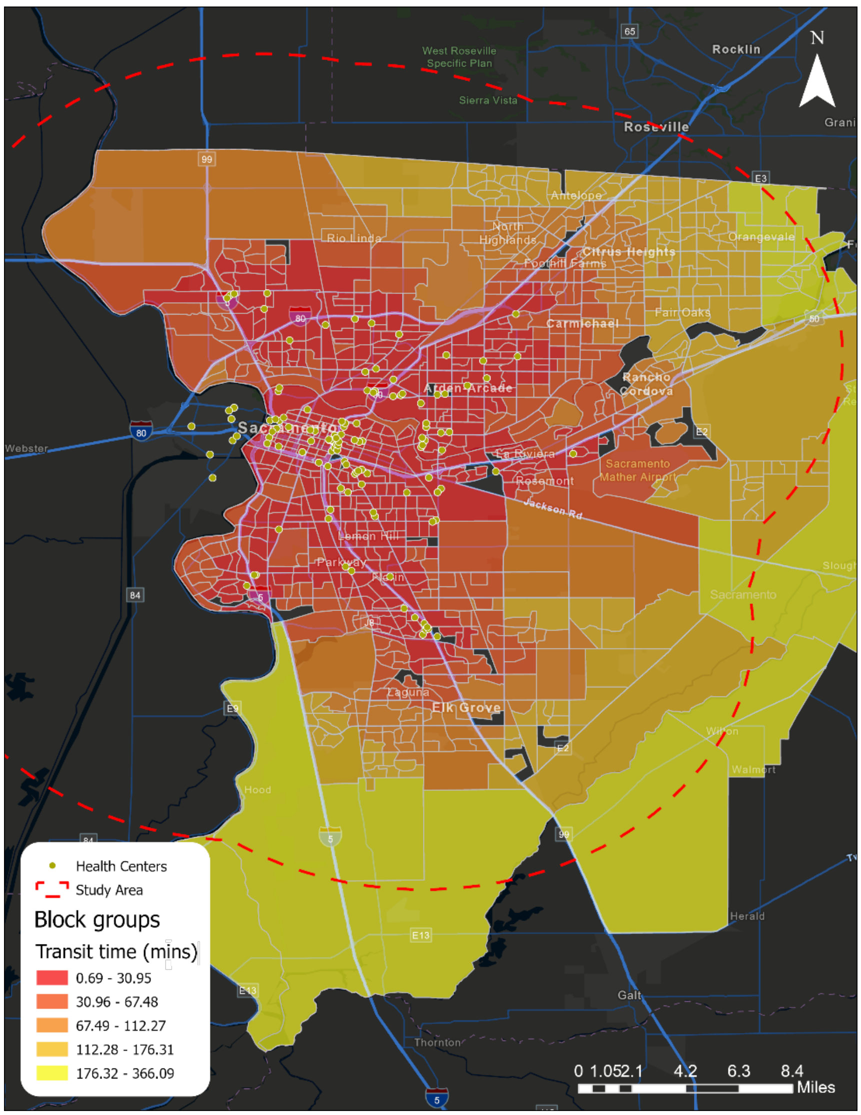
The *TWS* provides a continuous, spatially explicit indicator of transit-enabled accessibility and pedestrian readiness for essential destinations. High *TWS* values (approaching 100) represent block groups that combine shorter transit travel times with high-quality, walkable environments around the nearest healthcare centers. Low *TWS* values (approaching 0) identify block groups with both longer transit travel times and poor pedestrian conditions, highlighting potential inequities in transit and healthcare access. This composite metric provides a robust and interpretable framework for analyzing transit-linked accessibility to healthcare services and identifying neighborhoods that may benefit from targeted improvements in transit connectivity and walkability infrastructure.

# 4. Result and Discussion

## 4.1 Transit Accessibility to Healthcare Centers in Sacramento

Figure 3 illustrates block group–level transit travel times (in minutes) to the nearest audited healthcare center across Sacramento. While this study focused on healthcare facilities located within the City of Sacramento limits, transit accessibility was extended to encompass the entirety of Sacramento County. This approach enables a more comprehensive assessment of travel suitability to a diverse range of healthcare facilities, particularly for residents living in suburban areas. The 10-mile study boundary (red dashed line) defines the region of primary transit accessibility, capturing most urbanized areas within Sacramento County's service area.

Figure 3. Transit Travel Times to the Nearest Healthcare Facility



The map highlights substantial spatial disparities in health access when measured by transit travel time. Darker red areas indicate block groups with shorter travel times (under 30 minutes), primarily concentrated in central Sacramento, particularly around Midtown, Downtown, and East Sacramento. These areas benefit from higher public transit frequency, greater route density, and proximity to multiple healthcare centers, resulting in relatively efficient transit connections.

In contrast, lighter orange zones, spanning inner suburbs such as Natomas, Pocket and South Sacramento, and yellow zones, spanning outer suburbs such as Elk Grove and Citrus Heights exhibit longer travel times, in some cases exceeding 90 minutes. These patterns reflect a combination of lower service frequency, fewer direct routes, and greater physical distance from central healthcare facilities, excluding healthcare facilities not included in the study that exist outside the City of Sacramento. Many peripheral block groups rely on transfers or limited bus coverage, which substantially increases overall travel time despite relatively short straight-line distances.

A useful future extension of this study would be to address boundary effects by accounting for qualifying healthcare facilities located outside the City of Sacramento. Rather than expanding the walk audit to these suburban facilities, researchers could identify all regional healthcare centers that meet the same eligibility criteria used in the study and measure whether any census block is actually closer to an external qualifying facility than to the nearest one inside the study area. Census blocks with a nearer outside facility could then be excluded from analysis, ensuring that findings about suburban walk- and transit-based barriers reflect true accessibility challenges rather than artifacts of the study boundary.

Overall, the map underscores the centralization of healthcare accessibility and the transportation inequities faced by residents in outlying communities. It highlights the critical need to integrate transit planning with healthcare distribution, as well as investments in Complete Streets and first-mile/last-mile solutions, to improve equitable healthcare access across the studied area.

## 4.2 Walkability Audit

### 4.2.1 Scoring System

Upon completion of field data collection, walkability scores were generated for each audited segment. Table 2 presents the variables included in the scoring process, along with the associated scoring criteria. In addition to incorporating new variables introduced in the previous chapter, certain variables were excluded, consistent with prior studies utilizing the PEDS tool, because they did not directly reflect walkability conditions along the route from a transit stop to a healthcare facility. Each variable in the scoring system was evaluated on a scale from 0 to 1, with 1 representing the most favorable walking condition.

The variables were grouped into three categories: Safety/Security, Comfort, and Convenience. These categories were assigned weights of 55%, 20%, and 25% respectively, in the overall walkability score. Safety/Security was given the highest weight based on field observations in the Sacramento area, where safety/security concerns frequently appeared to be the primary deterrent to walking, outweighing considerations of comfort and convenience. It also aligns with previous efforts that underscore the importance of assigning different weights to walkability components, with safety/security receiving the highest emphasis, accounting for more than half of the overall walkability score (Ruiz-Padillo et al., 2018). Each category comprised 10 variables. Therefore, after applying the designated weights, the overall walkability score for each segment was calculated on a scale from 0 to 10.

Table 2. Variables in the Modified PEDS Tool and Scoring System

| **Part A – Safety/Security (55% of total walkability score)** | | |
|---|---|---|
| A1 | Sidewalk Continuity | Continuous (1); Not continuous (0) |
| A2 | Number of Lanes to Cross | No lanes to cross (1); One or more lanes (0) |
| A3 | Posted Speed Limit | <25 mph (1); 25–35 mph (0.5); >35 mph or unposted (0) |
| A4 | Crosswalks & Crossing Aids | No crosswalks (1); Crosswalks + stop sign (0.5); Crosswalks + signal + ped signal (0.5); Any other conditions (0) |
| A5 | Lighting | Pedestrian lighting (1); Road lighting (0.5); Other or None (0) |
| A6 | What Does the Parking Lot Access Look Like | Pedestrian path (1); Otherwise (0) |
| A7 | Buffers Between Path and Road | Buffer present (1); None (0) |
| A8 | On-Street Parking | Present (1); Absent (0) |
| A9 | Presence of High-Volume Driveways | <2 (1); 2–4 (0.5); >4 (0) |
| A10 | Is Segment Safe for Walking | 1 (1); 2 (.67); 3 (.33); 4(0) |
| **Part B – Comfort (20% of total walkability score)** | | |
| B1 | Curb Cuts – Existing | Present (1); Absent (0) |
| B2 | Powerlines Along Segment | None (1); Low-voltage (0.5); High-voltage (0) |
| B3 | Does Building Require Access Through Parking Lot | No (1); Yes (0) |
| B4 | Condition of Parking Lot Access | Good (1); Fair (0.5); Poor (0) |
| B5 | Segment Type | Low volume/bike-ped path (1); High volume (0) |
| B6 | Path Material | Concrete/asphalt (1); Paving bricks (0.66); Gravel (0.33); Dirt/sand (0) |
| B7 | Distance from Curb | At edge (0); <5 ft (0.5); >5 ft (1) |

| | | |
|---|---|---|
| B8 | Overall Cleanliness & Maintenance | Good (1); Fair (0.5); Poor (0) |
| B9 | Tree Coverage | Many (1); Some (0.5); Little-to-none (0) |
| B10 | Is Segment Attractive for Walking | 1 (1); 2 (.67); 3 (.33); 4(0) |
| **Part C – Convenience (25% of total walkability score)** | | |
| C1 | Can You See Building from Sidewalk | Yes (1); No (0) |
| C2 | Slope | Flat (1); Slight (0.5); Steep (0) |
| C3 | Path Condition | Good or under repair (1); Moderate (0.5); Poor (0) |
| C4 | Path Obstructions | None (1); Garbage cans/Greenery (0.5); Cars/Poles (0) |
| C5 | Sidewalk Width | <4 ft (0); 4-8 ft (0.5); >8 ft (1) |
| C6 | Building Setbacks from Sidewalk | At edge (1); Within 20 ft (0.5); >20 ft (0) |
| C7 | Types of Pedestrian Facilities (Existing) | Sidewalks/Pedestrian streets (1); Paved trail (0.5); Footpath (0) |
| C8 | Bus Stop Quality | Shelter (1); Bench (0.5); Sign only or none (0) |
| C9 | Wayfinding Aids Present | Yes (1); No (0) |
| C10 | Amenities | Each Amenity (+0.25) |
| **Part D – Variables Excluded from Scoring** | | |
| | Uses in segment, Segment intersections, Sidewalk connectivity, Road condition, Off-street parking, Parking lot general access, Traffic control devices (scored within crosswalks), Bike facilities, Degree of enclosure, Articulation in building design, Building height | |

### 4.2.2 Walkability Scores

As shown in Table 3, the walkability audit revealed a range of conditions affecting pedestrian access from transit stops to healthcare facilities in Sacramento. Overall, the average walkability score across all segments was 6.66 out of 10, indicating a moderate level of walkability. However, considerable variation was observed across the three main categories of assessment (Safety/Security, Comfort, and Convenience), with safety/security emerging as the most critical challenge.

Table 3. Walkability Audit Scores

| | Variable | Min | Max | Mean | Median | Standard Deviation |
|---|---|---|---|---|---|---|
| A1 | Sidewalk Continuity | 0.00 | 1.00 | 0.91 | 1.00 | 0.28 |
| A2 | Number of Lanes to Cross | 0.00 | 1.00 | 0.72 | 1.00 | 0.45 |
| A3 | Posted Speed Limit | 0.50 | 1.00 | 0.75 | 0.75 | 0.25 |
| A4 | Crosswalks & Crossing Aids | 0.00 | 1.00 | 0.77 | 1.00 | 0.30 |
| A5 | Lighting | 0.00 | 1.00 | 0.59 | 0.50 | 0.28 |
| A6 | What Does the Parking Lot Access Look Like | 0.00 | 1.00 | 0.82 | 1.00 | 0.39 |
| A7 | Buffers Between Path and Road | 0.00 | 1.00 | 0.45 | 0.00 | 0.50 |
| A8 | On-Street Parking | 0.00 | 1.00 | 0.41 | 0.00 | 0.50 |
| A9 | Presence of High-Volume Driveways | 0.00 | 1.00 | 0.92 | 1.00 | 0.21 |
| A10 | Is Segment Safe for Walking | 0.00 | 1.00 | 0.52 | 0.67 | 0.27 |
| | Safety/Security (0–10) | 3.00 | 10.00 | 6.71 | 6.67 | 1.61 |
| B1 | Curb Cuts – Existing | 0.00 | 1.00 | 0.46 | 0.00 | 0.50 |
| B2 | Powerlines Along Segment | 0.00 | 1.00 | 0.82 | 1.00 | 0.27 |
| B3 | Does Building Require Access Through Parking Lot | 0.00 | 1.00 | 0.66 | 1.00 | 0.48 |
| B4 | Condition of Parking Lot Access | 0.00 | 1.00 | 0.92 | 1.00 | 0.23 |
| B5 | Segment Type | 0.00 | 1.00 | 0.20 | 0.00 | 0.40 |
| B6 | Path Material | 0.66 | 1.00 | 0.99 | 1.00 | 0.05 |
| B7 | Distance from Curb | 0.00 | 1.00 | 0.49 | 0.50 | 0.49 |
| B8 | Overall Cleanliness & Maintenance | 0.00 | 1.00 | 0.88 | 1.00 | 0.28 |
| B9 | Tree Coverage | 0.00 | 1.00 | 0.31 | 0.50 | 0.29 |
| B10 | Is Segment Attractive for Walking | 0.00 | 1.00 | 0.46 | 0.33 | 0.30 |
| | Comfort (0–10) | 2.50 | 9.50 | 6.34 | 6.33 | 1.38 |
| C1 | Can You See Building from Sidewalk | 0.00 | 1.00 | 0.89 | 1.00 | 0.32 |
| C2 | Slope | 0.00 | 1.00 | 0.95 | 1.00 | 0.19 |
| C3 | Path Condition | 0.00 | 1.00 | 0.96 | 1.00 | 0.16 |
| C4 | Path Obstructions | 0.00 | 1.00 | 0.95 | 1.00 | 0.21 |
| C5 | Sidewalk Width | 0.00 | 1.00 | 0.55 | 0.50 | 0.19 |
| C6 | Building Setbacks from Sidewalk | 0.00 | 1.00 | 0.52 | 0.50 | 0.39 |
| C7 | Types of Pedestrian Facilities (Existing) | 0.00 | 1.00 | 0.96 | 1.00 | 0.17 |
| C8 | Bus Stop Quality | 0.00 | 1.00 | 0.31 | 0.00 | 0.41 |
| C9 | Wayfinding Aids Present | 0.00 | 1.00 | 0.63 | 1.00 | 0.48 |

|  | Variable | Min | Max | Mean | Median | Standard Deviation |
|---|---|---|---|---|---|---|
| C10 | Amenities | 0.00 | 0.75 | 0.10 | 0.00 | 0.16 |
|  | Convenience (0–10) | 3.50 | 8.75 | 6.81 | 7.00 | 0.94 |
|  | Overall (0–10) | 3.98 | 8.91 | 6.66 | 6.65 | 1.18 |

Within the safety/security category (weighted at 55% of the total score), sidewalk continuity and minimal presence of high-volume driveways were notable strengths, with mean scores of 0.91 and 0.92, respectively. These findings suggest that fundamental walking infrastructure is largely in place. Additionally, pedestrian-oriented parking lot access was relatively well-designed in most segments. Pedestrians primarily traveled along roadways with speed limits of 25 mph or lower and were infrequently required to cross major streets. When crossings were necessary, appropriate infrastructure, such as pedestrian signals or refuge islands, was typically present to facilitate safe passage. However, several safety-related variables scored poorly and contributed to lower overall safety/security scores ($M$ = 6.71). In particular, the lack of physical buffers between walking paths and roads ($M$ = 0.45), limited on-street parking ($M$ = 0.41), and insufficient pedestrian-scale lighting ($M$ = 0.59) were common. This further supports the fact that, while basic pedestrian facilities were typically present, there were often no additional steps taken to improve the safety/security of the segment.

As explained earlier, the PEDS tool also allows for the subjective rating of walking conditions. This means that an individual can evaluate the walking environment based on personal perceptions and lived experience. This represents an important complement to the objective measures, as subjective assessments can capture experiential qualities that influence walking behavior but may not be evident through physical infrastructure alone. The mean subjective safety/security rating (0.52 out of 1) is lower than the mean objective safety/security score (6.71 out of 10), confirming that auditors often did not perceive segments as safe/secure, which reinforces the need for targeted safety/security improvements.

The comfort category (20% of total weight) had an average score of 6.34, the lowest of the three categories, highlighting how it is often viewed as an optional addition to facilities rather than a necessity. Walking surfaces were almost universally well-paved ($M$ = 0.99), parking lot access points were generally well maintained ($M$ = 0.92), and pedestrians were not required to walk next to high-voltage power lines ($M$ = 0.82). Cleanliness and general upkeep of the walking environment also scored highly. Access to the building was often available directly from the sidewalk; however, in many cases, pedestrians were required to walk through a parking lot to reach the facility ($M$ = 0.66). However, other aspects of comfort were lacking. For instance, most segments lacked designated pedestrian or low-traffic routes ($M$ = 0.20), and tree coverage was sparse ($M$ = 0.31), reducing both the visual appeal and protection from environmental conditions. Furthermore, many segments were missing curb cuts ($M$ = 0.46), posing accessibility challenges for individuals with mobility impairments.

When comparing the subjective attractiveness of the walking environment to the objective comfort score, a trend similar to that of safety/security emerges. Auditors rated subjective comfort at an average of 0.46 out of 1, while the objective comfort score averaged 6.34 out of 10, indicating that, despite moderate infrastructure, the environment was perceived as even less inviting.

The convenience category (25% of the total score) had the highest average score at 6.81, suggesting generally favorable conditions for functionality. Segments were mostly flat (*M* = 0.95), representing the general topography of the Sacramento area. Walking segments were also unobstructed (*M* = 0.95) and well-maintained (*M* = 0.96), with clear visibility of healthcare facilities from the sidewalk (*M* = 0.89). However, convenience was undermined by the poor quality of bus stops (*M* = 0.31), which often lacked benches or shelters, the near absence of pedestrian amenities such as seating and water fountains (*M* = 0.10), and a lack of appropriate wayfinding signage intended explicitly for pedestrian use. Sidewalk width and building setbacks also showed only moderate performance.

In addition to the aggregated evaluation of walking scores, detailed results from the walkability audit for each of the assessed healthcare facilities are presented in the Appendix. These include site-specific observations and tailored recommendations aimed at improving pedestrian conditions and accessibility for each facility.

#### 4.2.3 Equity Pattern of Walkability Scores

To examine how neighborhood-level socioeconomic characteristics relate to objective walkability near healthcare facilities, we employed Random Forest regression modeling. The study area includes U.S. Census block group population centers located within a half-mile radius of identified healthcare facilities in the Sacramento region. Each population center was spatially joined to the nearest facility, and its associated walkability score was derived from the corresponding facility's audit results in 109 block groups.

Random Forest is a non-parametric, ensemble-based machine learning method that constructs multiple decision trees and aggregates their results to produce robust predictions. In this study, four separate Random Forest models were built—Safety/Security, Comfort, Convenience, and an Overall Walkability model—using normalized scores (0–10) derived from field audits and assessments. The predictors included the percentage of the population identifying as Hispanic, White, Black, or Indigenous; the percentage of households below the poverty line; median household income; and the percentage of residents with a university degree.

Table 4 shows the results of the statistical analysis using Random Forest. All models were implemented in Python using the scikit-learn library. The dataset, drawn from a half-mile buffer around healthcare facilities, was split into training and testing sets using an 80/20 split. Each Random Forest model was configured with 100 estimators (trees) and default hyperparameters to balance interpretability and performance. Model accuracy was evaluated using $R^2$ and Root Mean

Square Error (RMSE), with the best-performing model, Overall Walkability, achieving an $R^2$ of 0.389. Feature importance scores were extracted from each model to identify the most influential predictors. These results informed subsequent visualization and interpretation of equity-related patterns in pedestrian infrastructure quality.

Table 4. Summary of Random Forest Model for Walkability Scores

| Walkability Category | $R^2$ Score | RMSE | Top Predictors |
|---|---|---|---|
| Safety/Security | 0.352 | 0.192 | % of Uni Educated Pop, % of Hispanic, % of White |
| Comfort | 0.219 | 0.165 | % of Uni Educated Pop, % of Hispanic, Median Income |
| Convenience | 0.242 | 0.141 | % of White, % of Uni Educated Pop, % of Hispanic |
| Overall | 0.389 | 0.174 | % of Uni Educated Pop, % of Hispanic, % of Indigenous |

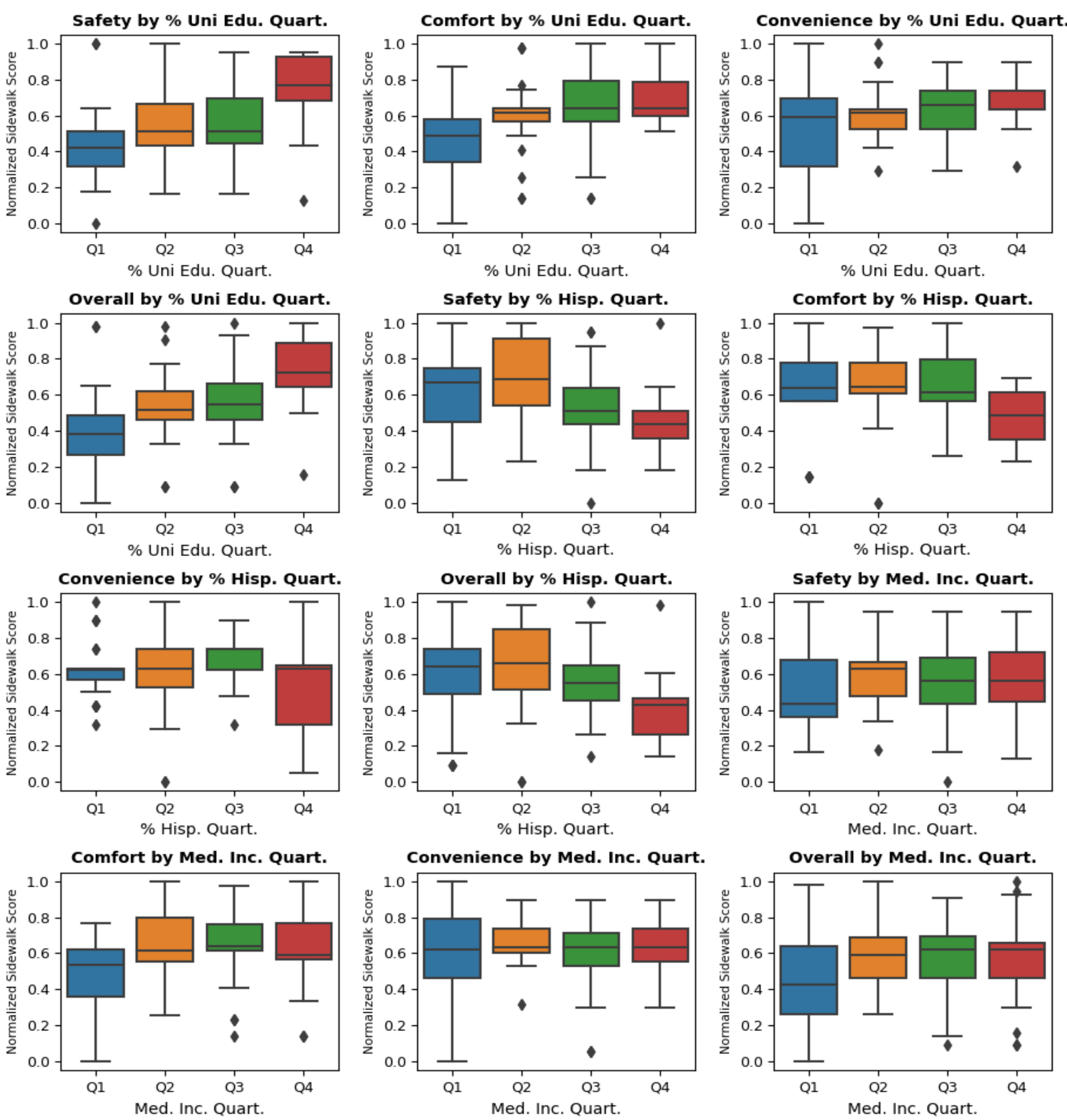
Across all models, the percentage of university-educated residents emerged as the most consistently influential predictor, suggesting that areas with higher educational attainment tend to have better walking environments near healthcare facilities. The percentage of the Hispanic population was also a strong negative predictor for Safety/Security, Comfort, and Overall Walkability, highlighting potential disparities in pedestrian infrastructure across ethnic lines. In the case of Comfort, median income played a notable role, while the percentage of the Indigenous population was particularly important for predicting Overall Walkability. The models explained between 22% and 39% of the variation in walkability scores, with Overall Walkability achieving the highest predictive accuracy. These findings underscore the importance of social equity considerations in urban infrastructure planning, particularly in walkability near essential services such as hospitals.

Figure 4 provides a critical look at how the quality of the pedestrian environment surrounding healthcare facilities in Sacramento varies based on the socioeconomic status of different neighborhoods. The chart breaks down walkability into three core pillars: Safety/Security, Comfort, and Convenience, showing how each category performs across different socioeconomic quartiles. By visualizing these metrics side-by-side, the figure highlights whether infrastructure quality—such as lighting, sidewalk buffers, and tree coverage—is equitably distributed or if certain populations are facing systemic disadvantages in accessing medical care.

The data reveal that while basic infrastructure such as continuous sidewalks and crossing aids are relatively common across the board, there are significant disparities in the features that make walking truly viable. For example, the Safety/Security category, which is weighted most heavily at 55% of the total walkability score, often scores lower in neighborhoods with higher Hispanic populations or lower income levels. These areas frequently lack pedestrian-scale lighting and physical buffers between the sidewalk and high-speed traffic, making the final "last-mile" walk from a transit stop to a clinic feel dangerous or unwelcoming.

Furthermore, the Comfort and Convenience categories in Figure 4 underscore a persistent car-oriented design that hinders equitable access. Lower socioeconomic quartiles often show a lack of "optional" amenities that are crucial for mobility-impaired or elderly residents, such as tree shading, benches at bus stops, and attractive streetscapes. By illustrating these gaps, the figure demonstrates that achieving healthcare equity requires more than just transit routes; it requires targeted investments in the pedestrian environment—specifically in lighting and safety features—within underserved communities to ensure that all residents can reach essential services with dignity.

Figure 4. Walkability Categories by Socioeconomic Quartiles

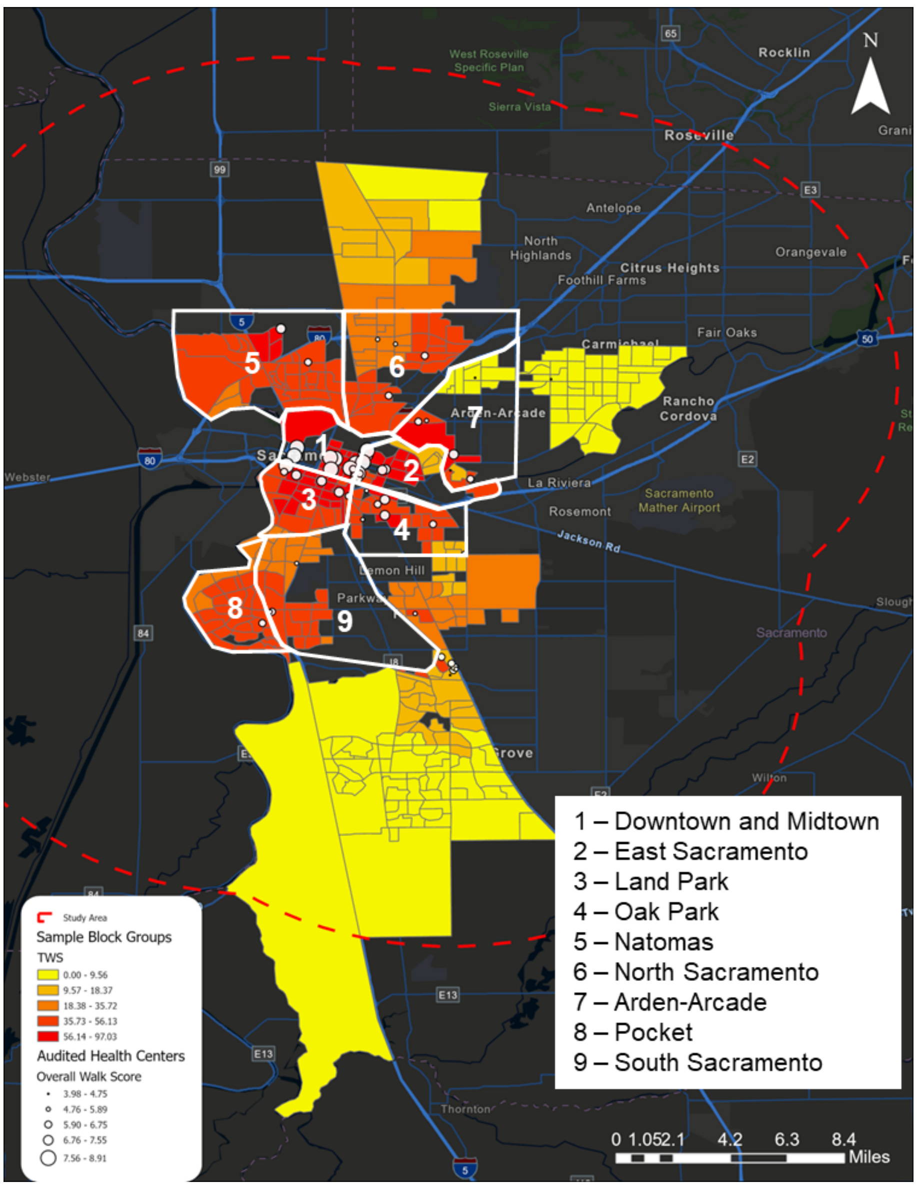


## 4.3 *Transit+Walk* Score (TWS)

### 4.3.1 *Transit+Walk Score* (TWS) Distribution in Sacramento, CA

Figure 5 presents the spatial distribution of the *TWS* across census block groups in Sacramento, CA, representing a composite index of transit accessibility and pedestrian environment quality around audited healthcare centers. The analysis focused on block groups within the 10-mile transit-accessible area of the audited facilities, corresponding to an approximate 30–45-minute transit travel range under typical urban speeds. This threshold delineates the region where access to healthcare services via public transportation is reasonably attainable for most residents.

Figure 5. Spatial Distribution of TWS



The TWS combines two critical dimensions of equitable access: (1) the Transit Access, which inversely scales travel time to the nearest healthcare center (shorter times yielding higher accessibility), and (2) the Walkability Score, which captures the quality of the pedestrian environment surrounding those destinations. Multiplying these measures allows transit accessibility to function as a weighting factor, meaning block groups closer to healthcare centers and better connected by transit systems amplify the influence of walkability in the final composite score.

To examine the spatial clustering of TWS, Sacramento was partitioned into nine principal neighborhoods, as illustrated in Figure 5. The resulting map reveals clear spatial clustering of high and low accessibility conditions. Block groups exhibiting the highest TWS values (above 55) are concentrated in central Sacramento. Notably, the Downtown and Midtown area (Region 1) and East Sacramento (Region 2) exhibited the highest TWS values. Downtown Sacramento, the city's central business district, hosts many of its key attractions, including the California State Capitol, the Sacramento Convention Center, and the Golden 1 Center. It also serves as a major hub for shopping, dining, and entertainment. Residential development in this area primarily consists of high-rise buildings.

Adjacent to it, Midtown Sacramento, located directly east of Downtown, is recognized for its tree-lined streets, historic Victorian homes, and vibrant arts and cultural scene. East Sacramento follows a similar urban and land-use pattern, characterized by mixed-use development and pedestrian-friendly street design. The presence of California State University, Sacramento, in this region has further promoted initiatives to improve accessibility to public transit, as well as walking and bicycling networks in and around the campus.

The land-use planning strategies employed across these neighborhoods emphasize multimodal accessibility, making them well-served by public transit and conducive to active transportation. As a result, many residents choose to live in these areas to reduce dependence on personal vehicles and lower transportation costs. These neighborhoods not only benefit from various bus routes and light rail services, but also are relatively affluent and host a wide range of healthcare services. Consequently, they are characterized by shorter travel times (typically under 30 minutes) and strong pedestrian infrastructure, including continuous sidewalks, marked crosswalks, mixed land uses, and high street connectivity. The convergence of multiple transit routes, higher population densities, and proximity to numerous healthcare facilities collectively reinforce these neighborhoods as key accessibility hubs within Sacramento.

As distance from the city center increases, a gradual decline in TWS values becomes apparent. Neighborhoods immediately adjacent to Regions 1 and 2, however, continue to exhibit relatively high TWS values. This pattern is particularly evident in the northern portions of Land Park (Region 3) and Oak Park (Region 4). Beyond these areas, moderate TWS values (ranging from 25 to 55) are observed across the inner suburban neighborhoods, including Natomas (Region 5), North Sacramento (Region 6), Arden-Arcade (Region 7), Pocket (Region 8), and

South Sacramento (Region 9). Although these regions maintain a reasonable level of transit accessibility, their walkability is often constrained by discontinuous pedestrian networks and automobile-oriented urban design. Such patterns limit the ease of access to nearby healthcare centers. While many of these communities lie within a 10-mile transit catchment of major healthcare facilities, indirect transit routes and reduced service frequencies contribute to longer effective travel times and lower composite accessibility scores.

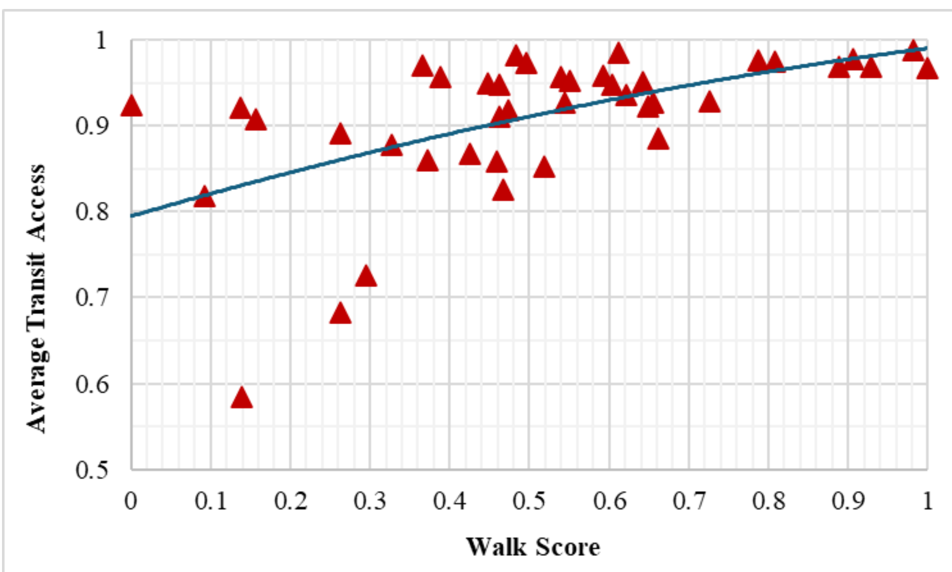
Within the City of Sacramento limits, the northern portion of Arden-Arcade (Region 7) stands out as an area exhibiting notably low TWS values (below 25). This suggests a need for targeted improvements in both walkability and transit accessibility. These block groups experience both limited public transit coverage and poor pedestrian conditions near healthcare centers. The built environment in these zones is often characterized by wider arterial roads, incomplete sidewalk networks, and greater separation between land uses, all of which diminish the feasibility of walking once transit users arrive at their destination. Enhancing pedestrian infrastructure, improving first- and last-mile connectivity, and increasing transit service frequency in this region could help mitigate accessibility disparities and better integrate it into the broader urban mobility network.

As explained earlier, while this study focused on healthcare facilities located within the City of Sacramento limits, transit accessibility was extended to encompass the entirety of Sacramento County. This approach enables a more comprehensive assessment of travel suitability to a diverse range of healthcare facilities, particularly for residents living in suburban areas. By accounting for interjurisdictional travel patterns, the analysis better reflects the real-world mobility behavior of individuals who may seek care beyond their immediate neighborhoods. As shown in Figure 5, low TWS values dominate the southern and northeastern peripheries of the county, particularly in Elk Grove, Citrus Heights, and rural areas south of the city. The combination of long travel times and lower walkability scores in the closest healthcare facility highlights the structural disadvantage of suburban and semi-rural communities in achieving equitable access to essential healthcare services in Sacramento.

Overall, the TWS map emphasizes how transit connectivity and pedestrian environment quality jointly shape spatial equity in healthcare access. Central urban areas, where transit is frequent and the built environment supports walking, benefit from overlapping advantages, while outlying regions face compounded barriers. These disparities underscore the need for coordinated planning between transit agencies and local governments. By identifying where high-quality pedestrian environments coincide or fail to coincide with effective transit access, the TWS framework provides a diagnostic tool for prioritizing investments that enhance both mobility and health equity. Future planning efforts can use these results to target infrastructure improvements in low-scoring areas, particularly along key transit corridors and in disadvantaged communities where improved walkability would yield the greatest gains in accessibility and quality of life.

One potential concern with the TWS framework is its commutative formulation, which can lead to similar composite values arising from very different underlying conditions. For example, a high level of transit accessibility combined with low walkability may yield the same TWS as high walkability combined with low transit accessibility, despite these scenarios implying distinct urban contexts and policy needs. To assess whether this issue meaningfully affects interpretation in our case study, we examined the empirical relationship between walkability and transit access across audited healthcare facilities. Specifically, we evaluated the correlation between Walk Score and average Transit Access. As shown in Figure 6, the two measures exhibit a positive association, which was confirmed using Pearson's product–moment correlation test ($t = 4.1819$, $p < 0.001$). This significant correlation suggests that, within the study area, transit accessibility and walkability tend to co-occur rather than vary independently, thereby reducing the likelihood that identical TWS values represent fundamentally different conditions. Consequently, in the case of Sacramento, CA, while the TWS is mathematically commutative, its practical interpretation is less ambiguous in this empirical context, particularly when considered alongside its component measures. However, application of the proposed TWS framework in other contexts should be approached with caution, as the observed correlation between walkability and transit access may not hold universally. The TWS is best interpreted holistically and in conjunction with its constituent transit accessibility and walkability scores, as well as supporting spatial visualizations such as heatmaps. When used in this manner, the index functions as a useful integrative screening tool. Reliance on the composite score alone may obscure meaningful differences in underlying conditions.

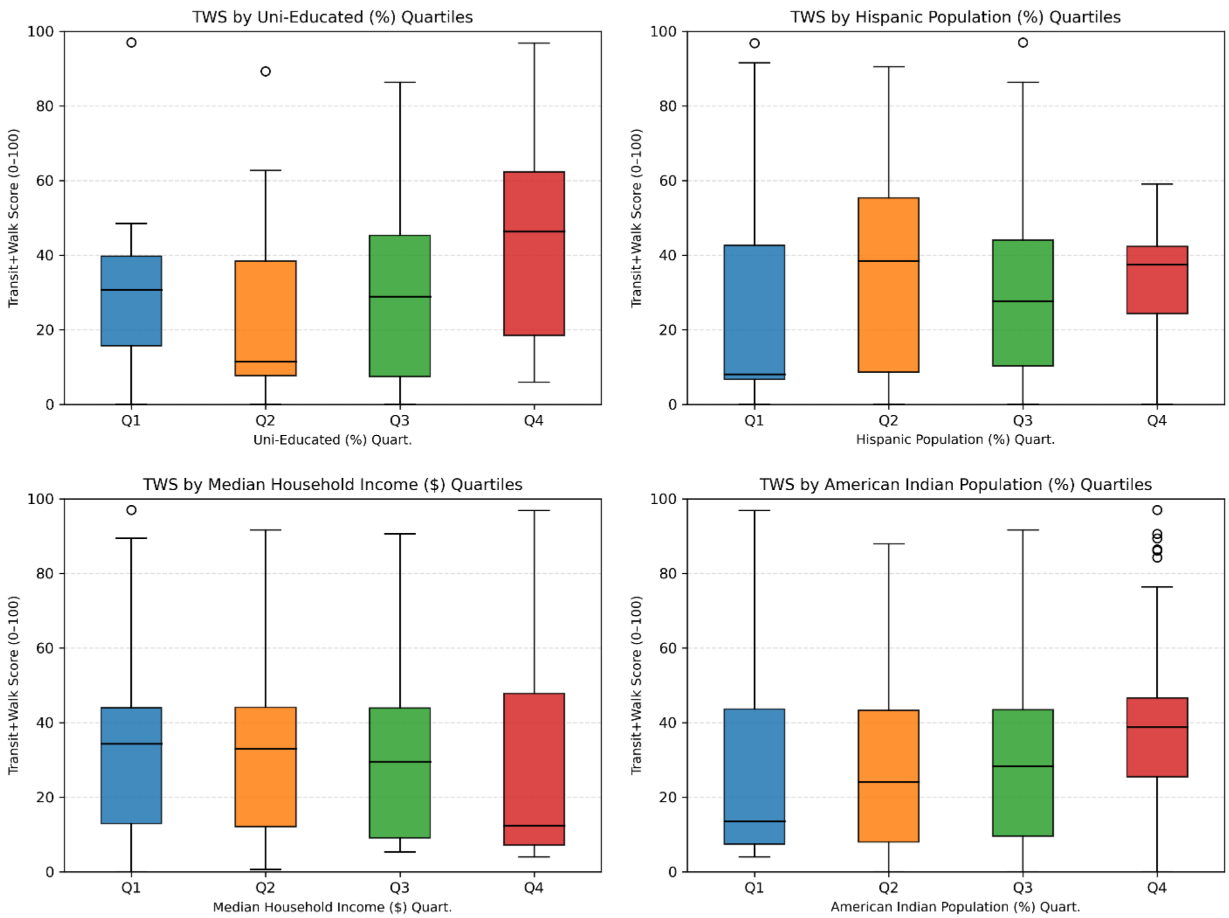
Figure 6. Walk Score vs. Transit Access




4.3.2 Equity Pattern of TWS

Figure 6 illustrates the distribution of *TWS* across quartiles of key socioeconomic indicators, including educational attainment, Hispanic population share, median household income, and American Indian population share. *TWS* integrates both transit accessibility (shorter travel times) and pedestrian environment quality near the nearest healthcare center, providing a comprehensive measure of transit-supported access to essential services.

Figure 7. TWS by Socioeconomic Quartiles




The first panel (Figure 6a) shows a clear positive gradient between educational attainment and TWS. Block groups in the lowest education quartile (Q1) display substantially lower TWS values, while those in the highest quartile (Q4) have the highest median and upper-range scores. This pattern suggests that residents living in areas with a greater share of college-educated adults tend to experience better transit accessibility and more walkable environments. These areas often correspond to central Sacramento neighborhoods (Regions 1 and 2 in Figure 5) where infrastructure investment, land-use density, and multimodal design reinforce both walkability and transit performance. In contrast, lower-education areas, often located on the urban periphery, (e.g., Region 7) tend to combine longer transit travel times with weaker pedestrian infrastructure.

The relationship between TWS and the percentage of Hispanic population (Figure 6b) shows a slightly different trend. Median TWS values are higher in the second quartile (Q2) but decline modestly toward Q3 and Q4, indicating that neighborhoods with the largest Hispanic population shares often face lower combined accessibility scores. This could reflect a mismatch between affordable housing locations and proximity to high-frequency transit corridors, a pattern observed in many metropolitan areas. Despite generally higher transit ridership rates among Hispanic populations, these communities experience poorer pedestrian conditions near essential destinations or longer overall travel times due to less frequent service coverage.

The distribution of TWS by income quartiles (Figure 6c) exhibits relatively moderate variation, though the highest income quartile (Q4) shows slightly greater dispersion and a modest upward shift in median scores. This suggests that higher-income neighborhoods tend to exhibit relatively better combined transit–walk accessibility; however, this pattern is not consistent across all areas. Many higher-income areas in suburban Sacramento have strong pedestrian environments but limited transit availability, while some lower-income neighborhoods benefit from proximity to bus or light-rail corridors yet face challenges in walking safely, comfortably, and conveniently. Overall, these observations highlight the multidimensional nature of accessibility: Income alone does not guarantee equitable access without concurrent investments in both transit frequency and pedestrian infrastructure.

The final panel (Figure 6d) displays TWS across quartiles of American Indian population percentage. While distributions are wide across all quartiles, the fourth quartile (Q4) exhibits slightly higher median TWS values, though accompanied by greater variability. This likely reflects the small and spatially dispersed nature of American Indian populations in Sacramento, where a few centrally located block groups near transit hubs skew upward while others in peripheral or semi-rural areas remain poorly connected. The large spread underscores persistent disparities in infrastructure investment and the heterogeneity of settlement patterns within this demographic group.

Taken together, these results reveal uneven access to walkable, transit-supported environments across socioeconomic groups. Education and, to a lesser extent, income, are positively associated with TWS, while higher shares of the Hispanic population correspond to relatively lower scores, signaling structural inequities in the geography of accessibility. These findings emphasize the importance of integrating equity-driven transit planning, Complete Streets investments, and Sustainable Communities Strategies (SB 375) to improve access in neighborhoods that combine lower socioeconomic status with weaker transit and pedestrian infrastructure.

# 5. Conclusion

This study represents the first comprehensive assessment of walkability from transit stops to healthcare facilities in Sacramento, aiming to identify key obstacles and areas for improvement. The safety of walking routes between transit stops and healthcare facilities is generally supported by fundamental infrastructure elements such as continuous sidewalks and adequate pedestrian crossing protection. While these components establish a basic level of pedestrian safety, additional factors, such as low posted speed limits, limited high-volume driveways, and accessible parking lot designs, further enhance the overall comfort and accessibility of walking in these areas.

Despite these advantages, certain environmental deficiencies persist. The lack of adequate lighting and minimal separation (landscape buffers) between sidewalks and adjacent roadways reduces the perceived and actual safety/security of pedestrians traveling from transit stops to healthcare entrances. Although installing physical buffers may be infeasible in some areas due to limited right-of-way, improving lighting conditions represents a practical and impactful intervention to enhance pedestrian safety/security along these routes. In many cases, comfort appeared to be treated as an optional aspect of design, as reflected in its consistently lower scores compared to the other main evaluation categories.

Furthermore, even though sidewalks were generally well maintained, pedestrian routes often concluded within parking lots rather than at street-facing entrances. This design pattern underscores a continued preference for automobile-oriented development, where entrances are optimized for drivers rather than pedestrians. Notably, while the quantitative comfort scores were only marginally lower than other categories, auditors' subjective comfort ratings were substantially lower, suggesting that perceived comfort during pedestrian travel may be worse than what standardized audit metrics indicate.

Walking routes from transit stops to healthcare facilities were generally found to be convenient, characterized by flat, well-maintained, and unobstructed segments. However, the overall convenience score was constrained by inadequate bus stop infrastructure: many stops consisted solely of a sign with no shelter, seating, or lighting, and there were no wayfinding features along pedestrian paths. Although digital navigation tools such as smartphones can partially compensate for this, individuals with limited technological proficiency, visual impairments, or financial barriers remain at a significant disadvantage. Consequently, the lack of physical wayfinding elements has important implications for equitable accessibility and inclusive urban design.

This study also introduced and applied the *Transit+Walk Score* (*TWS*) as an integrated framework to evaluate accessibility and pedestrian environment quality around healthcare centers in Sacramento. By combining modeled transit travel times with walkability scores derived from on-the-ground assessments, the *TWS* provides a holistic measure of transit-enabled walkability, reflecting both the efficiency of reaching essential destinations and the safety/security, comfort, and convenience of navigating them on foot.

The findings demonstrate a distinct spatial gradient of accessibility across the studied area. High *TWS* values cluster around central Sacramento, particularly Downtown, Midtown, East Sacramento, South Park, and Oak Park, where the convergence of transit routes, higher population densities, and connected street networks support both walkability and transit use. These areas benefit from a historic urban form shaped during Sacramento's streetcar era, when neighborhoods were designed around compact blocks and pedestrian access to transit (Burg, 2007). In contrast, inner suburban zones and rural communities on the southern and northeastern peripheries exhibit lower *TWS* values due to longer transit travel times, limited route coverage, and fragmented pedestrian networks.

Following World War II, widespread automobile ownership and suburban expansion transformed Sacramento's land-use patterns. Development spread beyond the former streetcar suburbs into auto-oriented areas such as Arden Arcade, where sidewalks and dense street grids were often deemed unnecessary, reflecting a shift toward car-dependent design (Goldman, 2017). This postwar transition contributed to a spatial divide between the transit-supportive core and outlying communities reliant on private vehicles.

The socioeconomic analysis of *TWS* by quartiles further reinforces these spatial inequities. Block groups with higher educational attainment generally exhibit better combined transit and walkability conditions, while those with higher proportions of Hispanic residents or lower-income households tend to experience weaker access. These disparities mirror long-standing effects of redlining, freeway construction, and urban renewal that displaced ethnic enclaves and fragmented established neighborhoods, concentrating marginalized populations in areas with limited infrastructure investment and transit access (University of Richmond, Digital Scholarship Lab, n.d.).

From a policy perspective, the *TWS* framework offers a scalable, evidence-based tool for identifying and addressing accessibility gaps. Integrating such metrics into California's Sustainable Communities Strategies (SB 375), Active Transportation Program (ATP), Transit and Intercity Rail Capital Program (TIRCP), and Affordable Housing and Sustainable Communities (AHSC) can help ensure that infrastructure investments and climate initiatives explicitly consider walkability and transit access together. By quantifying where walking quality and transit connectivity overlap or fail to overlap, the *TWS* enables planners and policymakers to prioritize interventions in areas where improvements can yield the most equitable and impactful outcomes.

Findings from this study could also inform policy and planning decisions by state agencies such as the California Air Resources Board (CARB) and local jurisdictions such as Sacramento Regional Transit (SacRT). Transit and active transportation investments should focus on transit-accessible but pedestrian-deficient neighborhoods, particularly those with lower educational attainment and higher minority populations. Enhancing sidewalks, crosswalks, lighting, and safety/security features in these areas would significantly improve last-mile connectivity and equitable access to healthcare and other essential services.

Ultimately, this research underscores that equitable accessibility requires both transit connectivity and high-quality pedestrian environments. Transit alone cannot deliver inclusive mobility without safe, comfortable, and continuous walking networks that connect people to destinations. The *TWS* provides a replicable, transparent framework that can guide planners, transit agencies, and policymakers in aligning transportation, land use, and health equity goals. Future applications of this approach can extend beyond healthcare access to evaluate transit-linked walkability for schools, job centers, and affordable housing, helping California move closer to a truly sustainable, healthy, and equitable transportation system.

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