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MTI MINETA TRANSPORTATION INSTITUTE

Scoring Equitable Transit: A Data-Driven Framework for Affordable Transit-Oriented Development in California

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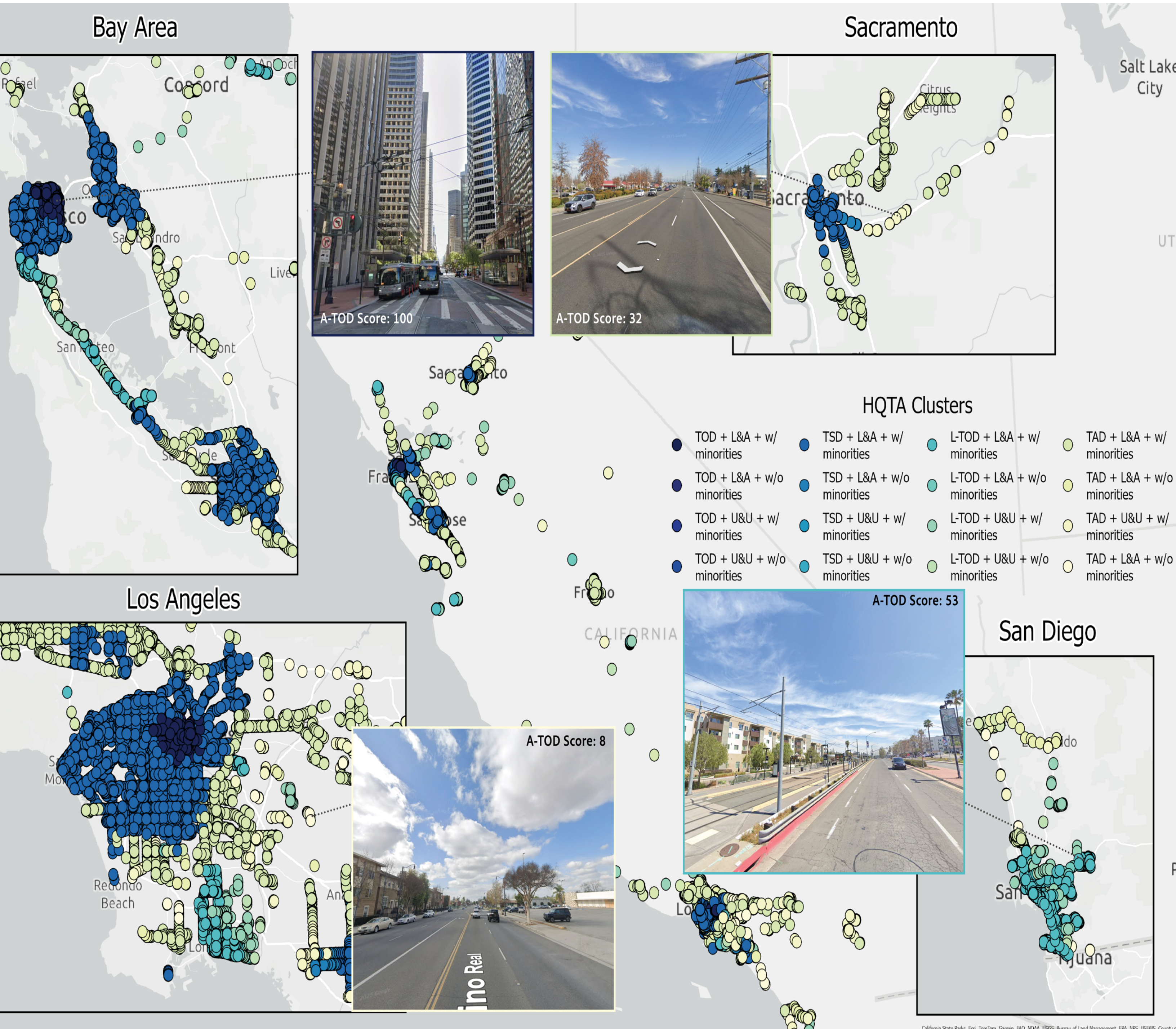

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Report 25-34

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16. Abstract

Transit-Oriented Development (TOD) is a cornerstone of California's climate and land use policy, promising walkable, compact neighborhoods near high-quality transit. However, these benefits are not always distributed equitably. This study introduces a scalable framework for identifying and scoring Affordable Transit-Oriented Development (A-TOD) across the state's High-Quality Transit Areas (HQTAs). The goal is to equip policymakers, planners, and housing agencies with tools to evaluate station areas based on their physical form, affordability, and equity outcomes. Using a 1.5-mile network-based pedestrian buffer around over 66,000 transit stations, the research team developed a three-stage clustering and scoring system. Station areas were classified by built environment characteristics, modeled housing and transportation cost burdens, and social vulnerability indicators, including minority population concentration. Each station received a composite raw score (0.5 to 6), which was normalized to a 0–100 scale to create an accessible equity index. Key findings reveal that while most HQTA stations are nominally affordable, nearly all are located in historically marginalized or currently vulnerable communities. High-scoring station areas tend to cluster in dense urban cores such as Los Angeles, Oakland, and Sacramento, while lower scores are concentrated in exurban and auto-oriented regions such as the Inland Empire and northern San Diego. These insights underscore the need for policy interventions that align transit investments with affordability and racial equity. The resulting typology and web-based equity map provide a powerful planning tool for guiding equitable development, CEQA streamlining, and preserving transit-oriented housing across California.

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Executive Summary

This report presents a novel, data-driven framework for measuring and evaluating Affordable Transit-Oriented Development (A-TOD) across California's High-Quality Transit Areas (HQTAs). Rooted in the principles of spatial equity and land use integration, this study introduces a replicable methodology for classifying and scoring transit station areas based on three critical dimensions: built environment characteristics, housing affordability, and the presence of minority populations. The outcome is a policy-ready tool that can guide more equitable transit and housing investment strategies across the state.

The analysis covers over 66,000 transit stations statewide, including BRT, rail, and high-frequency bus stops, using a 1.5-mile network-based pedestrian buffer around each station to capture realistic walkable access. A three-stage classification framework was employed to group station areas by their built environment form (using indicators such as density, land use mix, and transit frequency), cost burden across household types (using modeled housing + transportation costs), and social vulnerability metrics (using components of the CDC Social Vulnerability Index).

The resulting typology defines four station types—Transit-Oriented Development (TOD), Transit-Supportive Development (TSD), Limited TOD (L-TOD), and Transit-Adjacent Development (TAD)—which are then cross-classified by affordability status (Livable & Affordable or Unlivable & Unaffordable) and minority population presence. Each station area was assigned a composite equity score ranging from 0.5 to 6, reflecting its combined performance across the three dimensions. These scores were subsequently normalized to a 0–100 scale, allowing for cross-comparison and public visualization through an interactive statewide equity map.

Key findings indicate that while over 90% of HQTA stations qualify as Livable & Affordable under modeled cost burdens, the vast majority of these are concentrated in disadvantaged communities of color. This reinforces the need to treat racial equity as central, not peripheral, to TOD planning. Conversely, the lowest-scoring station clusters are disproportionately located in auto-oriented, low-density areas in exurban Southern California, the Central Valley, and North San Diego County, where affordability gaps, limited walkability, and underperforming transit converge to reinforce structural exclusion.

The composite scoring system provides actionable insights for a wide range of stakeholders. State agencies can integrate the scores into CEQA streamlining and AHSC funding criteria. Regional and local planners can utilize the typology to prioritize infrastructure investments, zoning reforms, and housing preservation. Developers and housing advocates can identify opportunity sites that offer alignment between transit access and social need. Ultimately, the tool can support broader environmental justice goals by highlighting the intersections of transit, housing, and climate policy.

By systematically quantifying where TOD efforts are succeeding—and where they are falling short—this study equips policymakers with a flexible and scalable approach to ensure that equitable access to transit is matched by inclusive, affordable, and racially just urban development.

1. Introduction

1.1 Background and Policy Context

California continues to lead efforts in integrating land use, transportation, and housing policy to advance sustainable and equitable urban development. Programs such as the Affordable Housing and Sustainable Communities (AHSC) initiative reflect the state's commitment to reducing greenhouse gas emissions, promoting public transit, and addressing the affordable housing crisis. However, these initiatives must be evaluated not only for their environmental and mobility outcomes, but also for their effectiveness in serving low-income and historically marginalized communities. This report presents a novel framework for identifying and classifying Affordable Transit-Oriented Development (A-TOD) across California's High-Quality Transit Areas (HQTAs), specifically focusing on areas surrounding rail and bus rapid transit stations, excluding ferry terminals. Ferry terminals were excluded from this analysis because the land use and accessibility patterns surrounding waterborne transit nodes differ substantially from those of rail- or bus-based systems. Unlike rail or bus rapid transit stations, which are embedded within urban street networks and support walkable, mixed-use development, ferry terminals are often located in waterfront or industrial contexts with limited pedestrian connectivity and distinct development constraints. Including them would introduce methodological inconsistencies and reduce comparability across station types

1.2 Challenges of Equity in TOD Implementation

Transit-Oriented Development (TOD) promotes compact, walkable, and mixed-use communities organized around high-quality transit infrastructure (Sun, 2024). While TODs have been widely lauded for reducing car dependence and fostering economic activity, their implementation often leads to rising land values, displacement, and reduced housing affordability (Zhao, 2024; Haque, 2019). These dynamics disproportionately impact low-income and minority populations, who often face barriers to remaining in or accessing TOD zones. Research shows that while many TODs offer high transit access, a substantial number lack affordable housing options—only about 24 percent of TOD units are affordable to households earning 50–80 percent of Area Median Income, and nearly half of TODs offer few to no affordable units at all (Kaniewska, 2024).

1.3 Objectives and Conceptual Foundation

To better understand and address these challenges, this project develops a dual scoring and classification framework that integrates both built environment characteristics and social equity factors, including affordability and the presence of minorities. The classification framework is grounded in a comprehensive literature review conducted as part of this project, which synthesized over two dozen global and domestic studies on TOD measurement, affordability metrics, and spatial equity. In this study, we adopt a working definition of spatial equity as the fair and just distribution of transit access, affordable housing opportunities, and supportive urban amenities across different communities, with particular attention to historically marginalized populations. While related terms such as equality, inclusivity, and justice are often used interchangeably, we distinguish equity as emphasizing outcomes that address structural disparities, rather than simply providing identical resources to all groups. Equality suggests sameness in treatment, inclusivity stresses broad participation, and justice encompasses broader legal and social redress; equity, in contrast, foregrounds the need to rectify uneven access and opportunity across space. By grounding the analysis in spatial equity, we underscore why proximity to transit infrastructure must be matched with affordability and livability to avoid reinforcing displacement or exclusion, making equity not just a normative principle but a practical foundation for guiding more just transit and housing investments. The review confirmed the centrality of the "5Ds" framework—density, diversity, design, distance to transit, and destination accessibility—in TOD assessments, while also highlighting the importance of variables such as housing-plus-transportation costs, racial and economic segregation, and active transportation infrastructure.

This report is organized to inform both academic analysis and policy application. It begins with this introduction, followed by a literature review that synthesizes empirical methodologies for evaluating affordable TOD. The third chapter details the analytical methodology, which includes the use of hierarchical cluster analysis to identify TOD–TAD typologies and evaluate affordability and minority presence across the expanded High-Quality Transit Areas (HQTA) areas. It is important to clarify the distinction between TODs and HQTAs. TODs are compact, mixed-use, and walkable developments intentionally designed around transit stations to reduce car dependence and enhance accessibility, while HQTAs are state-defined geographic zones located within a half-mile of high-frequency transit stops, regardless of whether surrounding areas currently exhibit TOD characteristics. In this study, HQTAs serve as the unit of analysis: we classify all HQTA station areas statewide by their built environment, affordability, and equity conditions, with TOD emerging as one of several typologies within the broader HQTA system. The findings chapter presents spatial and statistical outcomes, including classifications and scores for station areas across the state. The final chapter concludes with key policy recommendations and pathways for future research and implementation.

1.4 Relevance to Policy and Public Engagement

This work is directly relevant to the California Department of Housing and Community Development (HCD) and other agencies responsible for TOD and AHSC funding decisions. By offering a replicable, equity-centered typology and scoring system, this project equips policymakers with a decision-support tool to better target investments and ensure that TOD efforts are inclusive and just. To facilitate public access and practical application, the results will be delivered through an interactive web-based map, allowing policymakers, planners, and the public to explore A-TOD typologies, affordability levels, and the distribution of disadvantaged populations throughout California.

2. Literature Review: Measuring Affordable Transit-Oriented Development (A-TOD)

This chapter synthesizes current scholarly and applied research on Transit-Oriented Development (TOD), with a focus on how affordability and minority presence can be integrated into TOD classification frameworks. It supports the project's goal of developing a methodologically robust, equity-focused Affordable Transit-Oriented Development (A-TOD) index that is actionable for planners and policymakers in California.

2.1 Defining TOD and the Equity Challenge

Transit-Oriented Development (TOD) is widely recognized as a strategy for sustainable urban development, emphasizing high-density, mixed-use communities built around transit hubs. Originally popularized by Peter Calthorpe in the 1990s, TOD has become a global model for reducing automobile dependence, promoting walkability, and stimulating economic development (Sun, 2024). Hallmark characteristics of TOD include compact development, pedestrian connectivity, and access to diverse land uses—residential, commercial, and recreational—within walking distance of a transit station.

Yet, while TODs are often associated with social, environmental, and economic benefits, they also risk producing exclusionary outcomes. Numerous studies document rising land values and housing costs in TOD zones, which can limit access for low-income households and displace long-standing communities, particularly communities of color (Zhao, 2024; Barajas, 2020). This dynamic has been termed the "affordability paradox": the very qualities that make TODs desirable and successful (e.g., high-quality transit access, walkability, and vibrant land use) also drive up demand, leading to higher housing costs that undermine inclusivity. The paradox is thus a tension between two goals: (i) the creation of transit-rich, amenity-rich urban environments and (ii) the commitment to avoid exclusion of vulnerable populations. Without safeguards, the success of TOD can inadvertently reproduce the very inequities it seeks to remedy.

This tension is closely tied to the concept of gentrification, which occurs when neighborhood improvements, including those associated with transit investment, attract higher-income residents and capital investment while displacing lower-income households. While gentrification is not a necessary or inevitable outcome of TOD, it is a common risk when policy interventions are absent or insufficient. Framing inclusivity as opposed to gentrification does not mean rejecting development altogether; rather, it underscores the importance of intentional planning and policy design. Equitable TOD requires measures such as affordable housing mandates, tenant protections, and anti-displacement strategies to ensure that the benefits of transit-oriented development are broadly shared rather than concentrated among more affluent groups. In this way, inclusivity is not in conflict with TOD—it is a corrective principle that ensures TOD fulfills its promise of sustainable and just urban development.

2.2 Empirical Evidence on TOD and Affordability

Researchers have investigated the relationship between TOD and housing affordability using both qualitative and quantitative approaches. High demand for housing in TOD areas creates economic pressure, often resulting in price increases. According to Kaniewska et al. (2024), only 24% of residential units in 107 studied TODs were affordable to households earning between 50% and 80% of Area Median Income (AMI), with nearly half of TODs offering fewer than 10% affordable units. This geographic disparity highlights the uneven distribution of affordable TOD opportunities.

Furthermore, studies have shown that TODs are associated with significant increases in land value. Haque (2019) documents a rise in property prices by 6% to 45% in proximity to transit stations. In Western Australia, land values in TOD zones increased from approximately $170 to $270 per square meter within one year. Similarly, Renne (2016) and Zhao (2024) report increased rents and property taxes near TODs in the U.S.

The financial implications of TOD extend beyond housing costs. The Housing + Transportation (H+T) Index, developed by the Center for Neighborhood Technology (CNT), measures affordability by combining housing costs with transportation expenses, recommending that these combined costs not exceed 45% of household income. Specifically, the CNT suggests housing costs should not exceed 30% of household income, and transit costs should not exceed 15%. In a TOD context, the proximity to public transit and walkability would reduce dependence on automobiles, therefore reducing transportation costs. This is theoretically counteracted by the strong correlation between TODs and higher property values and housing expenses (Zhao, 2024; Renne, 2016; Paderio, 2019; Dong, 2017; Barajas, 2020). While TODs often reduce transportation expenses due to better access to transit, the resulting savings may not fully offset increased housing costs (Kaniewska, 2024).

Barajas (2020) identifies a spatial mismatch between affordable housing and TOD zones. The majority of federally subsidized housing (71%) is located in areas with low walkability and limited access to public transportation. In many metropolitan regions, transit-rich areas remain inaccessible due to zoning restrictions, racial segregation, or neighborhood opposition to affordable housing. Moreover, studies report significant disparities in TOD affordability and displacement risks across cities. Zhao's comparative study of 14 U.S. metro areas found severe displacement in places such as San Francisco and Denver, but equitable TOD outcomes in Portland due to targeted policy interventions.

2.3 Conceptualizing TOD-ness: The 5Ds Framework, Catchment Areas, and Transit Modes

The concept of "TOD-ness" refers to the extent to which a location meets TOD principles. The foundational measurement tool is the 5Ds framework, which includes:

- Density: Population and job density in the TOD area
- Diversity: Land use mix, typically measured using entropy indices
- Design: Quality of the pedestrian environment, such as intersection density and walkability
- Distance to Transit: Proximity to high-quality transit infrastructure
- Destination Accessibility: Regional accessibility to jobs and services

Studies using this framework typically combine these metrics using hierarchical cluster analysis, spatial multi-criteria analysis (SMCA), or latent class cluster analysis. For example, Singh et al. (2015, 2018) employ a multidimensional TOD index, utilizing 21 indicators organized into eight categories, including walkability, accessibility, and economic development. To address limitations in the 5Ds, scholars have introduced alternative typologies. Zhou et al. (2024) propose a Node-Place-People model that integrates transit service (node), land use and built form (place), and socio-demographic vulnerability (people). This model builds upon the earlier Node-Place model (Bertolini, 1999) and expands its equity orientation.

Data Envelopment Analysis (DEA) and spatial cluster statistics such as Moran's I and Getis-Ord Gi* have also been employed to identify high-performing TOD nodes and equity gaps (Ibrahim, 2021). These tools help planners visualize TOD distribution, detect clustering, and validate typology classification.

Catchment area definitions vary, but most studies apply a half-mile (800m) buffer—consistent with a 10-minute walk. Some use walkable networks instead of distance, which enhances accuracy particularly in areas with irregular street grids.

Transit mode also influences TOD classification. While rail-based TOD is most studied, emerging literature includes bus rapid transit (BRT), metro, and multimodal hubs. In California, the Transit Village Development Planning Act of 1994 initially focused on rail stations but was later expanded to include BRT and ferry terminals. However, the current A-TOD framework excludes ferry nodes due to inconsistent land use patterns surrounding waterborne transit.

2.4 Equity-Oriented Metrics and Methodologies

Researchers incorporate affordability and equity into TOD typologies using:

- H+T Index: To account for the tradeoffs between housing proximity to transit and transportation cost savings (Isalou, 2014; Kaniewska, 2024; Haque, 2019)
- Regression Models: To analyze the relationship between affordability, income, and travel behavior (Renne, 2016; Bostic et al., 2018)

- Propensity Score Matching: To control for confounding variables when comparing TOD and non-TOD areas (Dong, 2017; Scheer, 2017)
- Typology Frameworks: To classify station areas into TOD, TAD (Transit-Adjacent Development), and Hybrid zones based on performance (Kaniewska, 2024; Renne, 2016)
- Surveys and Stakeholder Interviews: To include community perspectives (Barajas, 2020; Garde, 2024; Oranga, 2015)

Before aggregating indicators into a TOD index, studies employ standardization techniques such as Min-Max normalization or entropy-based weighting. Singh (2015) uses a hybrid method, combining expert-driven weights (Borda Count) with statistical analysis. Others, such as Uddin (2023), apply CRITIC (Criteria Importance Through Intercriteria Correlation), and Zhao (2024) uses entropy weighting to reflect indicator variability and concentration.

SMCA and cluster-based TOD models are often tested through sensitivity analyses. For instance, Singh (2015) modified weighting schemes across 16 scenarios and found minimal change in TOD rankings, indicating model robustness. Khare (2021) similarly applied a 10% variation in weights and validated results using clustering diagnostics and stakeholder feedback.

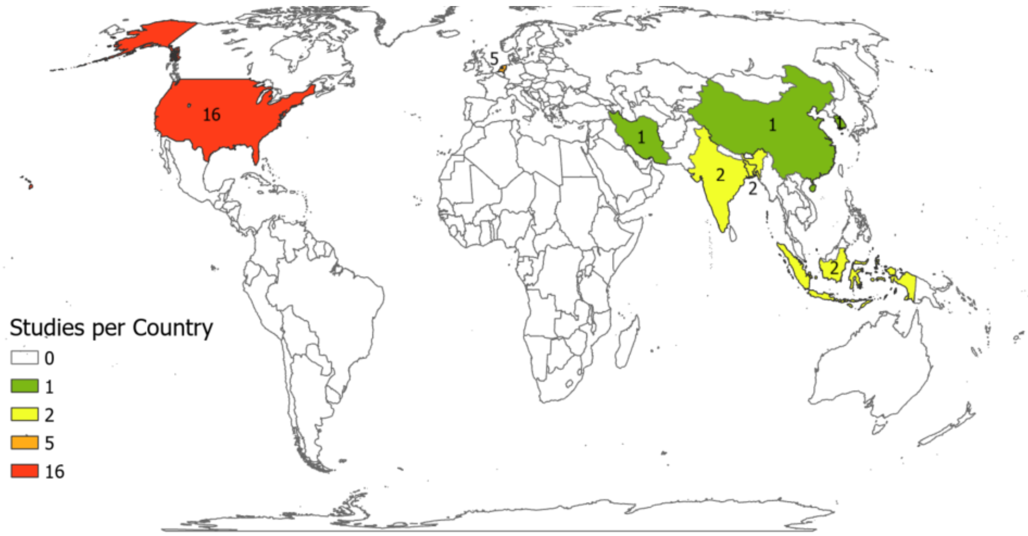
Spatial validation tools include:

- Global Moran's I: Measures spatial autocorrelation
- Getis-Ord Gi*: Identifies hot spots of TOD performance
- LISA (Local Indicators of Spatial Association): Highlights spatial outliers

2.5 Conclusion

The literature review compiled 35 studies, including international case studies. This global perspective supports the adaptability of the A-TOD framework to diverse urban contexts while grounding it in California's unique regulatory and socio-economic conditions through 5 studies specifically examining TOD and affordability within California.

Figure 1. Global Spread of Literature Review



The literature reviewed in this chapter establishes a detailed empirical and conceptual foundation for the A-TOD framework. TOD measurement methods are evolving beyond built form to include affordability, racial equity, and social vulnerability. However, the field still lacks a standardized methodology that fully integrates these dimensions across geographies. This project addresses that need by offering a dual-index approach—one measuring TOD physical form, the other scoring affordability and minority presence. Combined with GIS tools and public data accessibility via a web-based interface, this approach aims to inform equitable TOD siting in California. The next chapter details the analytical methods used to implement this framework.

3. Analytical Methodology

To evaluate patterns of transit-oriented development across California, this study focuses on High-Quality Transit Areas (HQTAs)—a planning designation defined by the California Air Resources Board (CARB) and the Strategic Growth Council. By definition, HQTAs are located within one-half mile of a high-frequency transit stop and play a central role in California's climate and land use strategies, particularly under Senate Bill 375 (SB 375). The traditional half-mile radius derives from the convention of a 10-minute walking distance, offering a straightforward, standardized benchmark for regional planning and regulatory purposes. However, while this approach provides consistency, it has notable drawbacks: it assumes uniform pedestrian access, disregards barriers in the built environment (such as freeways, cul-de-sacs, or disconnected street networks), and overlooks alternative first/last-mile connections such as bicycling, micro-mobility, and feeder transit. As a result, the static half-mile measure can overstate accessibility in some contexts and understate it in others, limiting its ability to capture the real-world reach of transit infrastructure.

To address these shortcomings, this study applies network-based pedestrian buffers of 1.5 miles around all qualifying transit stations (excluding ferry terminals). The 1.5-mile threshold is analytically appropriate because it captures both the core walkable catchment (typically 0.5–1 mile) and extended access zones that reflect realistic travel behavior in California's urban and suburban contexts (Renne, 2009; Chatman & Noland, 2011; Vale et al., 2016). By using a network-based buffer, the analysis accounts for actual street connectivity and pedestrian paths rather than simple straight-line distances. This approach enables a more comprehensive and accurate assessment of transit-oriented development (TOD) potential, particularly when examining affordability and equitable access for historically marginalized communities. In total, the analysis covers more than 60,000 HQTA stations across the state, including bus rapid transit (BRT), rail, and high-frequency bus stops, with a very minor share of planned stations also included. This expanded and network-sensitive definition provides a more realistic foundation for identifying and classifying TOD opportunities within California's HQTA system.

The methodological framework of this project follows a multi-stage spatial analysis process grounded in Geographic Information Systems (GIS) and data analysis (clustering). After the collection of HQTA data, we created a custom network grid using publicly available TIGER/Line shapefiles from the U.S. Census Bureau. This grid was refined to include only potentially walkable streets, explicitly excluding highways and other auto-dominated routes. Using the Esri ArcGIS Pro 3.4 commercial license software, a network analysis was conducted to generate network-based buffers of 1.5 miles around each transit station, representing realistic walkable catchment areas. Census unit centroids falling within these buffers were selected, and associated demographic, socioeconomic, and built environment variables were spatially joined to the grid.

To ensure comparability across diverse data types, ranging from housing costs to intersection density, all variables were standardized using z-scores. This method transforms each variable x into a standardized value z using the formula:

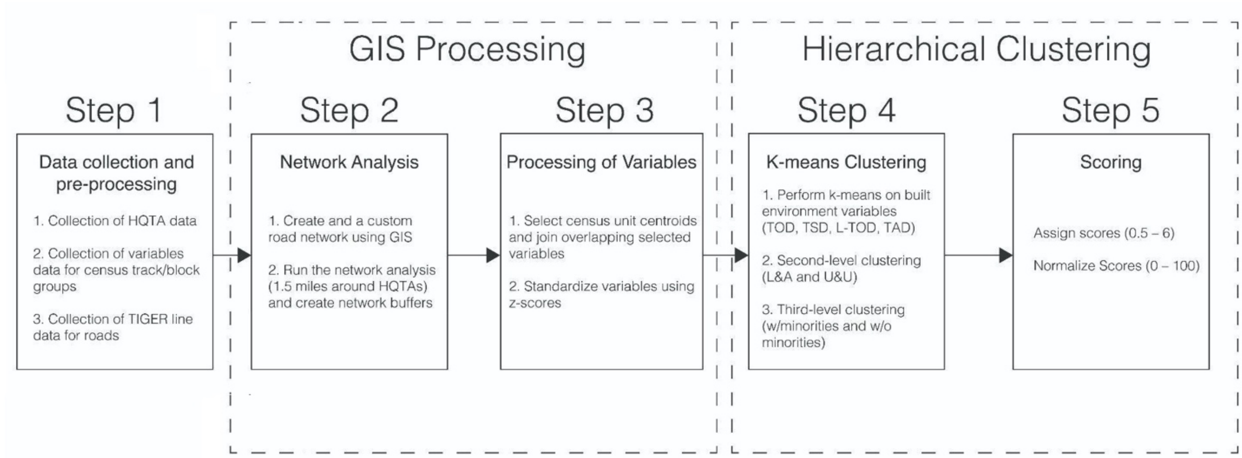
$$z = \frac{x - \mu}{\sigma}$$

where μ is the variable's mean, and σ is its standard deviation.

Standardization is critical for clustering because it eliminates the influence of variable scale and unit differences, enabling each variable to contribute equally to the clustering process. K-means clustering was first applied to built environment variables, and the elbow method, supported by empirical knowledge (e.g., Zhao et al., 2021; Singh et al., 2015; Vale, 2015), guided the selection of four primary cluster types: Transit-Oriented Development (TOD), Transit-Supportive Development (TSD), Limited TOD (L-TOD), and Transit-Adjacent Development (TAD). Each of these four categories was then clustered further into two subtypes (Livable & Affordable vs. Unlivable & Unaffordable), resulting in eight total clusters. A final round of clustering was conducted within each of these eight groups to distinguish areas with higher minority populations from those without, resulting in a total of 16 final cluster types.

Following classification, each HQTA point received a composite score ranging from 0.5 to 6 based on its characteristics and cluster ranking. These scores were then normalized to a 0–100 scale to facilitate interpretation and comparison across geographies. The methodological structure, shown in Figure 2, provides a scalable and reproducible approach to identifying spatial disparities and opportunities for more equitable transit-oriented planning.

Figure 2. Conceptual Methodological Workflow



3.1 Study Area

Our study area encompasses the expanded area of California High Quality Transit Area (HQTAs), for which we developed a 1.5-mile pedestrian network buffer for all of the stations, excluding ferry stations. The HQTA data is from the CalTrans Open GIS data portal, most recently updated on May 29, 2025. High-Quality Transit Areas (HQTAs) are defined by the California Air Resources Board (CARB) and the Strategic Growth Council as areas within one-half mile of a well-serviced transit stop or station, typically with service intervals of 15 minutes or less during peak commute times. HQTAs are central to California's sustainable development goals, particularly under Senate Bill 375 (SB 375), which promotes integrated land use and transportation planning to reduce greenhouse gas (GHG) emissions. These areas are prioritized in regional planning strategies such as Sustainable Communities Strategies (SCS) and are often the focus of state-level incentives for infill development, housing, and transit infrastructure. For the purposes of this study, we expand the analysis beyond the core HQTA designation by generating pedestrian network-based buffers of 1.5 miles around all eligible transit stations, excluding ferry terminals, to capture a more comprehensive urban accessibility zone. This approach enables us to analyze not only proximity but also walkable connectivity to high-quality transit across diverse urban settings. This analysis includes 66,332 HQTA stations. In some locations, the HQTA station refers to multiple stations with the same coordinates, particularly when there is more than one distinctive route (e.g., bus) passing through the station. The HQTA's surround 66,412 transit stations, including 80 ferry stations (omitted from this analysis), 22,886 Bus Rapid Transit (BRT) and bus stations, 40,319 high-quality bus corridors, and 3,127 rail stations.

Figure 3. HQTA Stations by Transit Type

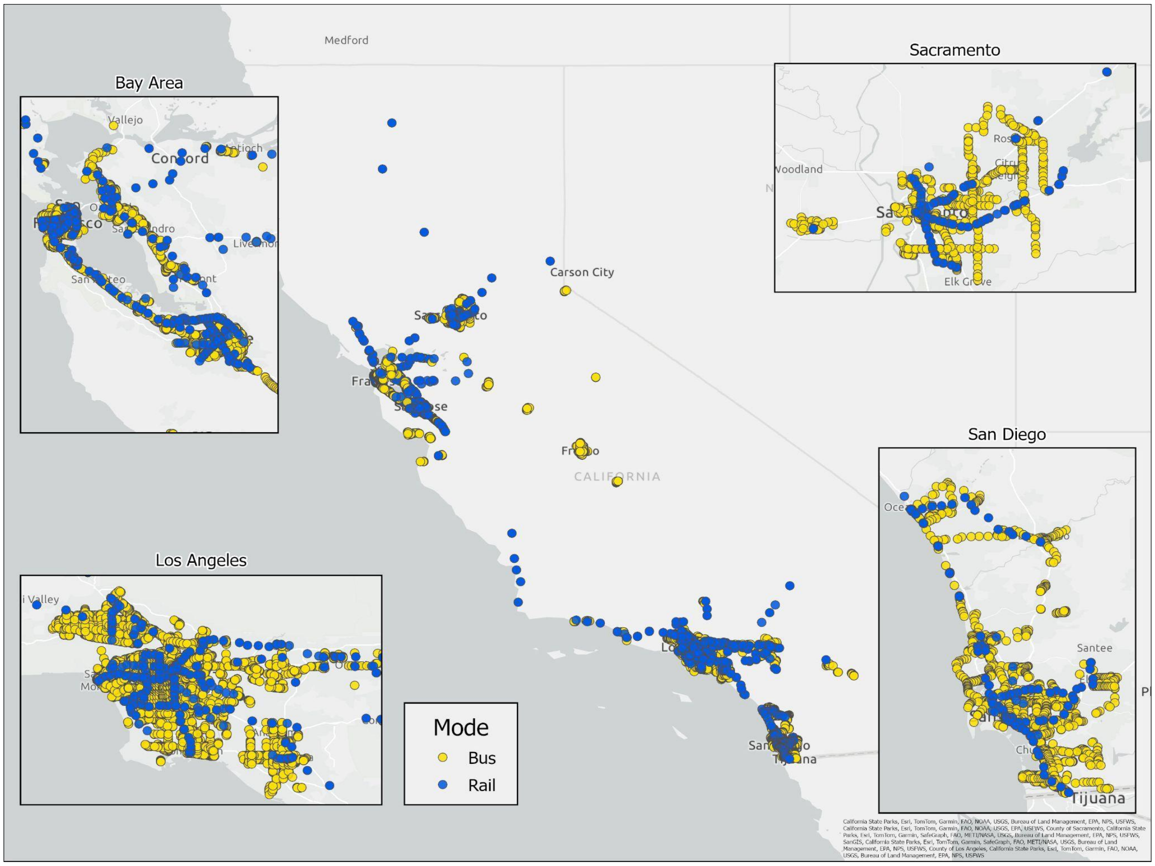
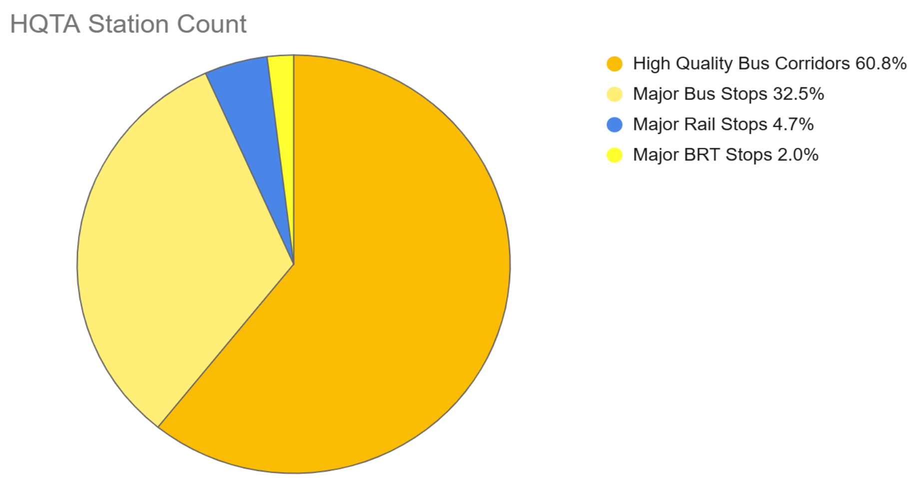


Figure 3 illustrates the rail and bus networks in four major California regions: the Bay Area, Sacramento, Los Angeles, and San Diego. Spots in yellow represent bus transit, including major BRT stops, major bus stops, and high-quality bus corridors. Blue stations represent the major rail stops within the study area. Bus stations constitute the majority of the Californian HQTAs (95.3%), as shown in Figure 4.

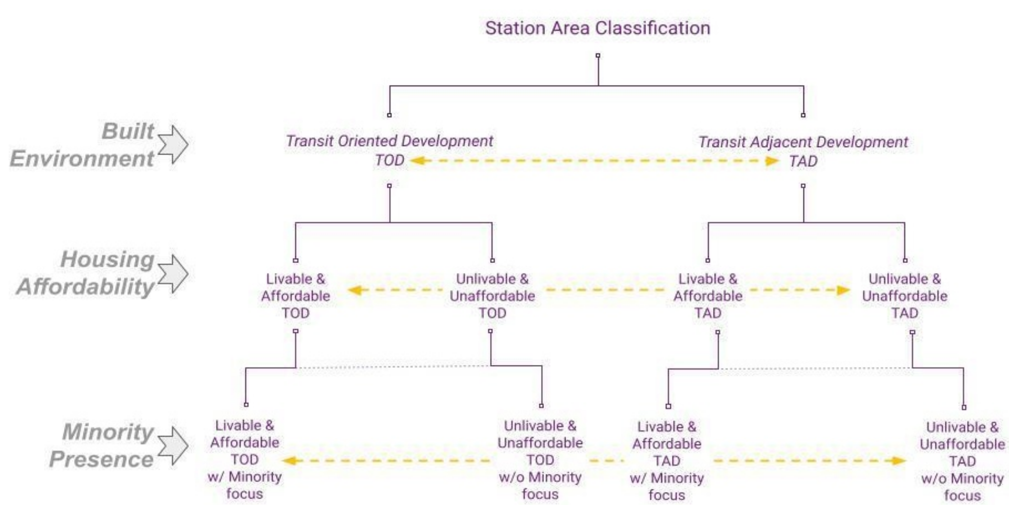
Figure 4. Proportion of HQTAs by Transit Mode



3.2 Station Area Classification Framework

This section outlines a three-stage sequential clustering framework (k-means algorithm) developed to categorize station areas across the study region. The framework serves as a methodological structure for organizing station types based on their physical characteristics, affordability context, and demographic composition. The classification logic is summarized visually in Figure 5 (Conceptual Framework for Station Area Classification).

Figure 5. Conceptual Framework for Station Area Classification



The purpose is not to assign fixed labels, but to allow a data-driven classification that can later be interpreted in the findings section. The class groupings described below are hypothetical—they are informed by prior theory and literature on transit-oriented development and urban form (Cervero & Kockelman, 1997; Renne, 2009; Vale, 2015), but will be empirically validated through multivariate clustering techniques (Guerra et al., 2020; Zhao et al., 2021). Details about all variables used in the clustering process are provided in Section 3.3.

3.2.1 Step 1: Clustering by Built Environment

This includes indicators related to land use intensity, street connectivity, transit access and frequency, land use diversity, accessibility to regional opportunities, and proximity to downtown centers. These measures collectively reflect each station area's capacity to support multimodal transit and compact development patterns.

We anticipate four general categories of built form to emerge, ranging from transit-adjacent areas with limited integration to highly connected, dense, and walkable station areas near CBDs. The exact configuration of built environment clusters will be interpreted through the findings.

3.2.2 Step 2: Clustering by Housing Affordability

The second stage further differentiates station areas by their housing affordability profile. This includes modeled estimates of housing and transportation costs relative to income for various household types. Rather than relying solely on market prices, this step considers affordability through the lens of cost burdens across income levels and household structures. Measures of subsidized housing availability are also incorporated to contextualize affordability conditions. This clustering is expected to yield a spectrum from highly affordable to highly unaffordable station areas, though the precise structure will depend on empirical outcomes.

3.2.3 Step 3: Clustering by Minority Presence and Social Vulnerability

The third step clusters station areas based on demographic and social vulnerability indicators, drawing from an equity-focused framework. This includes measures of socioeconomic disadvantage, racial and ethnic minority concentration, linguistic isolation, age structure, disability, and housing stability. These indicators provide insight into the population characteristics surrounding each station. The purpose of this clustering is not evaluative but structural—it allows us to explore how affordability and built form intersect with broader social patterns. In this report, we use race as a socially constructed category that reflects how people are grouped based on perceived physical characteristics, such as skin color, which carry historical and structural implications for access to resources, opportunities, and exposure to discrimination. Ethnicity, by contrast, refers to shared cultural, linguistic, or ancestral heritage that may or may not overlap with racial categories. While the two terms are sometimes used interchangeably in common usage, we distinguish them analytically: racial categories are central to understanding structural inequities in housing, transit access, and land use, whereas ethnicity captures cultural or national identities that can intersect with but are not reducible to race. Our classification of "racial and ethnic minority concentration" follows the CDC Social Vulnerability Index, which treats race and ethnicity together as a dimension of vulnerability, but throughout the text we aim to be precise about whether we are referring to race, ethnicity, or their intersection.

3.2.4 Composite Scoring and Normalization

To develop a normalized composite score across station areas, we assign values to each dimension based on the number of clusters identified through the sequential clustering analysis. The score ranges are as follows:

- **Built Environment (BE): 0.5 to 2.0:** The minimum value for BE is set at **0.5** rather than zero because all analyzed stations are located within designated High-Quality Transit Areas (HQTAs) as defined by CARB. These areas, by policy definition, meet a baseline threshold of transit accessibility and connectivity. Assigning a score of zero would inaccurately represent these stations as lacking transit access entirely. Thus, the 0.5 floor reflects their guaranteed baseline performance. Additionally, several HQTA stations (~50) are not connected to the road network (e.g., located in the center of the airport), so these stations also received a score of zero.

- **Housing Affordability (HA): 0 to 2.0:** Affordability scores range from 0 (least affordable) to 2 (most affordable) based on modeled cost burdens, income-relative H+T metrics, and the presence of subsidized housing. A floor score of zero is used here to allow full differentiation between highly unaffordable and more equitable station areas, acknowledging that some locations may offer negligible affordability support.

- **Social Vulnerability (SV): 0 to 2.0:** Social vulnerability scores reflect the relative presence of disadvantaged populations and equity-related factors (e.g., racial/ethnic minority status, linguistic isolation, disability, and housing instability). This score ranges from 0 (lowest vulnerability presence) to 2 (highest), enabling a full range of equity-related clustering across station areas.

3.3 Data and Variables

Table 1 below provides an explanation of the datasets used in this project. The variables used are categorized into three areas: built environment, housing affordability, and minority presence, measured via social vulnerability indicators. These categories follow the conceptual framework presented in Figure 5.

Table 1. Data and Variables

Name	Description	Source	Mean	(S.D.)
		Built Environment		
Act. Dens.	D1B_ (Gross population density (people/acre) on unprotected land) + D1C_ (Gross employment density Uobs/acre) on unprotected land)	EPA* Smart Data (2021)	46.729	40.543
Transit Fq.	Aggregate frequency of transit service [D4c] per capita	EPA Smart Data (2021)	-20,917.142	37,284.939
Emp. Mix	8-tier employment entropy (denominator set to observed employment types in the CBG)	EPA Smart Data (2021)	0.699	0.076
Int. Dens.	Street intersection density (weighted, auto-oriented intersections eliminated)	EPA Smart Data (2021)	165.014	51.169
Job Acc.	Jobs within 45-minute transit commute, distance decay (walk network travel time, GTFS schedules) weighted	EPA Smart Data (2021)	304,040.962	236,018.312
Reg. Acc.	Proportional Accessibility of Regional Destinations - Transit: Employment accessibility expressed as a ratio of total MSA accessibility	EPA Smart Data (2021)	-5,232.107	16,750.470
Walkscore	stopwalkscore	WalkScore Inc. (2024)	75.098	15.592

Name	Description	Source	Mean	(S.D.)
CBD Acc.	Proximity (Reversed Distance) to CBD, miles	Hamidi, 2015	-4.868	6.031
		Affordability		
Mod.HT%	Housing + Transportation Costs % Income for the Regional Moderate Household	CNT** (2020)	50.480	10.860
HH1 HT%	hh1 - Median income family (income"' MHHI) hh size"' 4 commuters "' 2 ht - The modeled housing and transportation costs as a percent of income	LAI*** (2016)	44.463	5.159
HH2 HT%	hh2 - Very low-income family (income"' national poverty line) hh size"' 1 commuters "' 1 ht - The modeled housing and transportation costs as a percent of income	LAI (2016)	96.764	11.742
HH3 HT%	hh3 - Working individual (income "' 50% of MHHI) hh size"' 1 commuters "' 1 ht - The modeled housing and transportation costs as a percent of income	LAI (2016)	50.980	6.562
LIHTC. Cap.	LIHTC units/Population		1.254	2.200
		Social Vulnerability/Minority Presence		

Name	Description	Source	Mean	(S.D.)
Soc-Ec. Vul.	Percentile ranking for Socioeconomic Status theme summary	CDC**** Social Vulnerability (2020–2023)	0.532	0.199
Minority	Percentile ranking for Racial and Ethnic Minority Status theme	CDC Social Vulnerability (2023)	0.591	0.210
H+T Vul.	Percentile ranking for Housing Type/Transportation theme	CDC Social Vulnerability (2020)	0.613	0.142
0-Car %	% of 0-car HH	EPA Smart Data (2021)	0.154	0.127

**Environmental Protection Agency*
*** Center for Neighborhood Technology*
**** Centers for Disease Control*

This project integrates a multi-dimensional dataset capturing built environment characteristics, housing affordability, and social vulnerability across High-Quality Transit Area (HQTA) station areas in California. Built environment indicators are primarily drawn from the 2021 Smart Location Database developed by the Environmental Protection Agency (EPA) and include metrics such as gross population and employment density (Activity Density), intersection density (D3B), land use diversity (D2B_E8MIX), transit service frequency (D4E_), and regional job accessibility via transit (D5BR, D5DR). These are supplemented by WalkScore data and proximity to central business districts (CBD Access) to assess pedestrian and urban integration.

Housing affordability is modeled through a combination of sources, including the Center for Neighborhood Technology (CNT) (2020) and Location Affordability Index (LAI) (2016), which estimate housing and transportation costs as a share of income for various household types—from moderate-income families to low-income individuals. Additionally, the ratio of Low-Income Housing Tax Credit (LIHTC) units to population serves as a proxy for affordable housing supply. Social vulnerability is measured using the CDC Social Vulnerability Index (SVI) percentiles across four categories: socioeconomic status, household characteristics, racial and ethnic minority status, and housing type/transportation.

Because the CDC Social Vulnerability Index (SVI) is calculated at the census tract level, we replicated the index methodology using data available at the block group level. Table 2 outlines the specific census tables used in this replication. Minor discrepancies exist between our dataset and the CDC's original data, primarily due to differences in data availability and collection years. While the CDC SVI relies on the 2018–2022 American Community Survey (ACS) 5-year estimates, our analysis uses ACS 1-year estimates from 2020 to 2023, where possible. Additionally, the variable for households without vehicles was sourced from the EPA Smart Location Database rather than the ACS.

There are also definitional adjustments due to data limitations. The CDC defines poverty as individuals living below 150% of the Federal Poverty Level (FPL), whereas our study uses the standard FPL threshold due to data constraints. Similarly, the CDC defines housing cost burden as the percentage of occupied housing units with incomes under $75,000 that spend more than 30% of their income on housing costs. At the block group level, a combined measure of income and housing burden is unavailable; thus, we define housing cost burden more broadly as the percentage of all households spending more than 30% of their income on housing, regardless of income level.

Table 2. Data Sources for CDC Social Vulnerability Index

Name	Description	Table for Project Methodology	Table for CDC* Methodology
		Socioeconomic Status	
EP_POV	Percentage of persons below poverty level	ACS** Table B17021: *Poverty Status of Individuals by Living Arrangement* (2021)	ACS Table S1701: *Poverty Status in the Past 12 Months* (2018–2022)
EP_UNEMP	Percentage of civilians (age 16+) who are unemployed	ACS Table B23025: *Employment Status for the Population 16 Years and Over* (2023)	ACS Table DP03: *Selected Economic Characteristics* (2018–2022)
EP_HBURD	Percentage of housing cost-burdened occupied housing units with annual income less than $75,000 (30%+ of income spent on housing costs)	ACS Table B25140: *Housing Costs as a Percentage of Household Income in the Past 12 Months* (2023)	ACS Table S2503: *Financial Characteristics* (2018–2022)
EP_NOHSDP	Percentage of persons with no high school diploma (age 25+)	ACS Table B15003: *Educational Attainment for the Population 25 Years and Over* (2023)	ACS Table B06009: *Place of Birth by Educational Attainment in the United States* (2018–2022)
EP_UNINSUR	Percentage of uninsured persons	ACS Table B27010: *Types of Health Insurance Coverage by Age* (2023)	ACS Table S2701: *Selected Characteristics of Health Insurance Coverage in the United States* (2018–2022)
		Household Characteristics	
EP_AGE65	Percentage of persons aged 65 and older estimate	ACS Table B01001: *Sex by Age* (2023)	ACS Table S0101: *Age and Sex* (2018–2022)
EP_AGE17	Percentage of persons aged 17 and younger estimate	ACS Table B01001: *Sex by Age* (2023)	ACS Table DP05: *ACS Demographic and Housing Estimates* (2018–2022)
EP_DISABL	Percentage of civilian noninstitutionalized population with a disability estimate	ACS Table B23024: *Poverty Status in the Past 12 Months by Disability Status for the Population 20-64 Years* (2023)	ACS Table DP02: *Selected Social Characteristics in the United States* (2018–2022)
EP_SNGPNT	Percentage of single-parent households with children under 18 estimate	ACS Table B11003: *Family Type by Presence and Age of Own Children Under 18 Years* (2023)	ACS Table DP02: *Selected Social Characteristics in the United States* (2018–2022)
EP_LIMENG	Percentage of persons (age 5+) who speak English "less than well" estimate	ACS Table B16004: *Age by Language Spoken at Home by Ability to Speak English for the Population 5 Years and Older* (2023)	ACS Table B16005: *Nativity by Language Spoken at Home by Ability to Speak English for the Population 5 Years and Over* (2018–2022)

Name	Description	Table for Project Methodology	Table for CDC* Methodology
		Racial and Ethnic Minority Status	
EP_MINRTY	Percentage minority (Hispanic or Latino, Black and African American, American Indian and Alaska Native, Asian, Native Hawaiian or Other Pacific Islander, Two or More Races, and Other Races)	ACS Table B02001: *Race* (2023)	ACS Table DP05: *ACS Demographic and Housing Estimates* (2018–2022)
		Housing Type/Transportation	
EP_MUNIT	Percentage of housing in structures with 10 or more units estimate	ACS Table B25024: *Units in Structure* (2023)	ACS Table DP04: *Selected Housing Characteristics* (2018–2022)
EP_MOBILE	Percentage of mobile homes estimate	ACS Table B25024: *Units in Structure* (2023)	ACS Table DP04: *Selected Housing Characteristics* (2018–2022)
EP_CROWD	Percentage of occupied housing units with more people than rooms estimate	ACS Table B25014: *Tenure by Occupants per Room* (2023)	ACS Table DP04: *Selected Housing Characteristics* (2018–2022)
EP_NOVEH	Percentage of households with no vehicle available estimate	EPA*** Smart Location Database (2021)	ACS Table DP04: *Selected Housing Characteristics* (2018–2022)
EP_GROUPQ	Percentage of persons in group quarters estimate	Decennial Census P17: *HOUSEHOLD TYPE (INCLUDING LIVING ALONE) BY RELATIONSHIP* (2020)	ACS Table B26001: *Group Quarters Population* (2018–2022)

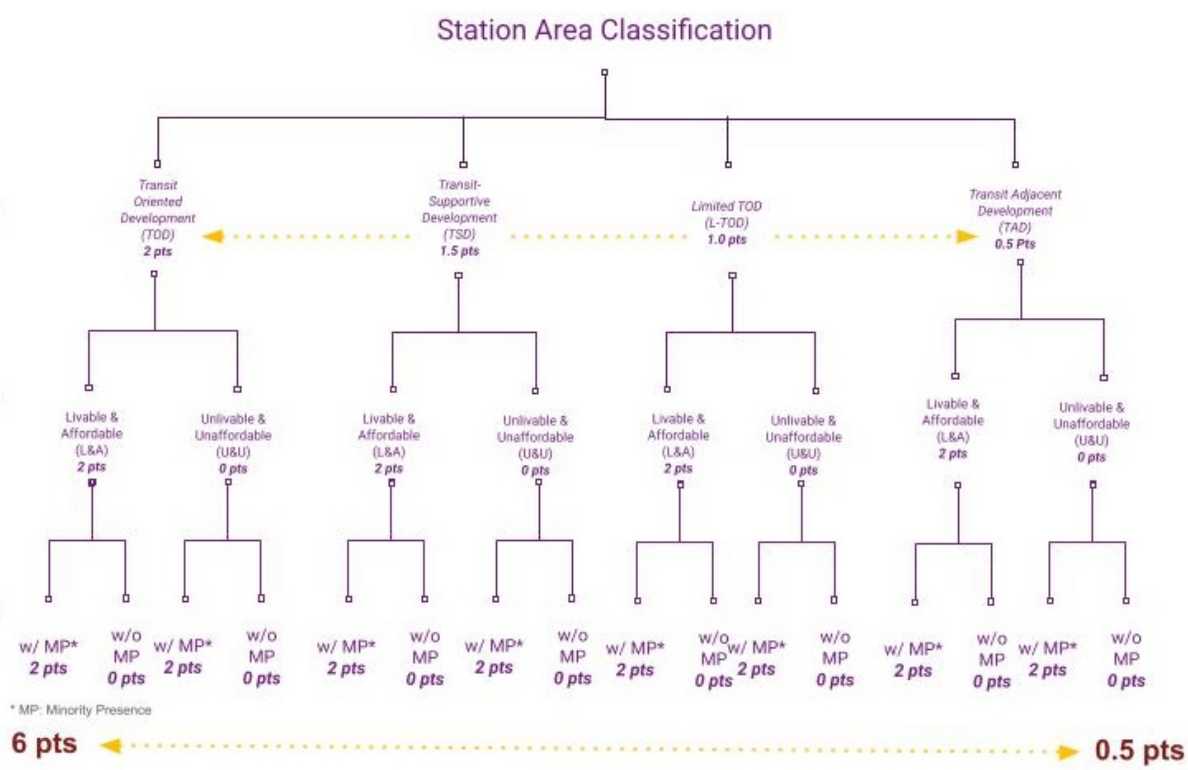
***Centers for Disease Control**
**** American Community Survey**
***** Environmental Protection Agency**

All variables were collected at the census block group level, with the exception of the Location Affordability Index, which was available at the census tract level. We used census population-weighted centroids to spatially aggregate these indicators to each station area using a 1.5-mile pedestrian network buffer around each transit station.

4. Result and Discussion

As shown in Figure 6, we implement a hierarchical station area scoring framework that integrates built environment characteristics, housing affordability, and social vulnerability to classify each transit station area. The total composite score ranges from 0.5 to 6.0, with each dimension contributing incrementally based on cluster membership. Built environment typologies range from Transit-Oriented Development (2 pts) to Transit-Adjacent Development (0.5 pts), reflecting the degree of physical integration with high-quality transit. Affordability and social equity layers are then overlaid, with additional points assigned based on whether areas are both livable and affordable, as well as whether they demonstrate a focus on socially vulnerable or minority populations. This structured logic allows for a nuanced classification of station areas—distinguishing, for example, between high-performing equitable TODs and more exclusionary or disconnected transit-adjacent areas—providing a robust foundation for spatial equity and accessibility analysis.

Figure 6. Composite Scoring Hierarchy for Classifying Transit Station Areas



4.1 Built Environment Classification of HQTA Station Areas

The four built environment clusters derived from the multivariate analysis provide a clear typology of station area urban form across California's HQTA network. As detailed in Table 3, these clusters reflect meaningful variation in density, transit access, connectivity, land use diversity, and proximity to central business districts. The first cluster, labeled Transit-Oriented Development

(TOD), comprises station areas with the highest levels of activity density, transit frequency, intersection density, and walkability, alongside close access to the CBD—hallmarks of compact, well-integrated urban environments. The second cluster, Transit-Supportive Development (TSD), is characterized by moderate scores across these same indicators, typically located along secondary corridors with adequate but not exceptional transit integration. The third cluster, Limited Transit-Oriented Development (L-TOD), includes peripheral or suburban nodes with modest land use and transit characteristics. Finally, Transit-Adjacent Development (TAD) areas show consistently low built environment scores, indicating station areas that formally qualify as HQTA zones but functionally lack the urban form required to support high-quality transit use. These typologies serve as the foundation for the subsequent layering of affordability and social equity dimensions.

Table 3. Summary of Built Environment Cluster Characteristics and Interpretations

Cluster	Indicator Highlights	Interpretation	Label
Transit-Oriented Development (TOD)	High: Activity Density, Transit Frequency, Intersection Density, WalkScore; Low CBD Distance	Dense, walkable, well-integrated urban nodes near downtowns	High-density, well-connected, transit-integrated urban nodes
Transit-Supportive Development (TSD)	Moderate: Density, Land Use Mix, Connectivity, Accessibility; Lower WalkScore	Transit-friendly corridors or secondary centers with moderate urban form	Moderately dense, transit-friendly but less walkable environments
Transit-Accessible Development (L-TOD)	Low-to-Moderate: Density, Transit Frequency, WalkScore; Higher CBD Distance	Peripheral/suburban areas with limited TOD features, some transit infrastructure	Suburban nodes with limited TOD-supportive form
Transit-Adjacent Development (TAD)	Low: Density, Transit Frequency, Connectivity, WalkScore; High CBD Distance	Low-density, auto-oriented areas with limited TOD functionality despite transit access	Low-density, auto-oriented environments near transit

Figure 7 illustrates the distribution of standardized built environment indicators across the four identified station area clusters: Transit-Oriented Development (TOD), Transit-Supportive Development (TSD), Limited Transit-Oriented Development (L-TOD), and Transit-Adjacent Development (TAD). The TOD cluster consistently outperforms others, achieving the highest Z-scores across key indicators, including activity density, transit frequency, intersection density, job accessibility, and WalkScore, while maintaining the lowest distance to the CBD, signifying highly integrated, dense, and walkable urban contexts. TSD areas exhibit moderate but positive values across most dimensions, particularly in employment mix and connectivity; however, they fall short of TOD levels in regional accessibility and walkability. L-TODs demonstrate weaker built environment support, with values clustering around or slightly below the mean across all indicators, especially in transit and intersection density. TADs, in contrast, exhibit the lowest performance, with negative Z-scores across nearly every variable, most notably in walkability, transit service, and CBD access, indicating auto-oriented, low-density environments that, despite proximity to transit, lack the supportive urban form necessary for true TOD functionality. These contrasts highlight the structural differences that justify the classification of the built environment and establish the foundation for further analysis of affordability and equity dimensions.

Figure 7. Standardized Built Environment Variables by Cluster Type (TOD–TAD)

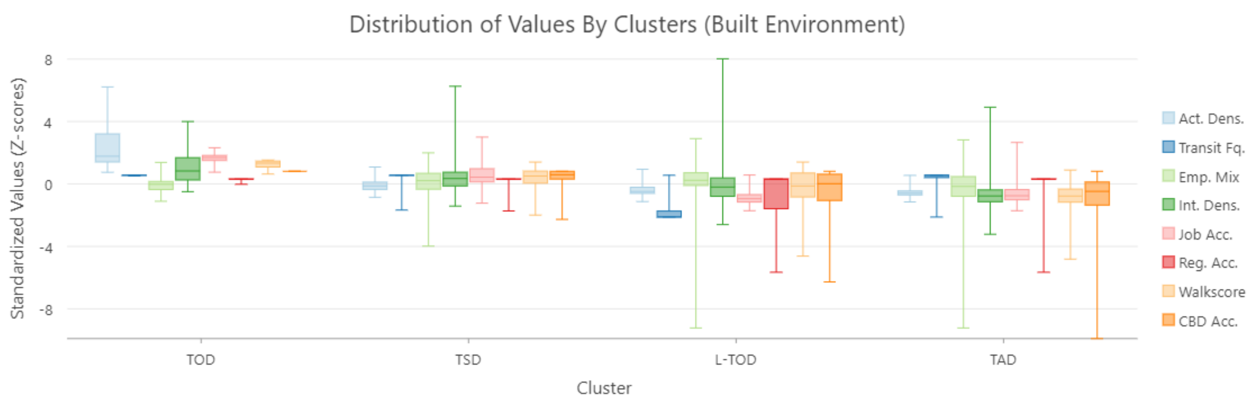


Figure 8 presents the proportional breakdown of HQTA station areas by built environment classification. The majority of station areas (38.3%) fall into the Transit-Supportive Development (TSD) category, reflecting moderately dense environments with partial support for transit-oriented lifestyles, characterized by mid-frequency service, a moderate land use mix, and somewhat walkable street networks. This is followed by Transit-Adjacent Development (TAD) at 25.6%, which includes station areas that technically meet HQTA definitions but lack supportive built environment features, such as intersection density or walkability, suggesting a disconnect between transit access and surrounding urban form. Limited Transit-Oriented Development (L-TOD) accounts for 21.97% of stations, capturing lower-density suburban or edge-area zones that offer some transit access but insufficient land use or design integration. Notably, only 14.1% of stations are classified as full Transit-Oriented Development (TOD)—the typology most aligned with compact, walkable, high-access urban design. This distribution highlights the rarity of fully supportive TOD environments, even within HQTA boundaries, and underscores the spatial mismatch between transit infrastructure and the readiness of the built environment across the state.

Figure 8. Proportion of HQTA Stations by Built Environment Typology

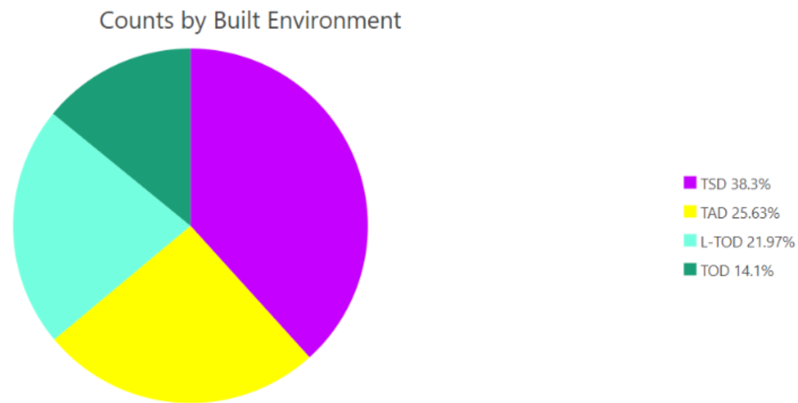
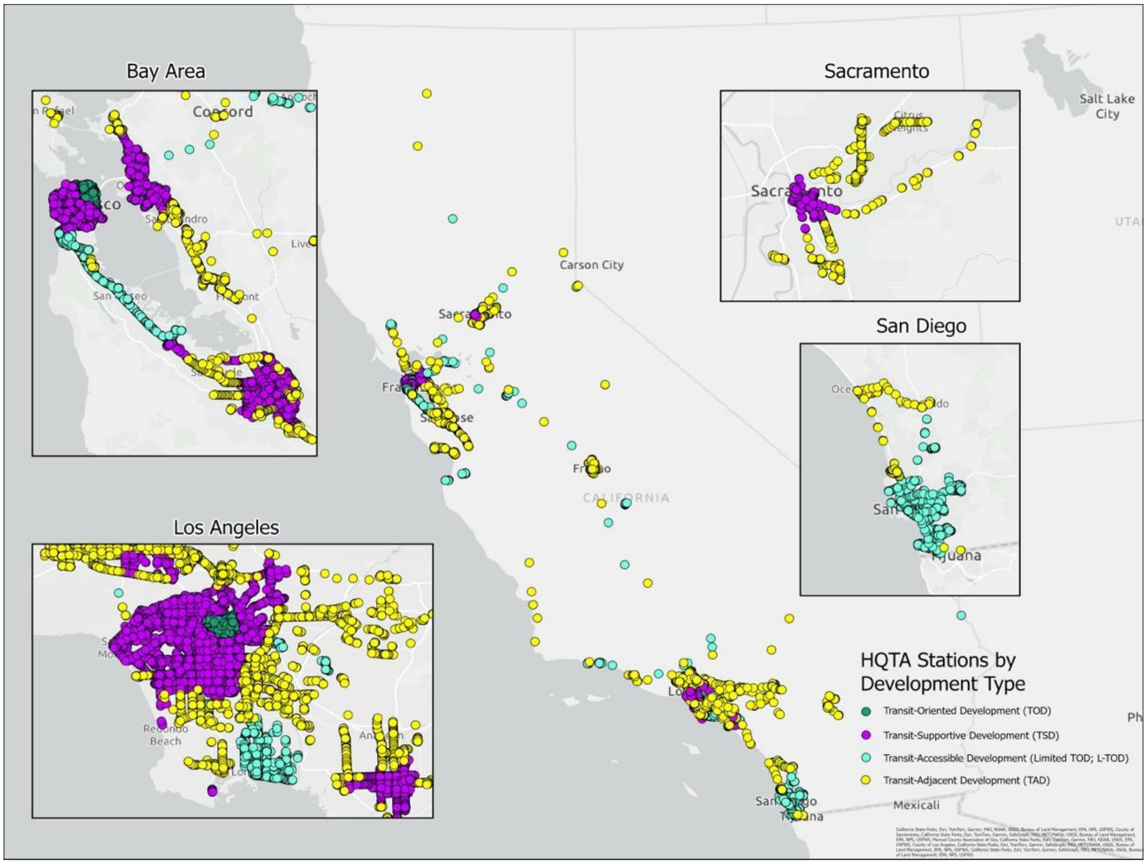


Figure 9 maps the spatial distribution of HQTA station areas across California, categorized by their built environment typology. The Transit-Oriented Development (TOD) category, shown in purple, is densely clustered in the urban cores of Los Angeles, San Francisco, and Sacramento. These areas exhibit the highest levels of density, walkability, and transit integration, aligning with compact development patterns and supportive land use policies. The Bay Area and Los Angeles regions show particularly dense groupings of TODs around BART and Metro rail systems, while Sacramento's central city also contains a significant concentration of TODs. In contrast, Transit-Supportive Developments (TSDs), shown in yellow, tend to follow radial transit corridors and extend outward from central cities into moderately dense neighborhoods. TSDs are especially visible in the East Bay, Peninsula, and Orange County, where transit frequency remains relatively strong, but the surrounding built form is less consistently walkable or dense.

The Limited Transit-Oriented Development (L-TOD) typology, indicated in teal, is most prominently concentrated in San Diego County and the Inland Empire, where land use is more dispersed and transit networks serve broader, lower-density catchments. These areas possess some degree of transit accessibility but lack the supporting urban design features, such as land use mix and street connectivity, that characterize full TODs. Finally, Transit-Adjacent Developments (TADs) (shown in light blue) are scattered across the urban fringe, especially in parts of Southern California, including outer Los Angeles, Riverside, and San Bernardino counties. Despite falling within designated HQTA boundaries, these areas lack the built environment conditions necessary to support active or transit-oriented travel behavior. The regional disparities evident in this map underscore the uneven relationship between transit infrastructure and supportive urban form, highlighting opportunities for targeted planning and investment to bridge the gap between transit access and true transit-oriented urban environments.

Figure 9. California HQTA Stations Categorized by Built Environment Cluster



4.2 Affordability Stratification Within Built Environment Typologies

Figure 10 maps HQTA station areas across California by their overall housing affordability classification, independent of built environment context. Station areas are grouped into two clusters: “Livable & Affordable” (shown in blue) and “Unlivable & Unaffordable” (shown in red). The Livable & Affordable cluster dominates the landscape, particularly across the Bay Area, Los Angeles, and Sacramento regions. These areas tend to offer relatively lower housing and transportation cost burdens for multiple household types, alongside a stronger presence of income-restricted housing, as indicated in earlier affordability metrics.

However, a significant number of Unlivable & Unaffordable station areas are visible throughout the map, especially in South Los Angeles, eastern San Diego, and parts of the Bay Area’s East Bay and Peninsula. These are areas where affordability is strained despite HQTA designation, likely due to high housing costs, limited subsidized housing, or increasing displacement pressures. This spatial distribution underscores the reality that not all HQTA station areas are equally livable from an affordability perspective and highlights the importance of layering built environment characteristics to better understand where affordability gaps persist despite transit access.

Figure 10. Affordability Stratification Within Built Environment Typologies

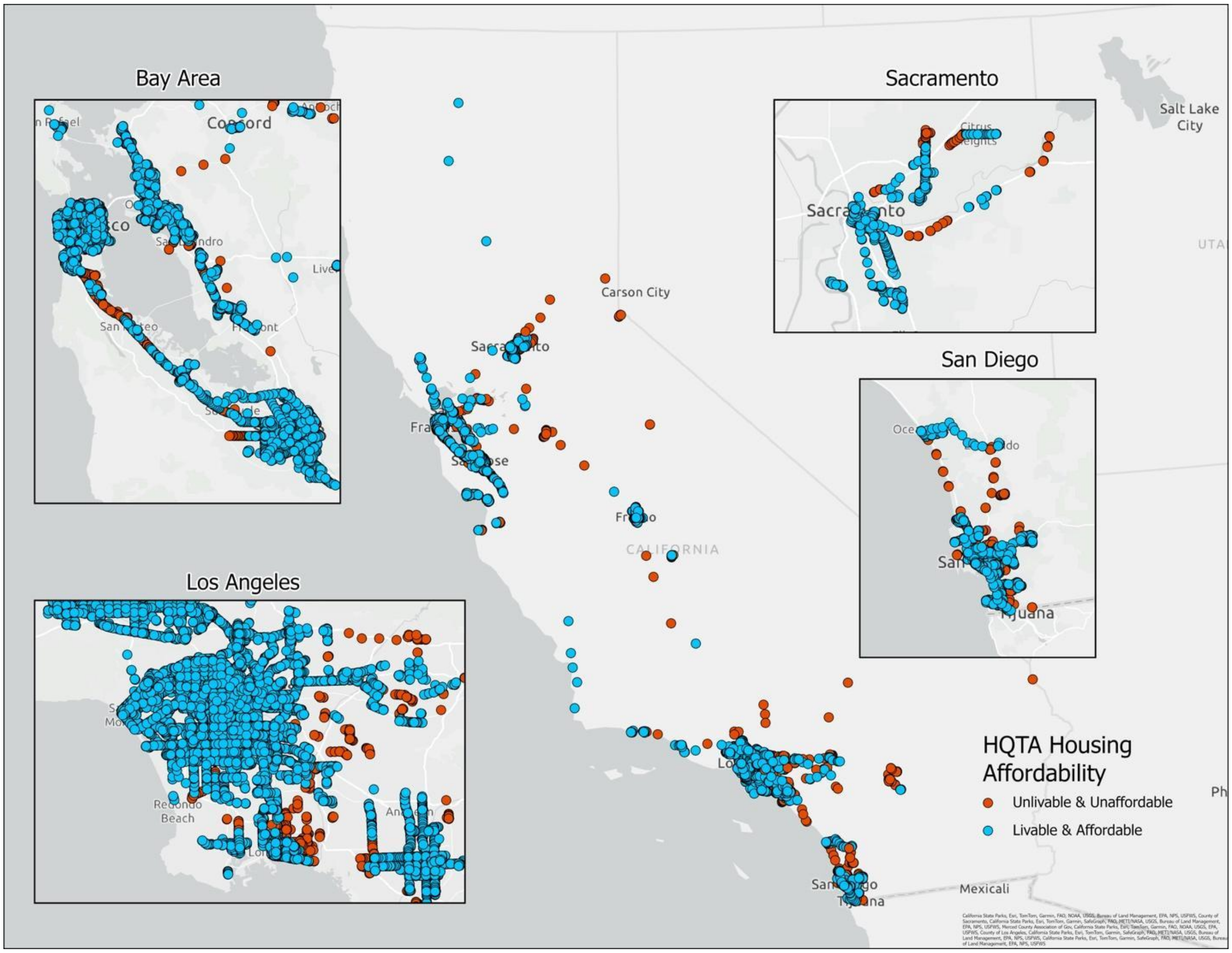


Figure 11 presents a summary distribution of station areas based on overall affordability classification. The vast majority of HQTA stations (93.6%) fall into the Livable & Affordable cluster, suggesting that, on average, most stations meet affordability thresholds when modeled housing and transportation (H+T) cost burdens and subsidized housing availability are considered. This high proportion may reflect the concentration of transit infrastructure in areas that historically offered more affordable housing, as well as the presence of LIHTC-supported developments and other affordability interventions in many regions.

However, 6.36% of stations are categorized as Unlivable and Unaffordable, representing areas where the cost burden significantly exceeds regional norms across all modeled household types. These areas, though numerically smaller, are spatially and socially significant, often appearing in high-demand or rapidly gentrifying locations where affordability protections may not be keeping pace with development pressure. The presence of this cluster highlights the need for proactive housing policies in transit-served neighborhoods and provides justification for further stratifying affordability by built environment context.

Figure 11. Share of HQTA Station Areas by Affordability Cluster

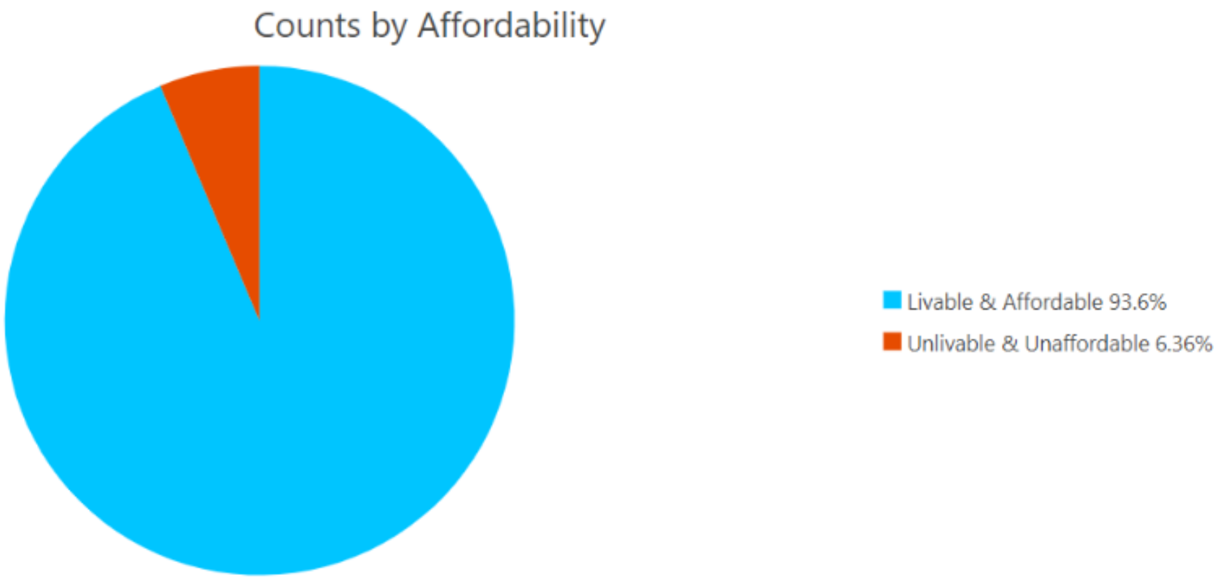
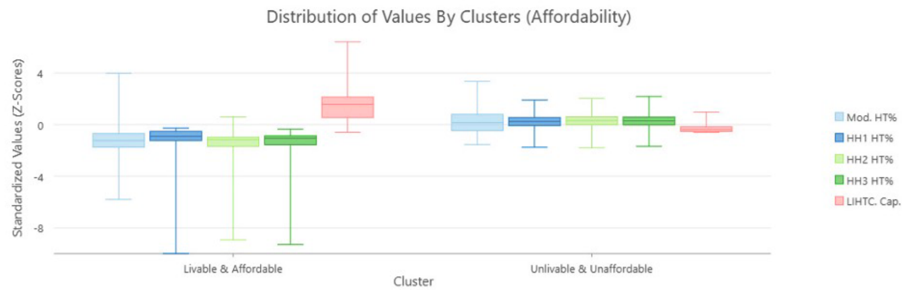


Figure 12 compares affordability clustering across the four built environment typologies—Transit-Oriented Development (TOD), Transit-Supportive Development (TSD), Limited Transit-Oriented Development (L-TOD), and Transit-Adjacent Development (TAD)—based on standardized housing and transportation (H+T) cost burdens and the per capita presence of LIHTC-supported units. Across all four panels, a consistent pattern emerges: "Livable & Affordable" clusters exhibit lower cost burdens across income groups and higher levels of subsidized housing. In contrast, "Unlivable & Unaffordable" clusters show elevated cost burdens—especially for very low-income (HH2) and single-worker (HH3) households—and a diminished presence of LIHTC units. Within TOD station areas (top panel), the two clusters are sharply differentiated, with the Livable cluster showing significantly lower costs and greater LIHTC saturation. This suggests that some high-density, transit-rich urban centers are successfully achieving affordability through coordinated land-use and housing policies.

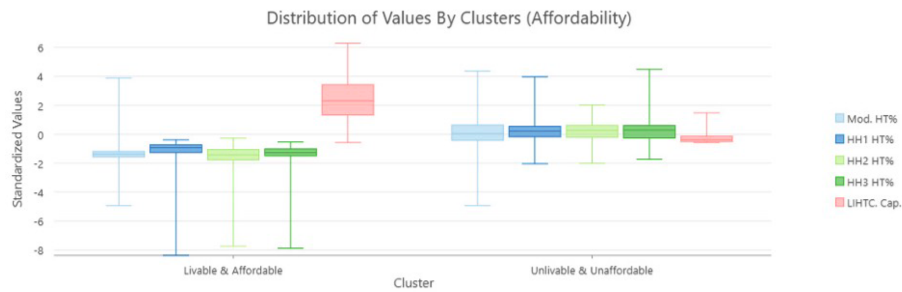
Affordability variation is particularly notable in TSD station areas (second panel), where the Unlivable cluster demonstrates the highest cost burdens across all household types and the lowest LIHTC representation, indicating affordability breakdowns in mid-density, corridor-based environments. In L-TOD areas (third panel), the spread between clusters is less pronounced, likely reflecting more uniformly moderate affordability in suburban contexts with weaker market pressures. Interestingly, TAD station areas (bottom panel) show a more balanced affordability profile: while their built environment is least supportive of transit-oriented outcomes, they include a substantial share of Livable & Affordable clusters, possibly due to lower land costs or legacy affordability mechanisms. Collectively, Figure 13 illustrates that the quality of the built environment alone does not determine affordability outcomes—and that effective housing policy is crucial across all station typologies, not just in high-density cores.

Figure 12. Boxplots of Affordability Metrics Across Built Environment Types

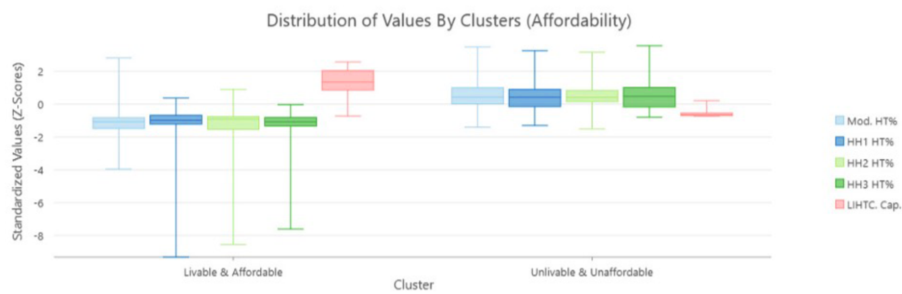
TOD:



TSD:



L-TOD:



TAD:

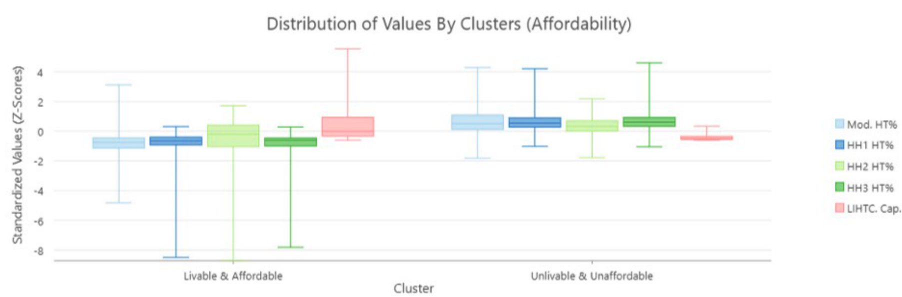


Figure 13 displays the spatial distribution of HQTA station areas classified into an eight-category typology that integrates both built environment type (Transit-Oriented Development (TOD), Transit-Supportive Development (TSD), Limited TOD (L-TOD), and Transit-Adjacent Development (TAD)) and affordability status (Livable & Affordable (L&A) or Unlivable & Unaffordable (U&U)). This composite framework offers a more comprehensive view of station area typologies, capturing not only physical form and transit accessibility but also whether these places are affordable and livable for a range of households. Each category reveals important regional and structural patterns that have implications for equity-centered planning and investment.

The TOD + L&A cluster (dark red) is primarily concentrated in high-density urban centers with strong transit infrastructure and housing affordability supports. These stations are most heavily clustered in central and south Los Angeles, downtown Sacramento, and around Oakland and parts of San José in the Bay Area. These areas tend to reflect legacy urban cores or places where proactive housing and transit investments have aligned. In contrast, TOD + U&U stations (red) also appear in central cities—especially in San Francisco, Pasadena, and parts of Silicon Valley—but they face significant affordability challenges, likely due to high housing demand, rising costs, and an insufficient supply of affordable housing. The juxtaposition of TOD areas that are both livable and unlivable demonstrates that transit access alone does not guarantee equity, particularly in economically pressured regions.

The TSD + L&A cluster (magenta) forms a broad band of coverage in South LA, inner East Bay suburbs, and San Diego's Mid-City and South Bay neighborhoods. These are moderately dense, transit-accessible places with decent walkability and somewhat supportive affordability conditions. However, TSD + U&U stations (light pink) are widespread across Orange County, inland LA suburbs such as El Monte and Pomona, and northern San Diego County, highlighting places where the built environment supports transit to some degree but affordability is lacking, suggesting missed opportunities for equitable TOD outcomes.

L-TOD + L&A and L-TOD + U&U stations (represented by gray tones) are predominantly located in lower-density suburbs and edge cities, particularly in the Inland Empire, northern San Diego County, eastern Contra Costa County, and outer Sacramento suburbs. These stations are generally auto-oriented or park-and-ride in nature. L-TODs with affordability (L&A) are fewer but tend to be located in older or less competitive housing markets. L-TOD + U&U stations, by contrast, reflect low-density environments that still impose high H+T costs on residents, especially when transit service is limited or disconnected from jobs.

Finally, TAD + L&A and TAD + U&U clusters are scattered across the periphery of the HQTA network, including far East Bay suburbs, outer Inland Empire, and exurban San Diego County. These are places that formally meet the 0.5-mile HQTA transit access threshold but lack walkability, density, and transit frequency, and thus rely heavily on automobiles. Interestingly, while some TADs offer affordability (L&A), likely due to their distance from urban job centers and lower land values, many still fall into the U&U category, underscoring that mere proximity to transit is insufficient to generate equitable, livable outcomes without supportive land use and affordability interventions.

Figure 13. Composite Classification of HQTA Station Areas by Urban Form and Affordability Status

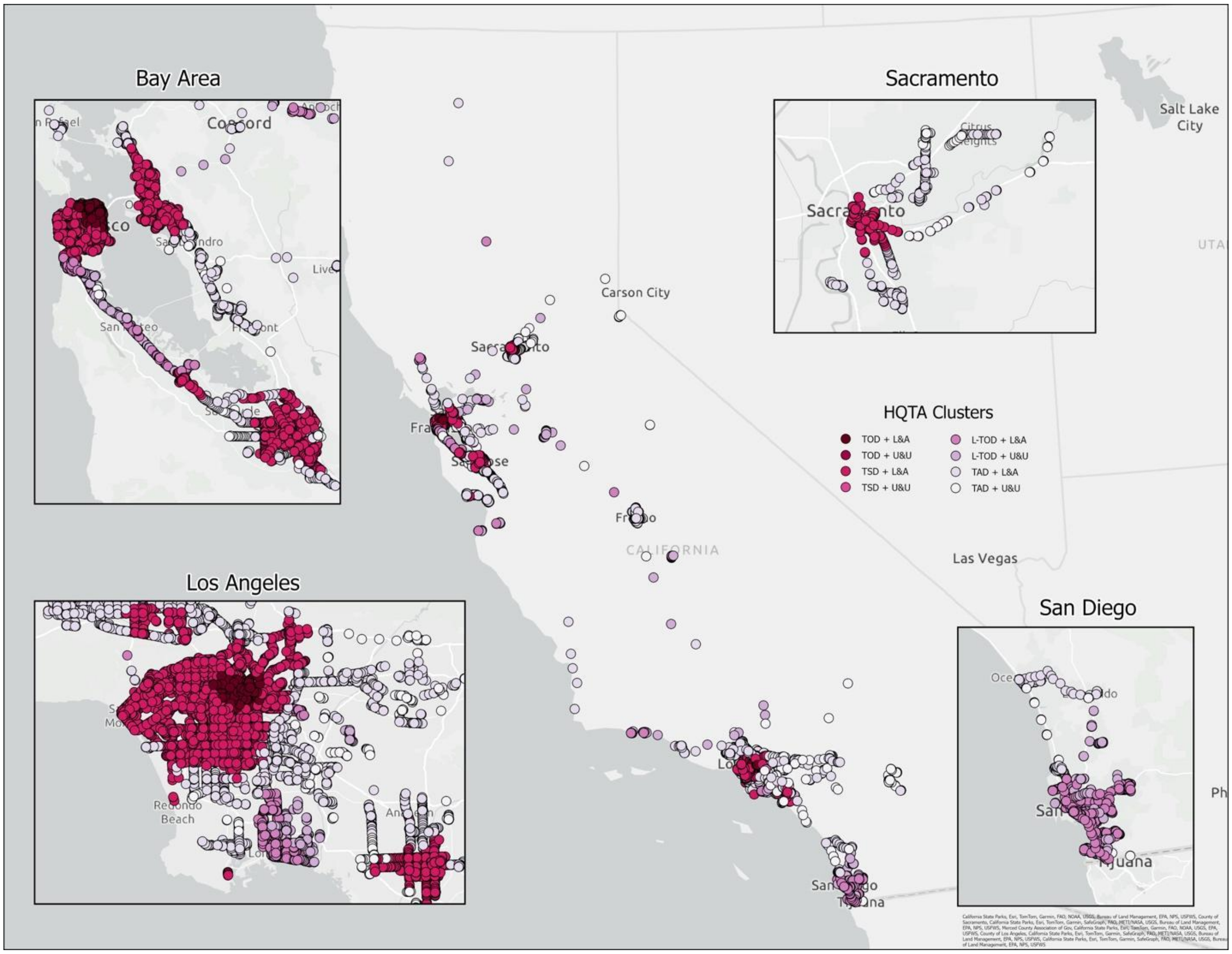


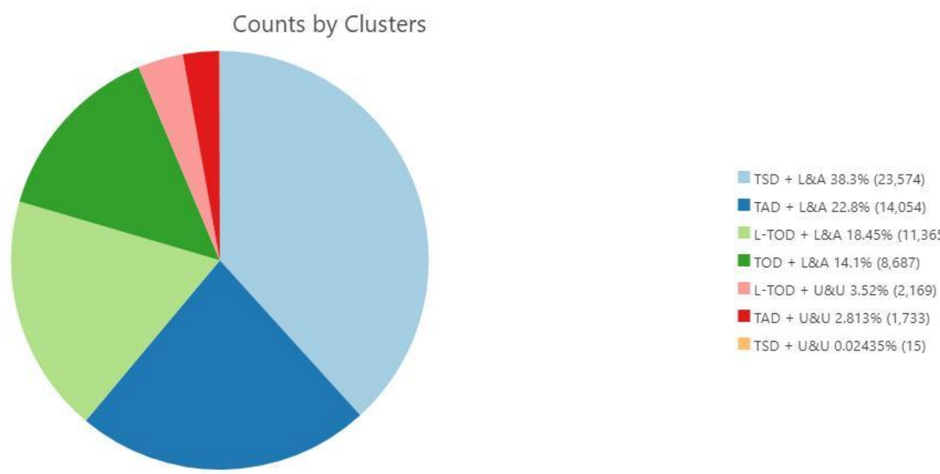
Figure 14 displays the proportional distribution of HQTA station areas across the eight built environment + affordability clusters, offering a quantitative snapshot of how station typologies are composed statewide. The largest share (38.3% of all stations) falls into the TSD + Livable & Affordable (L&A) category, indicating that moderately dense, transit-supportive station areas make up the core of the HQTA network and often align with affordability. These are likely the kinds of places with decent transit service, lower-cost housing, and relatively balanced land use mixes, such as portions of South LA, the East Bay suburbs, and central San Diego.

The second-largest cluster, TAD + L&A, accounts for 22.89% of stations. These are lower-density, auto-oriented station areas that still meet basic affordability criteria—likely due to lower land values in suburban or exurban areas of the Inland Empire, outer East Bay, or northern San Diego County. L-TOD + L&A and TOD + L&A each make up 18.45% and 14.1%, respectively, reinforcing that while full TODs are relatively limited in number, many of them do offer meaningful affordability and livability.

In contrast, the Unlivable & Unaffordable (U&U) station types are far less prevalent but critically important from an equity and policy perspective. L-TOD + U&U and TAD + U&U represent 3.52% and 2.81% of stations, respectively, illustrating cases where affordability has broken down in suburban or fringe areas that were never well-integrated into the transit or land use system. TOD + U&U stations are rare in number but significant in impact, making up just 2.13% (based on the map, though not listed on the chart), and are likely found in highly gentrified areas such as central San Francisco or Pasadena. Finally, TSD + U&U is an extreme outlier, representing just 0.02% of the network (15 stations total), but still emblematic of affordability breakdowns even in moderately supportive environments.

Together, this distribution reinforces two key points: First, most HQTA stations combine at least moderate transit support with affordability, suggesting many planning successes. Second, the relatively small but spatially concentrated U&U station areas represent urgent equity intervention zones, where housing policy and transit access are misaligned, and residents face both mobility and affordability barriers.

Figure 14. Distribution of HQTA Station Areas by Built Environment and Affordability Cluster



4.3 Stratifying Social Equity Outcomes by Built Environment and Affordability Type

Figure 15 displays the spatial distribution of minority presence across HQTA station areas in California, independent of affordability status or built environment typology. Station areas identified as having elevated concentrations of racial and ethnic minority populations are shown in magenta, while those without minority presence are marked in yellow. The visual reveals that the vast majority of HQTA stations, across all major metropolitan regions, are in areas with substantial minority populations. This pattern is especially pronounced in Los Angeles County, the Bay Area, Sacramento, and San Diego, where the presence of minorities is nearly ubiquitous along most transit corridors.

Only a limited number of HQTA stations, primarily located on the suburban edges of systems such as BART, LA Metro, and MTS (San Diego), fall outside these high-minority contexts. These "non-minority presence" stations (yellow) are sparsely scattered and tend to occur in more affluent, less racially diverse communities, particularly in parts of Orange County, the East Bay, and northern San Diego County. The overall spatial pattern reinforces the fact that HQTA access is heavily racialized, with most stations located in or near communities of color. This sets the stage for analyzing how livability, affordability, and transit-oriented planning intersect with equity and demographic vulnerability.

Figure 15. Spatial Pattern of Racial/Ethnic Minority Presence in California HQTAs

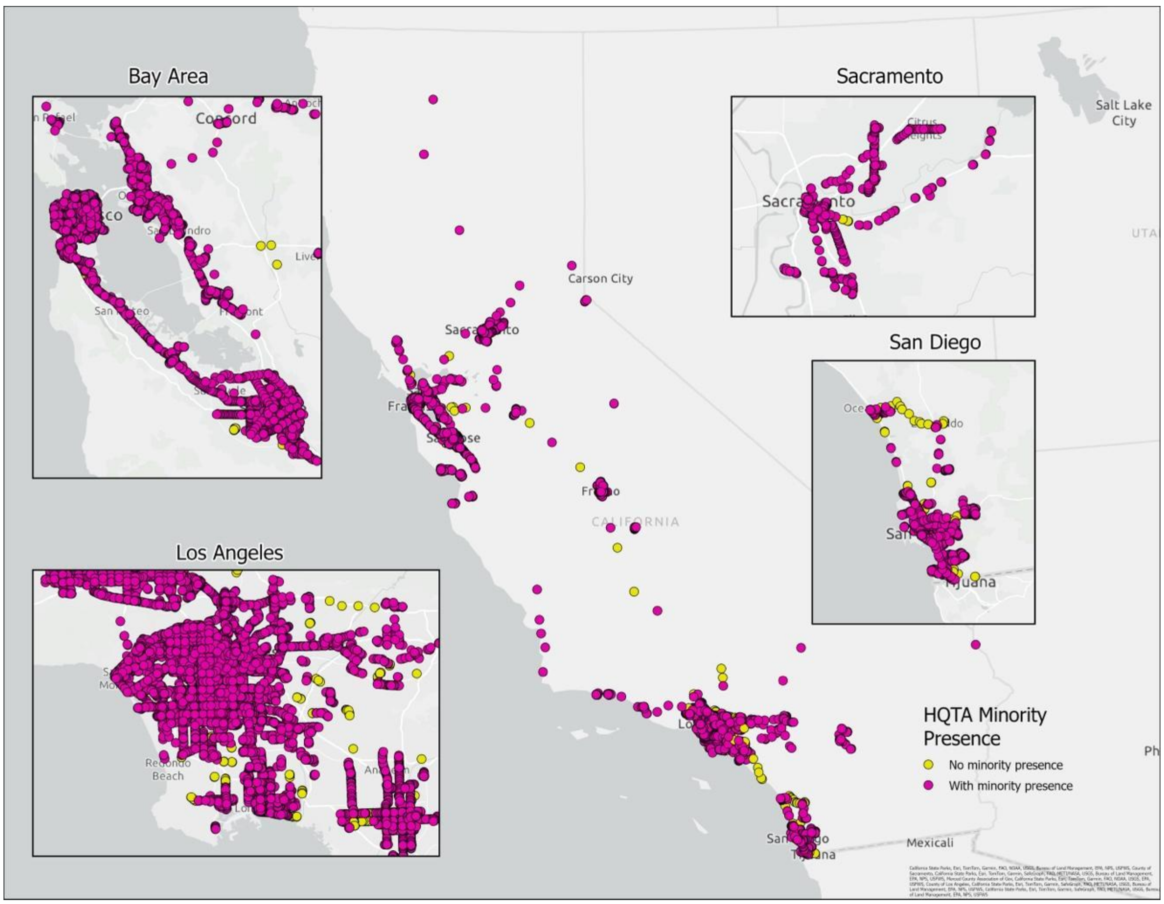
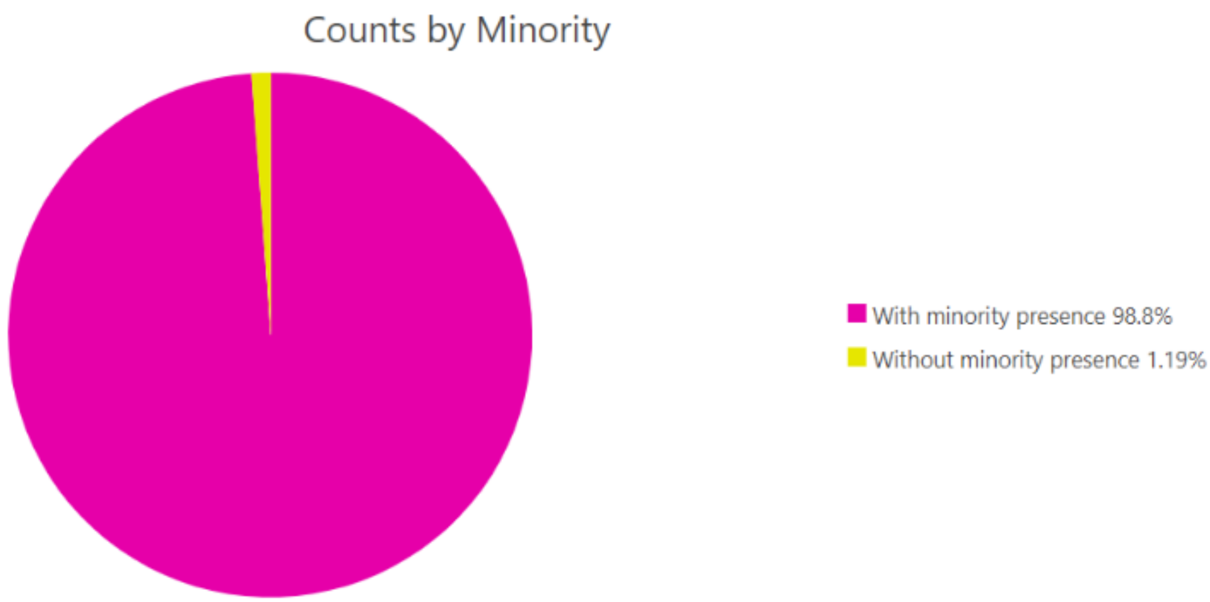


Figure 16 presents the proportional distribution of HQTA station areas by the presence of minorities. An overwhelming majority (98.8%) of stations are located in areas identified as having high concentrations of racial and ethnic minority populations, while only 1.19% are situated in neighborhoods without significant minority presence. This striking imbalance underscores the fact that California's HQTA network is overwhelmingly embedded in communities of color. Whether by historic demographic settlement patterns or the legacy of transit planning in underserved areas, the data confirm that virtually all high-frequency transit stations in the state are located in racially and ethnically diverse areas.

This finding has critical implications for equity planning. It highlights that virtually all policies and investments targeting HQTAs will disproportionately impact communities of color, meaning that issues such as displacement risk, housing affordability, and transit accessibility cannot be treated as race-neutral. Instead, equity planning must explicitly address racialized vulnerability by prioritizing anti-displacement protections, affordable housing production and preservation, and community benefits agreements in HQTA zones. Moreover, because transit investments in these areas have the potential to either reinforce exclusion or advance justice, planning frameworks must integrate racial equity as a central criterion for evaluating TOD performance. In short, this finding underscores that equitable TOD in California is inseparable from racial equity: strategies to improve transit, housing, and land use must be intentionally designed to support, rather than destabilize, the communities of color that overwhelmingly constitute the HQTA landscape.

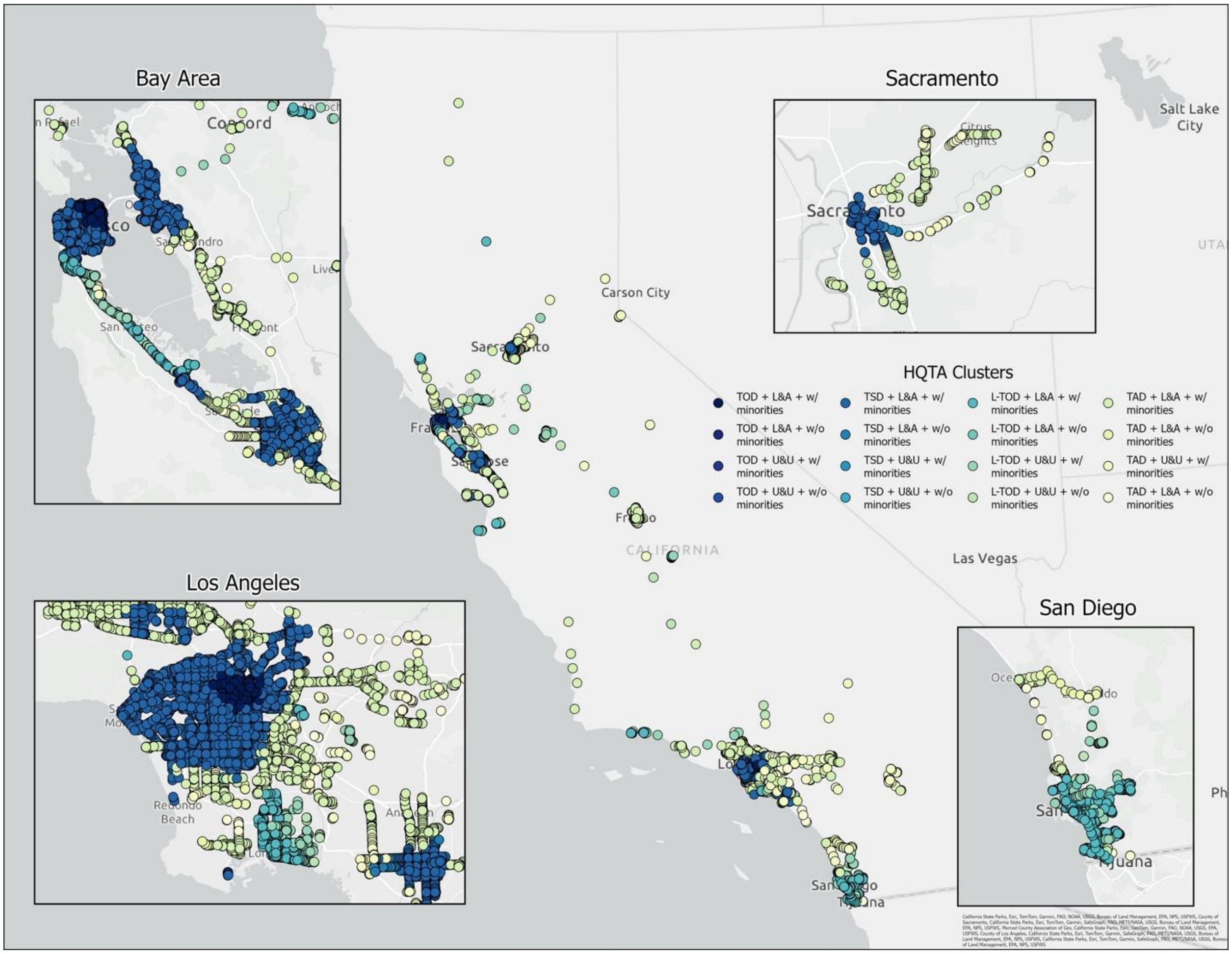
Figure 16. Share of HQTA Station Areas by Minority Population Presence



4.4 Integrated Interpretation: Built Environment × Affordability × Minority Presence

Figure 17 visualizes the final stratified typology of California's HQTA station areas, combining three critical dimensions: built environment classification (TOD, TSD, L-TOD, TAD), affordability status (Livable & Affordable [L&A] vs. Unlivable & Unaffordable [U&U]), and minority population presence (with vs. without). The resulting 16 categories provide a highly granular lens into spatial equity conditions at the station area level across the state. The map reveals striking regional differences in the spatial overlap and misalignment between transit access, affordability, and racialized social vulnerability. This is complemented by Figures 18 through 21, which illustrate boxplot comparisons of socioeconomic vulnerability, minority population share, housing + transportation (H+T) vulnerability, and zero-vehicle household share between minority-focused and non-minority-focused stations within each cluster.

Figure 17. Stratified Typology of HQTA Stations by Built Environment, Affordability, and Minority Presence (16 Clusters)



TOD Stations

This section compares minority-focused and non-minority-focused station areas within two key typologies: Transit-Oriented Development (TOD) + Livable & Affordable (L&A) and TOD + Unlivable & Unaffordable (U&U). In both typologies, minority-focused stations consistently exhibit higher levels of vulnerability across all measured dimensions. Within the TOD + L&A group, minority-serving stations exhibit markedly higher socioeconomic vulnerability and a higher concentration of minority populations, along with elevated housing + transportation (H+T) vulnerability and a greater share of zero-car households, indicating a deeper dependence on transit infrastructure. Meanwhile, non-minority TOD + L&A stations maintain lower vulnerability scores and slightly greater variability in car access, suggesting more economic and transportation flexibility. The disparities are even more pronounced in the TOD + U&U cluster, where minority-focused stations show the highest median Z-scores, approaching 2, in socioeconomic and H+T vulnerability. These areas reflect gentrification or cost-pressured zones where high-quality transit exists, but livability and inclusion have deteriorated. Overall, Figure 18 illustrates that even in well-connected TOD environments, racialized disadvantage amplifies exposure to economic and transportation hardship, reinforcing the need to incorporate social vulnerability metrics into TOD planning frameworks.

Figure 18. Distribution of Vulnerability Indicators in TOD + L&A
and TOD + U&U by Minority Presence

As shown in Figure 17, in central Los Angeles, downtown Oakland, and Sacramento's central grid, the TOD + L&A + with minority presence cluster (darkest blue) is dominant, reflecting highly urbanized station areas where dense transit infrastructure, affordability supports (e.g., LIHTC units), and historically underrepresented communities intersect. These areas reflect both equity potential and vulnerability: they are transit-rich and affordable but face long-term risks of displacement without sustained policy intervention.

In contrast, TOD + L&A + stations without minority presence (lighter blue) are rare and mainly found in isolated patches of the northern East Bay (e.g., parts of Walnut Creek or Lafayette), as well as possibly in Pasadena or Santa Monica, where affordability persists in less racially diverse, more affluent enclaves.

The TOD + U&U groups (teal and light teal) are limited in number but spatially significant. They appear in gentrified nodes such as San Francisco, parts of West LA, and around Diridon Station in San José. Most of these stations still exhibit minority presence, but with unaffordable cost burdens, reflecting equity breakdowns in some of the state's most transit-rich areas.

TSD Stations

This section compares minority-focused and non-minority-focused station areas within the Transit-Supportive Development (TSD) + Livable & Affordable (L&A) and TSD + Unlivable & Unaffordable (U&U) typologies. In both cases, the minority-focused stations reveal consistently higher levels of vulnerability. Within TSD + L&A, minority-focused stations exhibit higher socioeconomic vulnerability, minority population concentration, and especially elevated housing and transportation (H+T) vulnerability and zero-car household share. The widespread in H+T vulnerability and zero-car percentages suggests that while these station areas are nominally affordable, the resident populations often face deeper structural constraints and transit dependency, highlighting their functional role as equity anchors despite not being full TODs. In contrast, non-minority-focused TSD + L&A stations show lower median vulnerability across all indicators and greater variability, particularly in car ownership, implying more flexible mobility options. In the TSD + U&U group, minority-focused stations again show slightly higher vulnerability, although the difference is less stark than in the L&A group. These stations represent a troubling transition zone where affordability has eroded, and minority communities are increasingly burdened by inaccessible transit, unaffordable housing, and limited car access. Overall, Figure 19 reinforces that even moderately transit-supportive environments (TSD) exhibit racialized disparities in livability and vulnerability, and that minority-focused TSD stations, regardless of affordability, should be treated as critical intervention zones.

Figure 19. Social and Mobility Vulnerability by Minority Presence in TSD Station Areas

According to Figure 17, TSD + L&A + with minority presence stations (deep purple) are heavily concentrated in South and Southeast Los Angeles, the Inland Empire's Metrolink-adjacent communities, and across Oakland's flatlands and San Leandro. These are moderately dense areas with partial TOD characteristics, such as bus rapid transit corridors or frequent rail, but still support affordability. Their racial diversity and economic precarity signal priority areas for anti-displacement policy. TSD + L&A + without minority presence stations appear most commonly in Orange County, coastal San Diego, and affluent East Bay suburbs, often along Caltrain or Metrolink lines, where transit quality is decent, affordability still exists, but demographic vulnerability is low. The TSD + U&U clusters are extremely rare (as seen in the pie chart). Still, those that do exist may signal tipping-point locations, where moderate-density environments are beginning to lose affordability.

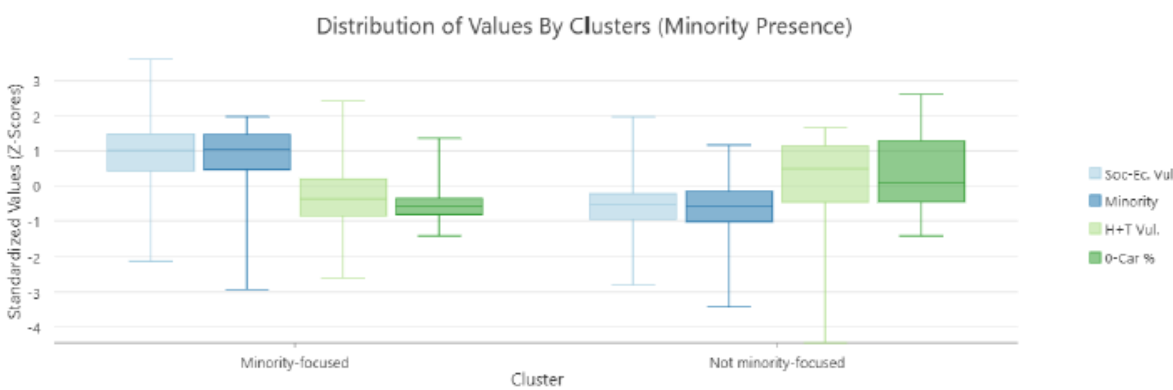
L-TOD Stations

Figure 20 illustrates the distribution of vulnerability indicators across minority-focused and non-minority-focused station areas in the Limited Transit-Oriented Development (L-TOD) typology, for both Livable & Affordable (L&A) and Unlivable & Unaffordable (U&U) clusters. In the

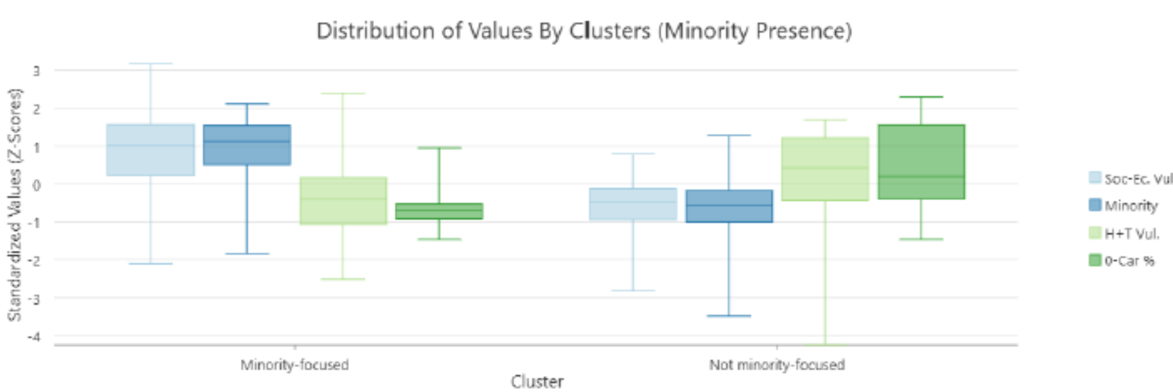
L-TOD + L&A group (top panel), minority-focused stations show higher median values for socioeconomic vulnerability and minority population concentration, with Z-scores approaching or exceeding 1.5. These stations also display moderately elevated H+T vulnerability and relatively narrow box ranges for zero-car household share, indicating a consistent reliance on transit in areas with weaker infrastructure. In contrast, non-minority-focused L-TOD + L&A stations have lower vulnerability scores overall, particularly for socioeconomic and H+T factors, and greater variability in car access, suggesting that residents have more mobility options and economic resilience. In the L-TOD + U&U group (bottom panel), the disparities grow sharper. Minority-focused stations exhibit the highest overall vulnerability levels, especially in socioeconomic vulnerability (median Z > 2) and H+T vulnerability, alongside a pronounced presence of zero-car households, suggesting deep transportation disadvantage. The non-minority-focused L-TOD + U&U stations, while still vulnerable, show slightly lower medians and wider ranges, reflecting more heterogeneous conditions and generally better access and resilience.

Figure 20. Racialized Vulnerability in Limited Transit-Oriented Station Areas (L-TOD): Minority vs. Non-Minority Comparison

L-TOD + L&A



L-TOD + U&U



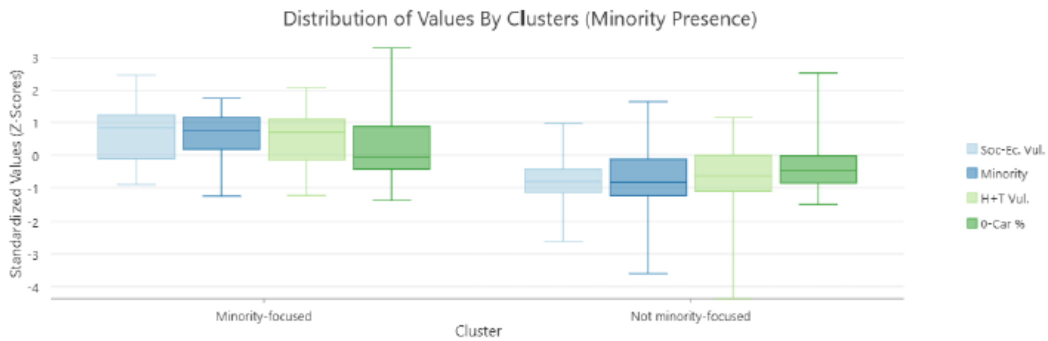
According to Figure 17, the L-TOD + L&A clusters are widely distributed in suburban Sacramento, parts of Chula Vista, East Contra Costa County (e.g., Pittsburg/Antioch), and San Bernardino County. These are low-density, often disconnected station areas where housing affordability may exist due to lower land costs and distance from core job centers. The "with minority presence" category dominates here, revealing that many suburban station areas with affordability still serve communities of color, highlighting hidden equity potential in non-urban TOD contexts. Conversely, L-TOD + U&U clusters are mainly found on the far edges of Southern California metro regions (inland San Diego County, western Riverside County, and parts of Ventura or northern Orange County). These areas represent low-density, auto-oriented stations with both unaffordability and minority concentration, which is a clear mismatch between transit investment and inclusive outcomes.

TAD Stations

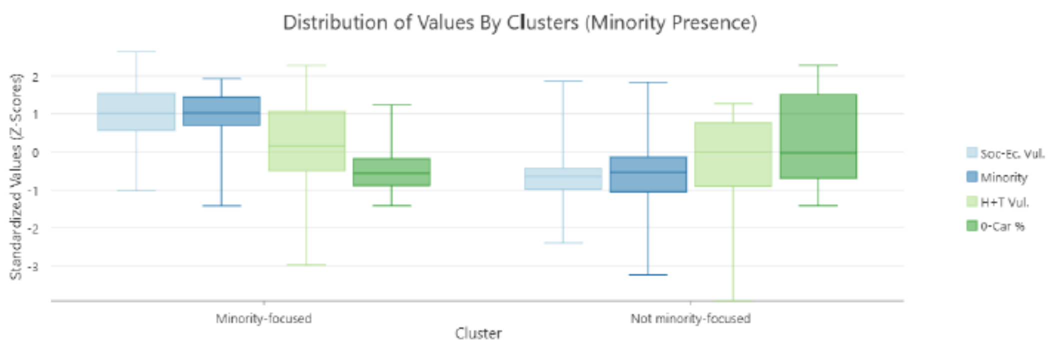
Figure 21 opens the analysis of Transit-Adjacent Development (TAD) station areas by comparing vulnerability indicators across minority-focused and non-minority-focused stations within both Livable & Affordable (L&A) and Unlivable & Unaffordable (U&U) clusters. In the TAD + L&A group (top panel), minority-focused stations show higher median values across all four indicators: socioeconomic vulnerability, minority concentration, H+T vulnerability, and zero-car household share, suggesting greater structural disadvantage despite affordability. Non-minority stations, by contrast, show lower and more variable vulnerability, indicating greater mobility and resilience. Disparities grow sharper in the TAD + U&U group (bottom panel), where minority-focused stations exhibit the highest vulnerability scores and limited car access, pointing to compounded exclusion in already disconnected, unaffordable environments. Overall, the boxplot indicates that even in auto-oriented, peripheral settings, racialized vulnerability significantly influences station area outcomes, setting the stage for a deeper spatial analysis.

Figure 21. TAD Station Area Vulnerability by Race and Affordability Cluster

TAD + L&A



TAD + U&U



According to Figure 17, TAD clusters reflect the least TOD-supportive built environment and are most prevalent in exurban San Bernardino and Riverside counties, rural parts of Solano or eastern Contra Costa, and north San Diego County. Interestingly, TAD + L&A + with minority presence stations are more numerous than one might expect, showing that even in environments poorly suited to TOD, affordability and demographic diversity may coincide, perhaps due to legacy affordability or informal density.

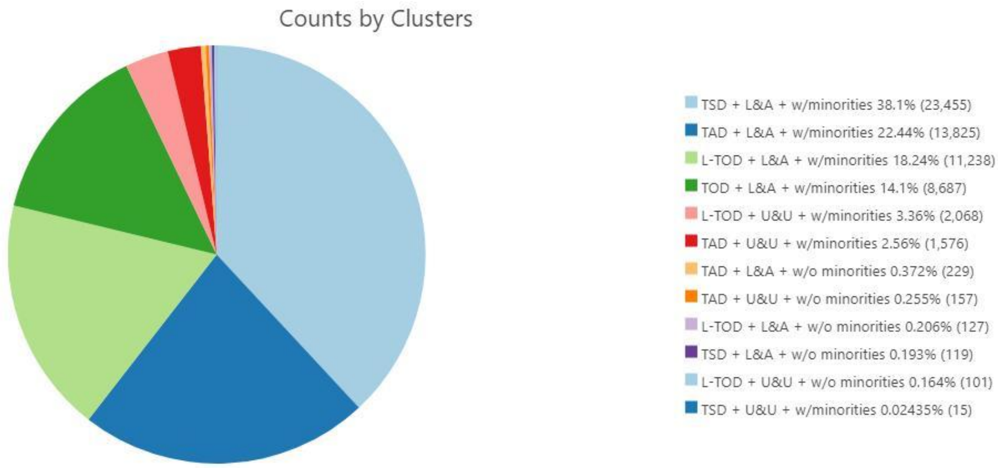
On the other hand, TAD + U&U + with minority presence stations are the most structurally excluded typology with low-quality built environment, unaffordability, and high racial vulnerability. These are often found in areas such as eastern Los Angeles County, central San Diego, and inland Central Valley feeder lines. These locations should be prioritized for comprehensive reinvestment, as they currently fail across all three dimensions of equity, livability, and transit-supportiveness.

Figure 22 summarizes the proportional distribution of all 16 built environment–affordability–minority presence clusters. The breakdown highlights how racialized equity concerns are embedded in the HQTA system: a staggering 94% of all stations classified as Livable & Affordable (L&A) across all built environment types are also located in areas with high minority presence.

The TSD + L&A + with minorities category alone accounts for 38.1% of all stations statewide, followed by TAD, L-TOD, and TOD stations with similar profiles.

Conversely, L&A stations without a minority presence constitute less than 1% of the total, indicating that affordability and livability benefits are overwhelmingly concentrated in communities of color.

Figure 22. Distribution of Station Areas by Built Environment, Affordability, and Minority Presence

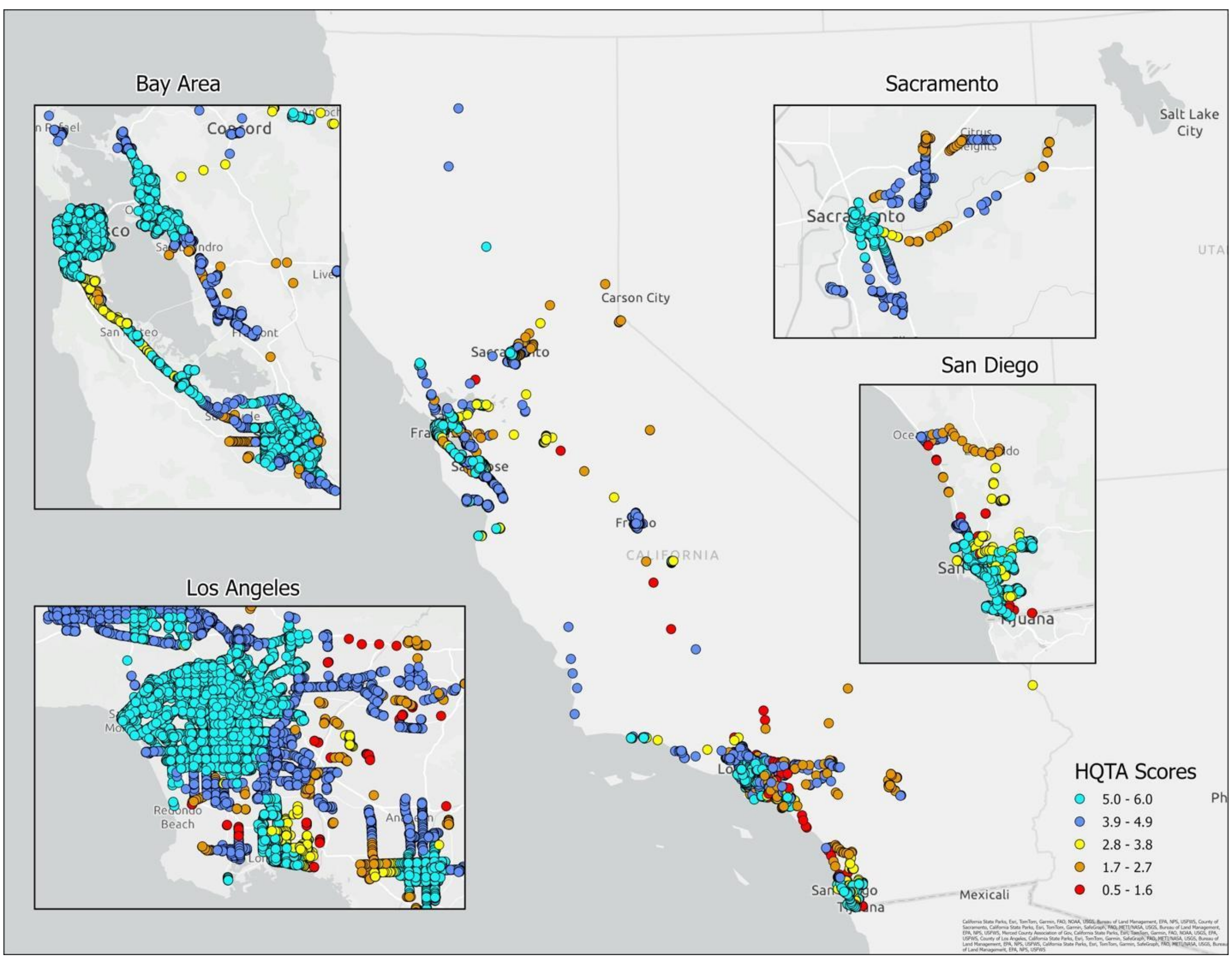


Among the Unlivable & Unaffordable (U&U) groups, the minority-focused clusters still dominate, such as L-TOD + U&U + with minorities (3.36%) and TAD + U&U + with minorities (2.56%), while their non-minority counterparts remain statistically insignificant. This reinforces a core finding: even where transit access or affordability exists, it is overwhelmingly tied to historically marginalized populations. These distributions make clear that transit equity cannot be disentangled from racial and socioeconomic stratification. As a whole, the data confirms that minority-focused station areas carry a disproportionate burden of both structural vulnerability and policy oversight and must be prioritized in any equitable TOD or HQTA reinvestment strategy.

5. Conclusion: Advancing Equitable Transit and Housing through Composite HQTA Scoring

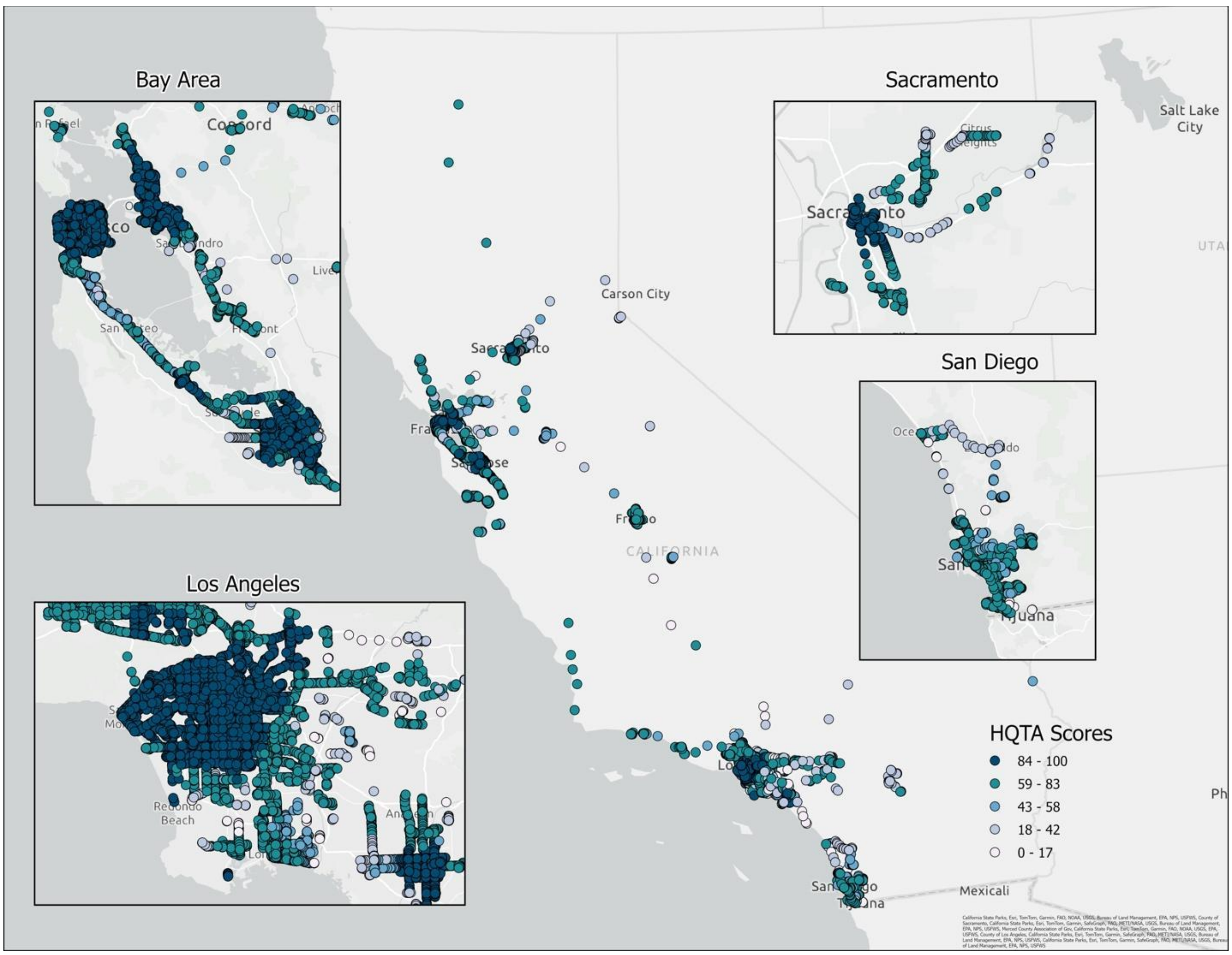
This section introduces the final scoring framework used to evaluate and compare station areas across California's High-Quality Transit Area (HQTA) network. As illustrated in Figure 6, the classification system began with a structured point hierarchy that assigned numeric values based on three integrated dimensions: built environment typology, affordability status, and minority presence. Each station area received a score of between 0.5 and 2 points for its built environment category, ranging from Transit-Oriented Development (TOD, 2 pts) to Transit-Adjacent Development (TAD, 0.5 pts). Stations were then scored on affordability, with Livable & Affordable areas receiving 2 points, and Unlivable & Unaffordable areas receiving 0 points. Finally, a social equity dimension was added: Stations located in areas with significant minority presence were assigned an additional point, while those without minority presence received none. This resulted in a cumulative raw score ranging from a minimum of 0.5 points to a maximum of 6 points.

Figure 23. Raw Equity Scores for HQTA Station Areas (0.5–6 Scale)



To facilitate broader cross-comparison and integration into planning tools, the raw score was then normalized onto a 0–100 scale, where higher values reflect stronger alignment with equitable transit-oriented development principles. This normalized score forms the basis for the final statewide HQTA equity map, enabling planners, policymakers, and housing professionals to assess station performance not only by access or density, but also by the intersection of mobility, affordability, and racialized vulnerability. The score's composite nature ensures that station areas are evaluated holistically, highlighting where TOD has succeeded equitably and where policy intervention is most urgently needed.

Figure 24. Final Normalized HQTA Equity Scores (0–100 Scale) for Station Areas Statewide



While our composite scoring framework incorporates a broad social vulnerability dimension—including indicators of socioeconomic status, disability, linguistic isolation, and housing instability—we place particular emphasis on minority population presence because racial and ethnic disparities are most consistently and strongly aligned with inequities in transit access, housing affordability, and displacement risk in California. This emphasis reflects both empirical findings (e.g., over 98% of HQTA stations fall within communities of color) and policy debates that explicitly center racial equity in housing and transit planning. However, we acknowledge that disability, housing instability, and other vulnerability factors are critical in shaping equitable access. Their relative underrepresentation in the discussion does not imply lesser importance, but rather stems from the fact that racialized disparities emerged most visibly and consistently in our results. Future iterations of this framework could more fully elevate non-racial dimensions of vulnerability to ensure that disability justice, housing precarity, and related forms of disadvantage are addressed with equal analytic and policy weight.

5.1 Interpreting the Composite HQTA Equity Score Map

The final map (Figure 24) represents the culmination of this multidimensional analysis by translating the typology of HQTA station areas, based on built environment form, affordability, and racialized vulnerability, into a single composite equity score ranging from 0 to 100. This score standardizes the full typology, rescaling from earlier categorical values to a normalized gradient that can be used across disciplines and planning contexts. High-scoring stations are those that align most closely with equitable TOD principles: they combine dense, walkable form, affordability for multiple income levels, and accessibility for historically marginalized populations. Low-scoring stations, by contrast, represent a misalignment between transit access and the equity outcomes that TOD intends to support; these are places where infrastructure exists, but affordability is lacking, walkability is weak, and residents are economically or racially excluded.

Geographically, the composite map reveals significant regional disparities in the distribution of transit and equity. Station areas with the highest scores cluster heavily in central Los Angeles, the East Bay, and core Sacramento neighborhoods, where frequent transit, compact development, and affordability have converged in ways that continue to support access for lower-income and minority populations. These places represent the strongest models of functional, equitable TOD in the state. Conversely, the lowest-scoring clusters are concentrated in inland Southern California, northern San Diego County, and exurban Central Valley regions, where station areas technically fall within High-Quality Transit Areas but, in practice, lack both affordability and a supportive urban form. In many of these zones, communities of color remain disproportionately burdened by transit disconnection, high housing costs, and limited access to services. The composite scoring system thus serves not only as a snapshot of performance but also as a diagnostic tool, identifying which places are falling short of the equity standards that California's transit and housing policies aspire to achieve.

5.2 Policy Applications and Recommendations

The composite HQTA equity score map has direct applications across the domains of land use planning, housing policy, transit investment, and environmental equity. For local governments and housing agencies, the score provides a clear framework for identifying station areas where affordability and community need align with development readiness. High-scoring areas, particularly those classified as Livable & Affordable and located in communities of color, should be prioritized for housing preservation and anti-displacement strategies. These places are functioning as equity anchors, and proactive policies such as rent stabilization, tenant protections, and community land trusts can help maintain affordability while growth continues. The score also offers a planning basis for CEQA streamlining and fast-tracked permitting processes under programs such as SB 35 and AB 2011, where developers can use the score to select infill sites that meet both environmental and social equity goals.

In lower-scoring areas, particularly those classified as Transit-Adjacent or Limited TOD and marked by Unlivable & Unaffordable conditions, there is a clear need for state and regional reinvestment. These areas, often located on the fringes of metropolitan regions, are places where transit infrastructure has outpaced land-use reform or affordability protection. In these cases, the HQTA equity score can help prioritize capital investments such as sidewalk infill, first-last mile improvements, or bus network enhancements, paired with zoning updates to support more compact, mixed-use development. Moreover, environmental justice agencies and public health departments can use the score in coordination with tools such as CalEnviroScreen or the Healthy Places Index to layer vulnerability assessments, targeting investments that simultaneously improve mobility, reduce emissions, and support housing access.

Finally, the composite HQTA score can serve as a coordination tool between transit agencies, MPOs, and affordable housing developers. It enables shared prioritization of station areas that offer the greatest return on investment for advancing climate, housing, and equity goals. By institutionalizing the score into capital improvement programs, regional planning strategies, and housing funding formulas, public agencies can more systematically allocate resources to the places most in need, ensuring that California's future transit investments are not only efficient, but truly equitable.

To facilitate broader access and application of this framework, we developed an interactive statewide webmap that visualizes the results of this study. The webmap allows users to explore Affordable Transit-Oriented Development (A-TOD) classifications, affordability status, social vulnerability patterns, and composite equity scores at the station-area level. By making the typologies and scoring system available in a dynamic format, the tool bridges technical analysis and policy practice, enabling planners, housing advocates, and decision-makers to identify opportunity sites, assess trade-offs, and prioritize interventions across California's High-Quality Transit Areas.

The webmap is publicly accessible at: https://css-cappnodejmap.sjsu.edu/A-TOD/

Bibliography

Barajas, J., Frick, K., & Cervero, R. (2020). Travel of TOD residents in the San Francisco Bay Area.

Bernstein, S., & Makarwicz. Carry. (2005). Rethinking affordability: The inherent value of TOD. Platform: Building the New Transit Town. https://escholarship.org/uc/item/1r20w0tv

Bostic, R., Boarnet, M., Burinskiy, E., Eisenlohr, A., Rodnyansky, S., Santiago-Bartolomei, R., ... & Center, M. T. (2018). Sustainable and affordable housing near rail transit: Refining and expanding a scenario planning tool (No. CA18-3125). METRANS Transportation Center (Calif.).

California Air Resources Board (CARB). (2018). SB 375 regional greenhouse gas emissions reduction targets. https://ww2.arb.ca.gov/our-work/programs/sustainable-communities-program

California Department of Transportation. (2025). High quality transit areas [GIS dataset]. Caltrans GIS Data. Retrieved July 7, 2025, from https://gisdata-caltrans.opendata.arcgis.com/datasets/863e61eacbf3463ab239beb3cee4a2c3_0

California Strategic Growth Council (SGC). (2020). Transformative climate communities program guidelines. https://sgc.ca.gov/programs/tcc/resources/

Center for Neighborhood Technology. (2022). H + T Index methods. https://htaindex.cnt.org/about/method-2022.pdf

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment*, *2*(3), 199–219.

Chatman, D. G., & Noland, R. B. (2011). Transit service, physical agglomeration and productivity in US metropolitan areas. *Urban Studies*, *48*(12), 2483–2505. https://doi.org/10.1177/0042098010397796

Clagett, M. T. (2014). If it's not mixed-income, it won't be transit-oriented: Ensuring our future developments are equitable & promote transit. *Transp. LJ*, *41*, 1.

Dong, H. (2017) Rail-transit-induced gentrification and the affordability paradox of TOD. *Journal of Transport Geography*, *63*, 1–10. https://doi.org/10.1016/j.jtrangeo.2017.07.001

Dong, H. (2021). Evaluating the impacts of transit-oriented developments (TODs) on household transportation expenditures in California. *Journal of Transport Geography*, *90*, 102946. https://doi.org/10.1016/j.jtrangeo.2020.102946

Econsult Solutions, & Penn Institute for Urban Research. (2013). Review of Location Affordability Index housing cost model. Retrieved from https://files.hudexchange.info/resources/documents/Review-of-LAI-Housing-Cost-Model.pdf

Faghri, A., & Venigalla, M. (2013). Measuring travel behavior and transit trip generation characteristics of transit-oriented developments. *Transportation Research Record: Journal of the Transportation Research Board*, *2397*(1), 72–79. https://doi.org/10.3141/2397-09

Fard, P. (2013). Measuring Transit Oriented Development—Implementing a GIS-based analytical tool for measuring existing TOD levels (Master's thesis, University of Twente).

Garde, A., Jamme, H.-T., Toney, B., Bahl, D., & Banerjee, T. (2024). Can TODs include affordable housing?: The Southern California experience. *Journal of the American Planning Association*, *90*(2),303–317. https://doi.org/10.1080/01944363.2023.2236586

Guerra, E., Cervero, R., & Tischler, D. (2020). The half-mile circle: Does it best represent transit station catchments? *Transportation Research Record*, *2674*(2), 88–97.

Haque, A., & Khan, F. K. S. A. (2018). Social cost of TOD: Evaluation on housing affordability along MRT corridor in Dhaka applying H+ T index.

Huang, R., Grigolon, A., Madureira, M., & Brussel, M. (2018). Measuring transit-oriented development (TOD) network complementarity based on TOD node typology. *Journal of Transport and Land Use*, *11*(1). https://doi.org/10.5198/jtlu.2018.1110

Ibrahim, S. M., Ayad, H. M., & Saadallah, D. M. (2021). *Measuring transit-oriented development levels: A methodological framework to incorporate the user into modelling*. 157–166. https://doi.org/10.2495/UT210131

Ibrahim, S. M., Ayad, H. M., & Saadallah, D. M. (2022). Planning Transit-Oriented Development (TOD): A systematic literature review of measuring the Transit-Oriented Development levels. *International Journal of Transport Development and Integration*, *6*(4), 378–398. https://doi.org/10.2495/TDI-V6-N4-378-398

Isalou, A. A., Litman, T., & Shahmoradi, B. (2014). Testing the housing and transportation affordability index in a developing world context: A sustainability comparison of central and suburban districts in Qom, Iran. *Transport Policy*, *33*, 33–39.

Jain, D., Jha, B., Singh, E., & Ashtt, R. (2020). Evaluation of measuring criteria for the success of Transit Oriented Development. *Solid State Technology*, *63*(3).

Kaniewska, J., Ewing, R., Sabouri, S., & Ameli, H. (2024). Is transit-oriented development affordable for low- and moderate-income households? *Cities*, *147*, 104772. https://doi.org/10.1016/j.cities.2023.104772

Khare, R., Villuri, V. G. K., Chaurasia, D., & Kumari, S. (2021). Measurement of transit-oriented development (TOD) using GIS technique: A case study. *Arabian Journal of Geosciences*, *14*(10), 832. https://doi.org/10.1007/s12517-021-07142-y

Landex, A., & Hansen, S. (2006). Examining the potential travellers in catchment areas for public transport. In *26th Annual Esri International User Conference*.

Lyons, T., & Choi, D. A. (2021). Transit economic equity index: developing a comprehensive measure of transit service equity. *Transportation Research Record*, *2675*(3), 288–300.

Newmark, G. L., & Kaplowitz, W. L. (2020). Defining TOD: Learning from California law. In *Transportation, Land Use, and Environmental Planning* (pp. 419–438). Elsevier.

Oliver, L. N., Schuurman, N., & Hall, A. W. (2007). Comparing circular and network buffers to examine the influence of land use on walking for leisure and errands. *International Journal of Health Geographics*, *6*, 1–11.

Oranga, B. (2015). Measuring equity in transit-oriented development: Application to affordable housing. 2811. https://digitalcollections.sit.edu/capstones/2811

Padeiro, M., Louro, A., & da Costa, N. M. (2019). Transit-oriented development and gentrification: a systematic review. *Transport Reviews*, *39*(6), 733–754. https://doi.org/10.1080/01441647.2019.1649316

Poerbo, H. W. (2020). Affordable Residential in TOD Area. *IOP Conference Series: Earth and Environmental Science*, *532*(1), 012012. https://doi.org/10.1088/1755-1315/532/1/012012

Pratama, D. C. (2023). Balancing Accessibility & Affordability in Indonesian Transit-Oriented Development Projects, Case Study: TOD Tanah Abang, Indonesia (Doctoral dissertation, Massachusetts Institute of Technology).

Renne, J. L. (2009). From transit-adjacent to transit-oriented development. *Local Environment*, *14*(1), 1–15.

Renne, J. L., Tolford, T., Hamidi, S., & Ewing, R. (2016). The cost and affordability paradox of Transit Oriented Development: A comparison of housing and transportation costs across Transit-Oriented Development, Hybrid and Transit-Adjacent Development station typologies. *Housing Policy Debate*, *26*(4–5), 819–834. https://doi.org/10.1080/10511482.2016.1193038

Scheer, B., Ewing, R., Park, K., & Khan, S. S. A. (2017). How does transportation affordability vary among TODs, TADs, and other areas?

Singh, Y. J. (2015). Measuring transit-oriented development (TOD) at regional and local scales: A planning support tool [PhD, University of Twente]. https://doi.org/10.3990/1.9789036539982

Singh, Y. J., Flacke, J., Zuidgeest, M., & Van Maarseveen, M. (2018). Planning for Transit Oriented Development (TOD) using a TOD Index. In M. Van Maarseveen, J. Martinez, & J. Flacke, *GIS in Sustainable Urban Planning and Management* (1st ed., pp. 267–282). CRC Press. https://doi.org/10.1201/9781315146638-15

Singh, Y. J., Lukman, A., Flacke, J., Zuidgeest, M., & Van Maarseveen, M. F. A. M. (2017). Measuring TOD around transit nodes—Towards TOD policy. *Transport Policy*, *56*, 96–111. https://doi.org/10.1016/j.tranpol.2017.03.013

Smith, R. W., Bertolaccini, K., & Lownes, N. E. (2021). Improving transit access measures in affordable housing funding criteria. *Transport Policy*, *106*, 239–248.

Sun, Y., Han, B., & Lu, F. (2024). An overview of TOD level assessment around rail transit stations. *Urban Rail Transit*, *10*(1), 1–12. https://doi.org/10.1007/s40864-023-00211-3

Tamakloe, R., & Hong, J. (2020). Assessing the efficiency of integrated public transit stations based on the concept of transit-oriented development. *Transportmetrica A: Transport Science*, *16*(3), 1459–1489. https://doi.org/10.1080/23249935.2020.1753849

Uddin, Md. A., Tamanna, T., Adiba, S., & Bin Kabir, S. (2023). Revolutionizing TOD planning in a developing country: An Objective-weighted framework for measuring nodal TOD Index. *Journal of Advanced Transportation*, *2023*, 1–25. https://doi.org/10.1155/2023/9911133

Vale, D. S. (2015). Transit-oriented development, integration of land use and transport, and pedestrian accessibility: Combining node-place model with pedestrian shed ratio to evaluate and classify station areas in Lisbon. *Journal of Transport Geography*, *45*, 70–80.

Vale, D. S., Saraiva, M., & Pereira, M. (2016). Active accessibility: A review of operational measures of walking and cycling accessibility. *Journal of Transport and Land Use*, *9*(1), 209–235. https://doi.org/10.5198/jtlu.2015.593

Zandiatashbar, A., & Laurito, A. (2023). An empirical analysis of the link between built environment and safety in Chicago's transit station areas. *Journal of the American planning association*, *89*(2), 225–239.

Zandiatashbar, A., Hamidi, S., Foster, N., & Park, K. (2019). The missing link between place and productivity? The impact of transit-oriented development on the knowledge and creative economy. *Journal of Planning Education and Research*, *39*(4), 429–441.

Zhao, P., Lü, B., de Roo, G., & Huang, X. (2021). Measuring transit-oriented development: A spatial multivariate clustering approach. *Cities*, *108*, 102944.

Zhao, Y., Hu, S., & Zhang, M. (2024). Evaluating equitable Transit-Oriented development (TOD) via the Node-Place-People model. *Transportation Research Part A: Policy and Practice*, *185*, 104116.

Zhou, J., Yang, Y., & Webster, C. (2020). Using big and open data to analyze transit-oriented development: new outcomes and improved attributes. *Journal of the American Planning Association*, *86*(3), 364–376.

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Dr. Ahoura Zandiatashbar is an Associate Professor of Urban and Regional Planning at San José State University (SJSU) and the Founding Director of the Spatial Analytics and Visualization Institute (SAVI). His research focuses on the intersection of urban analytics, active transportation, and spatial equity, with a particular emphasis on using GIScience to inform policy and infrastructure planning. Dr. Zandiatashbar's work integrates data-driven methods with community-engaged research to support inclusive and sustainable urban development.

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Stephanie Nemet is a master's student in Geographic Information Science (GISc) at SJSU. Her thesis research explores the intersection of affordable housing and transit-oriented development (TOD). She has contributed to numerous projects with the Spatial Analytics and Visualization Institute (SAVI), focusing on public transit, public health, and vulnerable communities. As the student GIS lead for the City of San José, she played a key role in expanding the BayWheels bike-share program into East San José. Her work is driven by a passion for reducing auto-dependency and promoting sustainable, equitable urban environments.

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Atticus Washington is a transportation engineer/planner with two years of professional experience in California. Atticus has transportation planning experience, specifically in travel demand modeling, SB 743, and big data analytics. He has contributed towards planning projects of varying sizes ranging from general plan updates to vehicle miles traveled (VMT) impacts all throughout the state of California. He holds a Bachelor's degree in civil engineering with a minor in sustainability in the built environment from the University of California, Davis.

Mounashree Prasanna

Mounashree Prasanna is a graduate student in Data Analytics with a strong interest in working with data to uncover patterns and communicate insights through visualization. She is passionate about using data not only for analysis but also for building intuitive and engaging tools that make information more accessible. Her academic and project experience spans data analysis, visualization, and web-based applications, with a focus on applying these skills to solve real-world problems.

For the A-TOD project, Mounashree contributed to the creation of interactive webmaps, combining geospatial data with modern visualization techniques. She focused on ensuring that the maps were informative, user-friendly, and capable of highlighting key insights effectively.

Mounashree is particularly motivated by projects that bridge data with storytelling, where complex datasets can be transformed into platforms that support learning, decision-making, and exploration. She continues to expand her skills in analytics and visualization with the goal of contributing to impactful data-driven solutions in both academic and professional settings.

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