Measuring the 15-Minute City Accessibility in Denver Urban Area: A Spatial Statistical Analysis

Introduction

The 15-minute city (15MC) concept, formally introduced by Carlos Moreno in 2016 and popularized during the COVID-19 pandemic, envisions urban neighborhoods where residents can access all essential daily services including work, commerce, healthcare, education, and leisure within a 15-minute walk or bicycle ride from their home (Moreno et al., 2021). The concept has rapidly ascended from an academic proposal to a globally adopted planning framework, with nearly 100 cities worldwide either implementing or planning to implement 15MC strategies as of 2024 (Teixeira et al., 2024). Despite its popularity, a growing body of scholarly literature has begun to critically examine the theoretical foundations, methodological inconsistencies, and empirical gaps that challenge the concept's operationalization, particularly in the North American and United States contexts, where car-centric urban morphology, exclusionary zoning, and sprawl present structurally distinct challenges (Mouratidis, 2024).

The vast majority of empirically rigorous 15MC studies using GIS-based network analysis focus on European cities particularly Paris, Barcelona, Rome, and Oslo with a much smaller body of work addressing North American cities (Omwamba et al., 2025). Among those studying the US, many rely on national-scale mobility datasets rather than fine-grained GIS network analyses of street and pedestrian infrastructure. There is a clear need for neighborhood-level, network-based GIS studies of American cities across diverse typologies, including medium-sized and Sun Belt cities that are structurally distinct from the few northeastern megacities that receive disproportionate research attention (Jin et al., 2023). This study addresses this empirical gap and proposes a GIS-based network analysis method to measure 15MC accessibility in the broader Denver-Aurora-Lakewood urban region. A slope-adjusted network dataset will be developed from detailed GIS analyses of street and pedestrian infrastructure to measure accessibility in terms of grocery store locations and public transportation stops. Spatial statistical models will then be applied to identify both global and local variability in accessibility across the region. Ultimately, this study seeks to answer the following central research question: Do all residents of the Denver-Aurora-Lakewood region have equal walking access to groceries and transit?

Objective

My study has two objectives:

1. To measure and map grocery store and transit accessibility across the Denver–Aurora–Lakewood urbanized area using a slope-adjusted pedestrian network model.
2. To identify and analyze spatial patterns of accessibility using spatial statistical models across Denver neighborhoods.

Based on my objectives the hypotheses I will examine are Grocery store and transit accessibility exhibit significant spatial clustering, that is high-access and low-access areas are not randomly distributed but concentrated in specific parts of the region.

Literature Review

GIS-based methods have become the dominant approach for measuring 15-minute city (15MC) conditions, used in 44% of empirical (Lima & Costa 2023). Early studies relied on Euclidian distance buffers, but more recent work has shifted toward network-based isochrones using tools such as OpenStreetMap, HERE API, and OSRM, producing more realistic accessibility estimates that reflect actual pedestrian routes (Jin et al., 2023). This methodological shift has been validated across multiple contexts: in Barcelona, Rhoads et al. (2023) showed that sidewalk-based network modeling better captures pedestrian accessibility, while Ferrer-Ortiz et al. (2022) used network analysis to reveal fine-grained spatial inequalities through a Synthetic Proximity Index.

Empirical research suggests that the 15MC remains largely unattainable in the American urban context. Using GPS data from 40 million smartphones across 418 US urban areas, Abbiasov et al. (2022) found that the median US resident makes only 12% of daily trips within walking distance, with regional disparities between northeastern and southern cities. Jin et al. (2023) similarly found that residents of the 12 most populous US cities can access only 47 essential destinations on foot within 15 minutes, with car-dependent cities like Atlanta, Dallas, and Houston performing worst.

This study will use spatial statistical models as a tool to see whether people in Denver urban area have accessibility to grocery stores and transit stops in terms of 15MC and reveal the spatial variability of accessibility through the models. The statistical models that will be used are Global and Local Moran's I to measure the spatial autocorrelation, Getis-Ord Gi* to find hotspots and coldspots and finally Geographic Weighted Regression to see how population density and the number of facilities affect Denver's neighborhoods locally.

Data Description and Sources

The overall data used and their specific source and formats are described below in the table below:

Table 1: Overall data used and their sources

Dataset	Description	Format	Source
Study area boundary	Denver–Aurora–Lakewood urbanized area polygon used to clip all datasets	Shapefile	US Census Bureau TIGER/Line Files
Population grid	Census Block Groups & ACS	Point Feature Class (Centroids)	US census website(data.census.gov)
Grocery stores	Point locations of supermarkets, grocery stores, and convenience stores across the study area	Point Shapefile	OpenStreetMap via Overpass Turbo; cross-validated with Denver Open Data Portal
Transit stops and departures	Locations of all RTD buses and light rail stops with total weekday daily departures per stop	Point Shapefile + CSV	Regional Transportation District (RTD) GTFS Feed
Pedestrian street network	Full walking network including sidewalks, paths, and streets used to build the routable network dataset	Shapefile (edges + nodes)	OpenStreetMap via OSMnx (Python)
Digital Elevation Model	Elevation surface for Denver at 1/3 arc-second (~10m) resolution used to	GeoTIFF Raster	USGS National Map (3DEP Program)

	derive slope per street segment		

Methods Used and Analysis

This study follows a five-step GIS framework developed by Mouratidis (2025) to measure 15-minute city conditions in Denver urban area. The framework covers defining the study scope, preparing spatial data, measuring walking and transit accessibility, mapping the results, and running statistical models. In addition, Geographically Weighted Regression (GWR) is applied to examine how population density and the availability of local services vary across neighborhoods, helping identify specific areas where infrastructure investment would have the greatest impact on accessibility.

Table 2: Five-step GIS methodology framework applied to Denver urban area

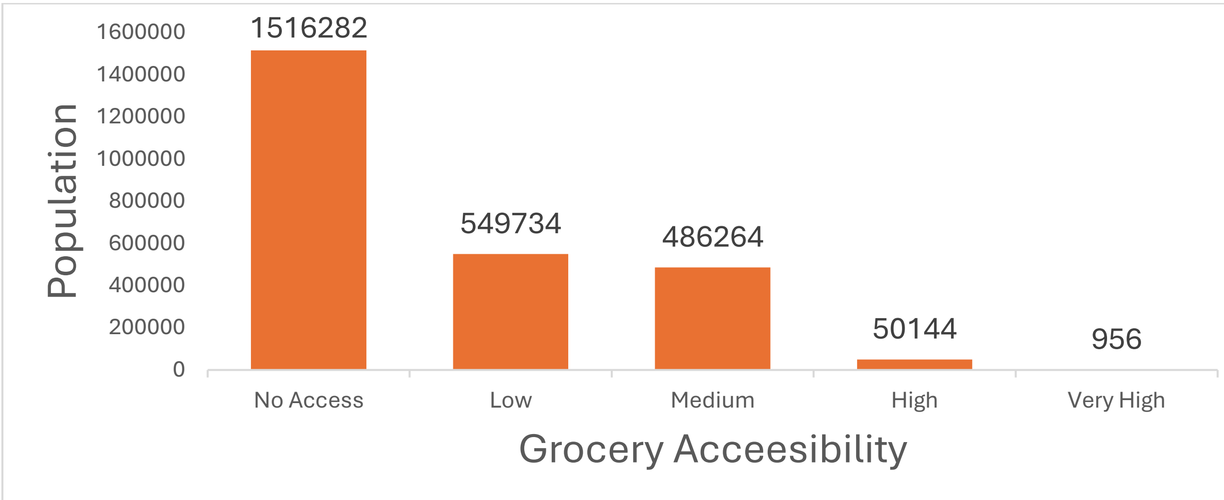
Step	Description	Application	Source
Project definition	Define the unit of analysis and destination categories	Census tracts; destinations include grocery stores, healthcare, parks, schools, and transit stops	Mouratidis (2025)
Data preparation	Build a routable pedestrian street network and compile POI data	OpenStreetMap + POI	Rahman (2025); Jin et al. (2023)
Accessibility measurement	Compute 15-minute walking isochrones and transit-extended catchments	Network-based isochrones from residential parcels; RTD bus and light rail stops for transit catchments (from GTFS diary)	Mouratidis (2025); Mouratidis (2024)
Visualization	Map accessibility scores at the neighborhood level	Block-group level maps showing spatial gaps by income, race, and neighborhood type across Denver	Mouratidis (2025)

Spatial statistical modeling	Apply GWR to identify where population density and facility density most constrain accessibility	Geographically Weighted Regression pinpoints Denver neighborhoods where infrastructure investment most needed	Feng et al. (2025)

The methodological workflow integrates multiple data sources and analytical tools across a multi-stage geospatial pipeline. Elevation data from the USGS Digital Elevation Model (DEM) was processed using the Python library Rasterio to extract slope values, which were then used to calculate Tobler-based walking times accounting for terrain effects on pedestrian travel speed. These slope-adjusted impedance values were incorporated into an ArcGIS pedestrian network dataset to realistically model walking accessibility across the study area. Grocery store locations sourced from OpenStreetMap (OSM) via Overpass Turbo and transit departure frequencies extracted from the Regional Transportation District (RTD) General Transit Feed Specification (GTFS) data using Python Pandas were each summarized per origin point using the ArcGIS Summarize Within tool, generating grocery count and transit departure variables respectively. Finally, sociodemographic data from the Census Bureau's American Community Survey (ACS) and TIGER boundary files were used to construct a population grid, which served as the spatial framework for statistical analyses in ArcGIS, including Global Moran's I for spatial autocorrelation, hot spot analysis for identifying accessibility clusters, and Geographically Weighted Regression (GWR) to examine local variability in the relationship between service (grocery, transit) accessibility and population density.

Results

At first, I incorporated population count across different accessibility classes and got a very intriguing result. The results reveal significant accessibility disparities across the Denver-Aurora-Lakewood region. For grocery accessibility, approximately 1.5 million residents fall within the No Access category, with very few achieving High (50,144) or Very High (956) accessibility, indicating that walkable access to grocery stores is largely unavailable to most residents. Transit accessibility shows a comparatively better distribution, with stronger representation in the High (573,351) and Very High (296,617) categories, though over 1 million residents still lack any transit access. Overall, these findings confirm that a significant portion of residents lack adequate walking access to both groceries and transit, highlighting persistent spatial inequities across the region.



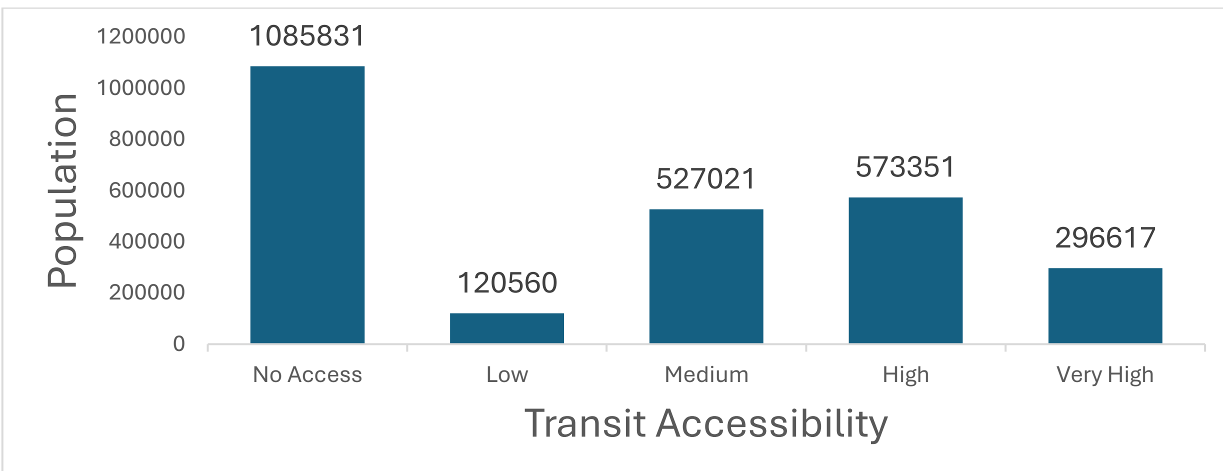


Figure 1: Population Statistics by Access Class

Spatial Statistical Model Used

Global Moran's I: The Global Moran's I confirmed statistically significant positive spatial autocorrelation for both accessibility measures. Grocery accessibility returned a Moran's Index of 0.100367 with a z-score of 6.06 and a p-value of 0.000, while transit accessibility returned a Moran's Index of 0.326 with a z-score of 19.78 and a p-value of 0.000. Both results are statistically significant at the 99% confidence level, confirming that high-access and low-access areas are strongly clustered.

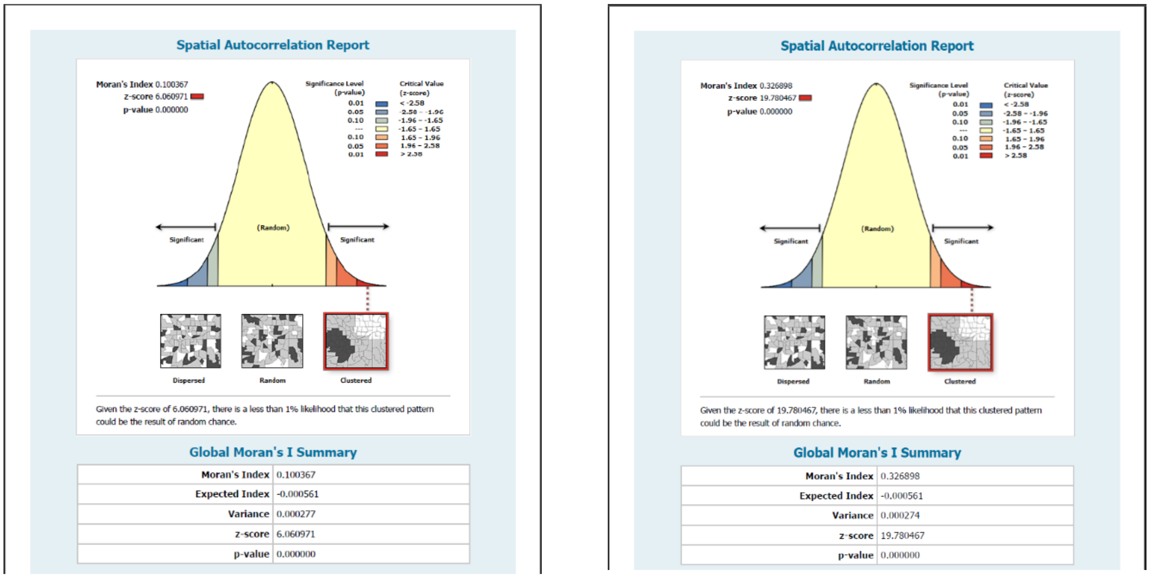


Figure 2: Global Moran's I Report

Local Moran's I: Local Moran's I identified distinct spatial cluster types across the region. For grocery accessibility, High-High clusters were concentrated in the urban core while Low-Low clusters dominated the peripheral areas. Transit accessibility showed a similar pattern, with High-High clusters in the central Denver area and extensive Low-Low clusters in the outer suburban zones, confirming localized pockets of persistent accessibility inequality.

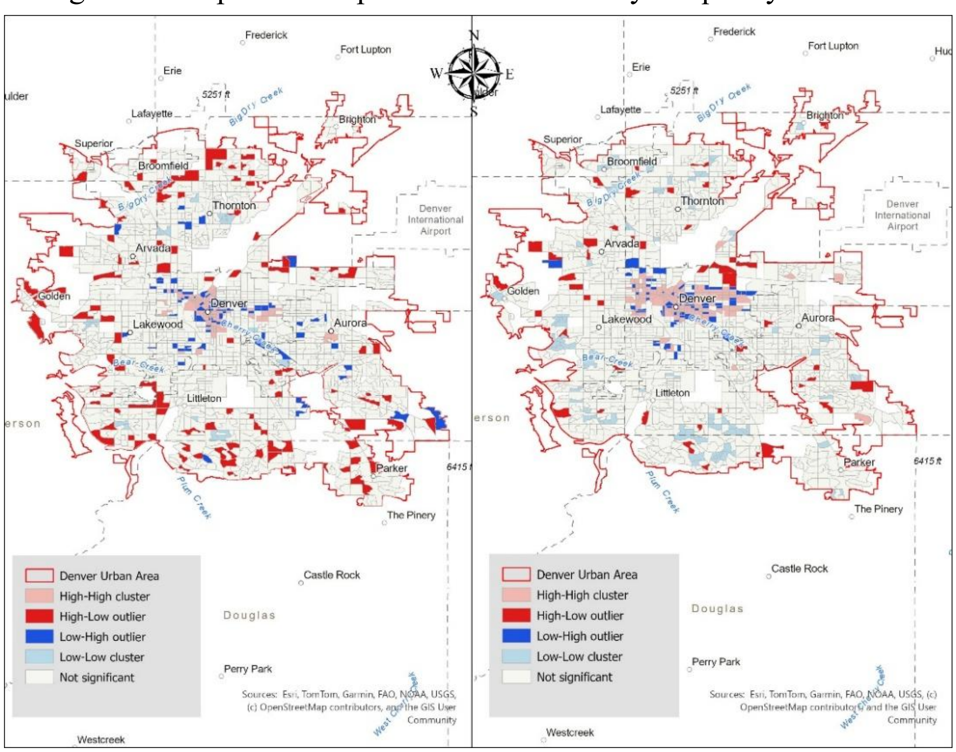


Figure 3: Local Moran's I Result

Hot Spot Analysis (Getis-Ord Gi)*: The Getis-Ord Gi* hot spot analysis identified statistically significant hot spots of high grocery and transit accessibility concentrated in the urban core of Denver, while cold spots of low accessibility were predominantly found in the outer suburban and peripheral areas of the region, further reinforcing the center-periphery pattern of accessibility disparity.

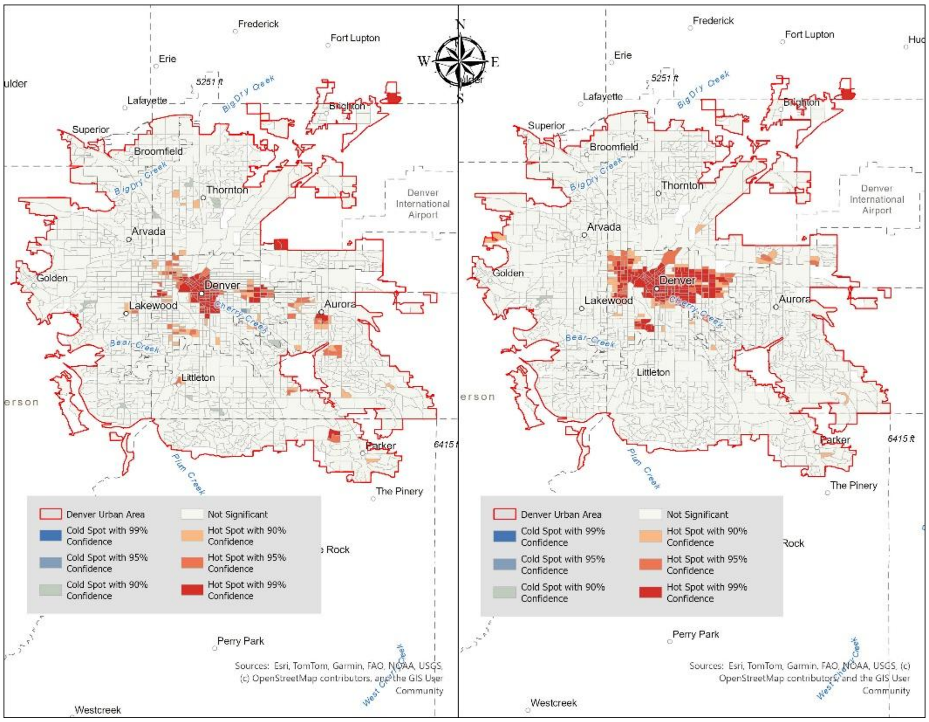


Figure 4: Hot Spot Analysis

Ordinary Least Squares (OLS): The OLS regression model returned an adjusted R-squared of 0.206, with an AICc of 5693.44. The Koenker statistic ($p = 0.000$) indicated non-stationarity, suggesting that the relationships vary spatially across the study area. The residuals when applied in a Global Moran's I model gave spatial clustering with significance. It allowed me to proceed towards GWR to find finer local variations.

Geographically Weighted Regression (GWR): GWR was applied to capture local spatial variation. I used grocery store points as my dependent variable and population density and transit poits as my explanatory variables. However, multicollinearity issues arose when transit and population density were included together. The adjusted R-squared value and AIC did not improve sufficiently ($R^2 = 0.2061$, $AdjR^2 = 0.2035$, AICc = 5700.93) compared to OLS, and residual autocorrelation persisted.

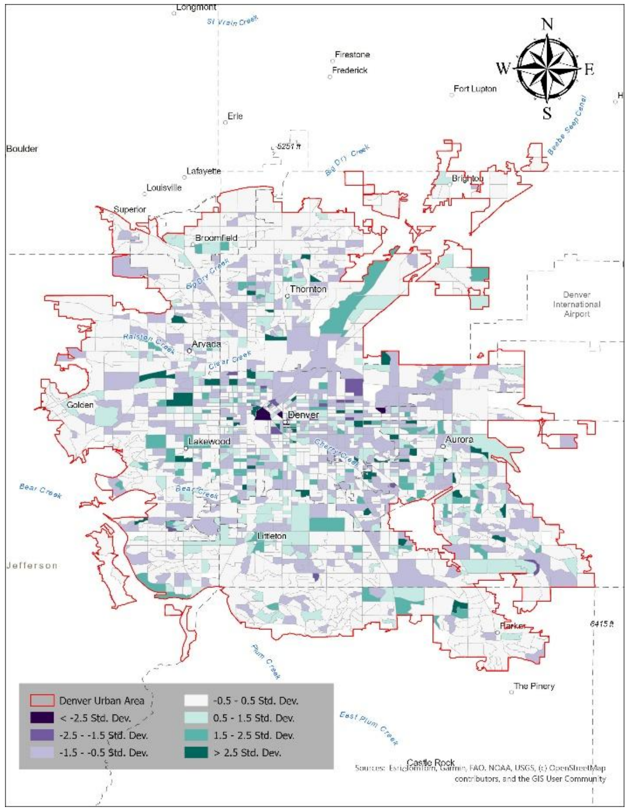


Figure 4: GWR Std Dev. distribution

From this result I thought perhaps a Multiscale Geographically Weighted Regression (MGWR) approach would better capture the spatially varying relationships across the Denver-Aurora-Lakewood region.

Limitations

This study has several limitations worth noting. The GWR model produced a modest adjusted R-squared of 0.2035 and an AICc of 5700.93, explaining only a limited portion of accessibility variability. Multicollinearity between transit departures and population density made it difficult to isolate the independent effect of each variable, while persistent spatial autocorrelation in the OLS residuals (Moran's I = 0.010, z-score = 2.647, p = 0.008) was not fully resolved by GWR. The model also excluded important predictors such as income, car ownership, and racial distribution, which likely influence walking accessibility. Finally, a heavily skewed distribution of accessibility values, with most residents falling into the No Access category, further limited the model's ability to detect meaningful local relationships.

Conclusion

This study sets out to measure and map grocery store and transit accessibility across the Denver-Aurora-Lakewood urbanized area using a slope-adjusted pedestrian network model, and to identify spatial patterns of accessibility inequality using spatial statistical methods. The findings largely confirm and reinforce the central research question: not all residents of the Denver-Aurora-Lakewood region have equal walking access to groceries and transit. Approximately 1.5 million residents lack any walkable access to grocery stores, and over 1 million residents remain without access to transit, revealing a deeply unequal distribution of essential services across the region. The Global Moran's I result confirmed that these disparities are not randomly distributed but are spatially structured, with Moran's Index values of 0.100 for grocery and 0.326 for transit accessibility, both significant at the 99% confidence level. Local Moran's I and hot spot analysis further identified that high-access clusters are concentrated in the urban core of Denver, while low-access cold spots dominate the peripheral and suburban areas, reflecting a divide in pedestrian accessibility between central and peripheral regions. The OLS regression provided initial evidence that population density is significantly associated with accessibility outcomes, though the relatively low R-squared of 0.207 and the presence of spatial non-stationarity suggest that these relationships vary considerably across the region. These findings have important implications for urban planning and transportation policy in the Denver metropolitan area. The concentration of lack of accessibility in peripheral neighborhoods suggests that investments in pedestrian infrastructure, grocery store sitting, and transit expansion should be strategically directed toward underserved outer areas rather than reinforcing already well-served urban core neighborhoods. Slope-adjusted network modeling also proved essential in revealing terrain-driven barriers that traditional Euclidean distance measures would overlook. It shows the importance of incorporating physical geography into accessibility planning. Ultimately, this study contributes empirical evidence to support more equitable, walkable, and inclusive urban development in the Denver-Aurora-Lakewood region.

Reference

Abbiasov, T., Heine, C., Glaeser, E. L., Ratti, C., Sabouri, S., Miranda, A. S., & Santi, P. (2022). The 15-Minute City Quantified Using Mobility Data. *National Bureau of Economic Research*. http://www.nber.org/papers/w30752.pdf

Feng, X., Jia, N., Su, X., Adams, M. D., Deng, Y., & Ling, S. (2025). Assessing the applicability of the 15-minute city: Insights from a spatial accessibility perspective. *Transportation Research Part A Policy and Practice*, *199*, 104579–104579. https://linkinghub.elsevier.com/retrieve/pii/S0965856425002071

Ferrer-Ortiz, C., Marquet, O., Mojica, L., & Vich, G. (2022). Barcelona under the 15-Minute City Lens: Mapping the Accessibility and Proximity Potential Based on Pedestrian Travel Times. *Smart Cities*, *5*(1), 146–161. https://www.mdpi.com/2624-6511/5/1/10

Jin, T., Wang, K., Xin, Y., Shi, J., Hong, Y., & Witlox, F. (2023). Is A 15-minute City within Reach in the United States? An Investigation of Activity-Based Mobility Flows in the 12 Most Populous US Cities. *arXiv (Cornell University)*. https://arxiv.org/abs/2310.14383

Lima, F., & Costa, C. F. R. (2023). The Quest for Proximity: A Systematic Review of Computational Approaches towards 15-Minute Cities. *Architecture*, *3*(3), 393–409. https://www.mdpi.com/2673-8945/3/3/21

Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities. *Smart Cities*, *4*(1), 93–111. https://www.mdpi.com/2624-6511/4/1/6

Mouratidis, K. (2025). The 15-minute city revisited: A GIS approach to measuring, visualizing, and analyzing accessibility by proximity and by public transport supply. *Travel Behaviour and Society*, *42*, 101151–101151. https://linkinghub.elsevier.com/retrieve/pii/S2214367X25001693

Rhoads, D. D., Solé-Ribalta, A., & Borge-Holthoefer, J. (2023). The inclusive 15-minute city: Walkability analysis with sidewalk networks. *Computers Environment and Urban Systems*, *100*, 101936–101936. https://linkinghub.elsevier.com/retrieve/pii/S0198971522001806

Teixeira, J. F., Silva, C., Seisenberger, S., Büttner, B., McCormick, B., Papa, E., & Cao, M. (2024). Classifying 15-minute Cities: A review of worldwide practices. *Transportation Research Part A Policy and Practice*, *189*, 104234–104234. https://linkinghub.elsevier.com/retrieve/pii/S0965856424002829