MS-GIST Capstone Project

Assessing the Impact of Muni Metro Transit Station Location on Public Transportation Accessibility: Case Study in San Francisco

Author Name: Yirui, Hu

Advisor: Rama, Sivakumar, Part-Time Lecturer, School of City & Regional Planning, College of Design, Georgia Institute of Technology

Date:07/26/2024

Institution: School of City & Regional Planning, College of Design, Georgia Institute of Technology

The Online Portfolio: yhu_map

Abstract

The light rail transit system plays a crucial role in San Francisco's urban public transportation, significantly impacting urban mobility and accessibility. This study focuses on enhancing the accessibility of the light rail transit system by integrating transit station location and travel time into accessibility calculations. By defining and quantifying accessibility based on transit station proximity and travel time, accessibility scores are developed to compare different transit stations. This comprehensive approach leverages data from SFMTA, Open Street Map, and U.S. Census to analyze the spatial distribution of transit stations and their impact on accessibility. A case study was conducted in San Francisco city, employing spatial analysis and network theory to examine the connectivity and accessibility of light rail stations as nodes within the transit system network. An accessibility index was developed to measure each station's accessibility based on connectivity. The integration of transit location and travel time into the accessibility index created a comprehensive accessibility score, which was used to identify a detailed areas for potential improvements in the light rail transit network.

Contents

1. Introduction

Background Information

According to the American Community Survey(2022),in San Francisco, California, the mean travel time to work is 29.5 minutes, and 90% residents spent less than 60 minutes on commuting trip, also according to SFMTA 2021 Travel Decision Survey report ,among all travel mode, trips by modes prioritized by the transit-first policy (walking, biking, and public transit) were used for just over one-third (38%) of all trips in San Francisco. Trips in privately-owned vehicles (drive alone, carpool, and TNCs) accounted for nearly two- thirds (62%) of all trips in San Francisco. Public transportation still take an important role in residents daily commuting and travel as the leading travel mode, followed the 'Transit-Frist policy', public Transportation identified as Muni, BART, Caltrain, Ferry Or Public Bus, still takes the leading position in transit mode choice with 24% after pandemic period.

The San Francisco Municipal Transportation Agency (SFMTA) oversees an extensive network of public transit options, including the city's crucial light rail transit system. The SFMTA's light rail network includes the J Church, K Ingleside, L Taraval, M Ocean View, and N Judah lines. The Muni Metro system consists of 113 stations with overall length 38.9 mi (62.6 km).

Figure 1 Muni Metro Map of San Francisco (Data Source: SFMTA)

Statement of the Problem

The inequitable access to public transportation exacerbates social unfairness, a reality substantiated by numerous studies. Historically, transport policies have prioritized highway development over public transit, leading to significant disparities. This approach has resulted in unaffordable housing and lower accessibility to jobs and social networks for low-income residents. Enhancing public transportation access is therefore crucial for improving social equity and ensuring that all residents can benefit from the city's resources.

Also, due to the pandemic break out, the usage of the public transportation experienced a long duration of rapid decrease, even after 3 years later of the breakout, San Francisco is experiencing a slower recovery in local transit use compared to other major metropolitan areas in the U.S. While at least seven of the nine largest mass transit systems in the country have bounced back to more than 50% of their pre-pandemic ridership, San Francisco's transit system lags. This slow recovery raises concerns about the accessibility and efficiency of the light rail system, highlighting the need to examine and improve transit station accessibility to boost ridership and support the city's overall recovery efforts.

The accessibility evaluation have always been the key element for travel demand estimation to meet the public needs, traditional method usually consider the travel time as the index for estimating the distance travel time usage for utilities performance, travel time increase the travel opportunities decrease which consisted a linear relationship, while in reality other factors also impacted the access.

Objectives of the Project

Public transportation is a vital component for providing equitable access to essential services such as health care and jobs particularly for marginalized residents, thereby promoting fairness in transportation. The primary objectives of this project are to comprehensively evaluate the current accessibility of the Muni Metro transit system in San Francisco, develop a robust accessibility index, analyze the spatial distribution of stations, identify and quantify barriers to accessibility, and compare different accessibility models. This involves using data sources such as transit station locations, travel times, connectivity, and demographic information to provide a detailed measure of each station's accessibility. By examining geographic factors contributing to disparities in accessibility and assessing models that integrate multiple factors, the study aims to identify a effective method for evaluating transit accessibility.

2. Literature Review

Definition of the accessibility

Accessibility is a complex and multifaceted concept extensively explored in urban planning and transportation studies. It primarily describes the interplay between land use and transportation systems, highlighting the spatial distribution of potential destinations and the opportunities for individuals to engage in various activities across a geographic area. Accessibility is fundamentally understood as an individual's potential to participate in activities and the relative ease of reaching different destinations (Geurs et al., 2004).

It also encompasses the notion of individual mobility within a transport network system, a crucial aspect that dictates how easily individuals can navigate the system without facing financial or physical barriers (Wixey et al., 2005). Further research emphasizes that accessibility measures must consider the ease of movement within the system, ensuring inclusivity and accommodating the needs of all users, particularly those who are socially disadvantaged (Cheng et al., 2015).

Accessibility is intricately linked to temporal and individual components, as well as broader factors such as land use, transportation, economic development, and public demand (Vandenbulcke et al., 2009). The temporal component acknowledges that travel behaviors vary throughout the day, impacting accessibility depending on the time of travel. The individual component addresses the specific needs and characteristics of travelers, including their requirements for employment, leisure activities, and essential services. This component also considers demographic factors such as income, age, gender, household situation, car ownership, and physical condition, all of which influence travel mode choices and overall accessibility levels.

Evaluation methods of the accessibility

Accessibility evaluation methodologies can be categorized into several key approaches: distance-based, opportunities-based, utility-based, and gravity-based methods (Malczewski, 2004).

1.Distance-Based Evaluation: This approach assesses accessibility based on the physical distance or travel time required to reach various destinations or services. It is a straightforward method commonly used in transportation planning and urban studies to determine access to essential services like healthcare, education, and employment.

2.Opportunities-Based Evaluation: This method considers the range of potential activities available from an origin within a specified threshold (Vickerman, 1974). It is particularly relevant for modeling access to employment and affordable housing. For example, optimizing the location of affordable housing can significantly increase access to job opportunities via public transportation (Zhong et al., 2019). This method often involves multiple objectives and constraints, reflecting the complexity of accessibility in urban environments. In real-world applications, such as a study conducted in Chile using real GPS data from bus services, this method has revealed that public transport may not sufficiently mitigate spatial inequities in access to jobs and healthcare services (Basso et al., 2020).

3.Utility-Based Measurement: Initially developed in the study of travel behavior (Ben-Akiva et al., 1977), this approach uses a utility function to express the temporal and spatial components of the utility derived from individual choices. It captures the subjective value individuals place on different travel options and destinations, factoring in considerations such as travel time, cost, and convenience.

4.Gravity Model: First introduced by Hansen (1959), the gravity model has evolved into a fundamental tool in spatial analysis. It addresses spatial inequities by considering both spatial and temporal aspects of accessibility. Recent applications include assessing public transport services at the community level through measures such as network node betweenness centrality (Yang et al., 2019) and evaluating hospital resource accessibility by incorporating a competition index that reflects resident demand (Shi et al., 2021).

Also, the new technologies were introduced companied with the GIS toolkits merging, A systematic review of methodologies (Higgins et al. 2022) for calculating accessibility, revealing the limitations of accessibility indices in spatial analysis. They highlight the need for more sophisticated tools and methods to accurately assess accessibility in diverse contexts. A GIS-based spatial approach to determine the optimal locations for bike-share stations in Washington D.C. Their study emphasizes the importance of strategic location-allocation models to enhance accessibility and promote the best shared station locations. (Ebrahimi et al.2022) In case study of the SNAMUTS tools used to support the policy decision and planning routes for subway in Perth, the integrated tools perform in achieving the multiple goal of accessibility increase under the complex land use transportation mixed development mode.(Curtis and Scheurer,2010)

Accessibility in transit network of the transfer location

The choice of service location is critical in research, particularly in the location planning of Park-and-Ride (P&R) facilities around rapid transit systems. Using the Multi-Criteria Decision-Making (MCDM) model, explored potential locations spatially, providing qualitative insights into optimizing transit locations to enhance accessibility. Accessibility was assessed in residential areas concerning subway services, focusing on station locations. (Kar et al. ,2023) The study employed the Non-dominated Sorting Genetic Algorithm II (NSGA-II) to identify optimal station locations, underscoring the importance of advanced algorithms in accessibility planning (Wang et al., 2023).

Although extensive research has addressed location selection issues, the context of urban development, particularly in city areas, often favors renovation and adjustment over large-scale development requiring substantial funding. Highlighted that regional large-scale investments in accessibility improvements positively but subtly impact regional employment. Instead of focusing solely on location planning, the schedule and internal connectivity of public transportation systems play a more vital role in promoting sustainable development and achieving regional equity. (Rokicki and Stępniak ,2018) In the case study of the urban transport network within a ferry transit system, timetabling adjustments enhanced connectivity, reduced government subsidies, and increased OD pairs following the development of the IRIT network (Sandell, 2015).

Recent studies have expanded traditional accessibility models to include factors such as transfer locations. The development of an accessibility index incorporated elements like competition and circuity degree, revealing that areas with lower direct public transport access exhibited lower accessibility. The circuity degree measured the additional transit time required for public transport compared to private vehicles, indicating that improved connectivity reduces extra penalty times (Lee et al., 2015). A new model introduced incorporated transit locations as a significant factor, based on the hypothesis that travelers have specific preferences for transit locations. (Chia and Lee ,2020) Their study on Brisbane's bus network demonstrated that inner-city suburbs exhibit relatively higher accessibility than outer-city suburbs when only travel time is considered.

3. Data and Methods

Data Sources

In this study, the primary data sources include the SFMTA GTFS dataset, San Francisco shapefiles from the U.S. Census Bureau, and population and commuting data also provided by the U.S. Census Bureau. The SFMTA GTFS dataset incorporates real-time data for map visualization, presenting vehicle positions and estimated arrival times. The data sample used for this study was retrieved from the June 2024 real-time data API provided by the 511 SF Bay's Portal for Open Transit Data. It contains comprehensive information on stop times, stop IDs, route IDs, trips, and transfer details, enabling users to plan their journeys and estimate waiting times at stops.

The study employed the U.S. Census Bureau's statistical concept of census tracts as the geographical unit for quantifying transit accessibility. San Francisco consists of 244 census tracts, each housing populations ranging from 1,200 to 8,000 people, with an optimal size of approximately 4,000 people. Each tract was analyzed to evaluate the accessibility of the SFMTA Muni Metro transit system, providing a thorough assessment of transit accessibility across the city. The U.S. Census Bureau's 2022 population and commuting data were utilized in a descriptive statistical analysis within the same geographic framework.

Study Area

San Francisco serves as the focal area for this study. With a population exceeding 8.7 million, it ranks as the second most densely populated city among all American cities. The Muni Metro network extends its services across the urban peninsula, reaching middle-class suburbs such as the Sunset District and the Richmond District, while primarily concentrating in the downtown area.

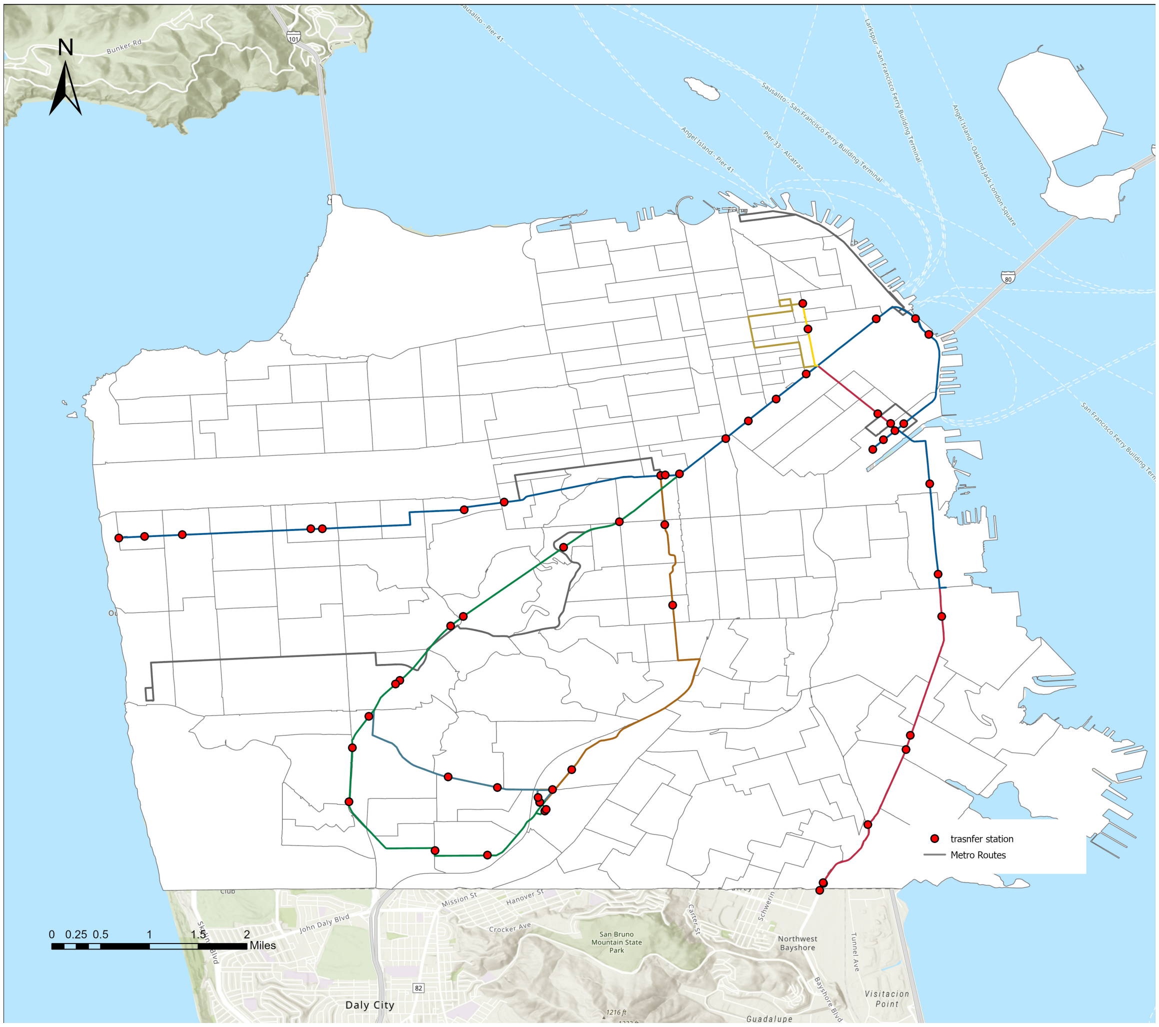

figure 2 Study Area with metro routes and stops

Methodology

The accessibility index calculation will use two different component representing travel time and transit location, the index is zone based and analyzed on a zone level (census tract level).

Transit Travel Time Component

In this analysis, I assume that for travel from Origin i to Destination j, the acceptable waiting time threshold varies depending on the total travel time. For trips lasting less than 10 minutes, a shorter waiting time is generally acceptable. Conversely, for trips exceeding 60 minutes, the acceptable waiting time threshold is set at 10 minutes. When the waiting time is less than 5 minutes, people are generally more willing to wait for transit. However, when the waiting time exceeds 15 minutes, there is a significant decline in people's willingness to wait, following a logistic decay regression curve.

This behavior aligns with findings from transportation studies, which indicate that shorter waiting times are strongly preferred by transit users, significantly influencing their satisfaction and choice of public transport (Fan, 2016). Additionally, research suggests that waiting time perceptions can drastically affect the perceived quality of a transit service, with extended waiting periods being a critical deterrent for potential users (Hickman & Wilson, 1995).

To determine the value of k in the logistic decay formula under these conditions, I can derive k based on the provided formula:

$$TDRDij = \frac{1}{1 + e^{-k(W-W0)}}$$

with a threshold W_0 of 10 minutes. For W=15 minutes, where:

$$TDRDij = \frac{1}{1 + e^{-5k}} = 0.07$$

$$e^{(-k(5-10))} = \frac{1}{0.07} - 1 = 13.29$$

can solve for k as the curve slope is approximately approaching to -0.52.
The final expression is:

$$TDRDij = \frac{1}{1 + e^{-0.52(W-10)}}$$

•TDRDij = Transit demand probability based on travel time from origin i to destination j.
•k= The limit of the logistic decay curve
•w= Transit travel time (minutes).

The figure 2 shows the relationship between transfer time at the station with the probability travelers used the transfer service. The expression reflects the probability of the transfer stays at a high probability when travel transfer time starts from 0-5 minutes, and then experience a decrease rapidly after 7.5 minutes waiting and drop at a low probability after 12.5 minutes. The slope of the decline becomes flatter after 15 minutes, the transfer chance convergence to zero when the transfer waiting time approaching to 20 minutes.

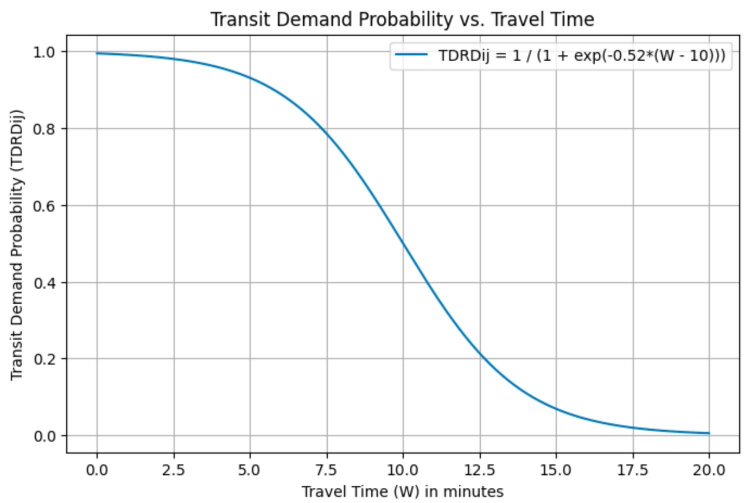

figure 3 The stop transit demand probability decay function

Transit Transfer Location Component

While travel time is a critical factor in calculating accessibility, it is influenced by various other components, such as the location of transfer stations. Studies have shown that both travel time and the ease of transfers significantly affect transit users' perceptions and choices, underscoring the importance of considering multiple aspects in accessibility assessments (Cervero & Murakami, 2010).

In this study, a binary parameter is introduced to indicate whether a transit route is direct or indirect. This variable takes a value of 1 for direct connections between an origin and a destination and 0 if the trip requires a transfer. The use of a binary parameter simplifies the modeling of route choices, as it clearly distinguishes between direct and indirect routes. Research has demonstrated that direct routes are generally preferred by passengers due to reduced travel time and increased convenience (Ben-Akiva & Lerman, 1985).

Multiple transfers are not considered in this analysis. The exclusion is based on the lower likelihood of passengers using routes requiring multiple transfers, as well as the increased computational complexity involved in modeling such scenarios. Prior research indicates that the inconvenience of multiple transfers often leads to a significant decrease in the likelihood of transit use (Guo & Wilson, 2011).

The Origin-Destination (OD) pairs are generated randomly, with 1,500 OD pairs representing journeys made using the metro service. Each OD pair is assigned a unique trip ID, corresponding with the transfer station list to ensure accurate representation of the entire transfer trip. These trips are categorized as either direct or requiring one transfer.

As shown in the accompanying table, if a direct service connects the origin and destination, the probability of taking that route is assigned a value of 1. In cases where a transfer is necessary, the probability is assigned a value between 0 and 1, based on the frequency of transfers. This approach reflects the nuanced decision-making process of passengers, who may still choose routes with transfers under certain conditions, such as shorter waiting times or fewer total transfers (Hensher et al., 2003).

Table 1 composition of the trips

Type of Trip	Number of Trips	Percentage	Transit Probability
Direct	1188	79.2%	1
Transfer(one time)	312	20.8%	Vary from 0 to 1 based on transfer location

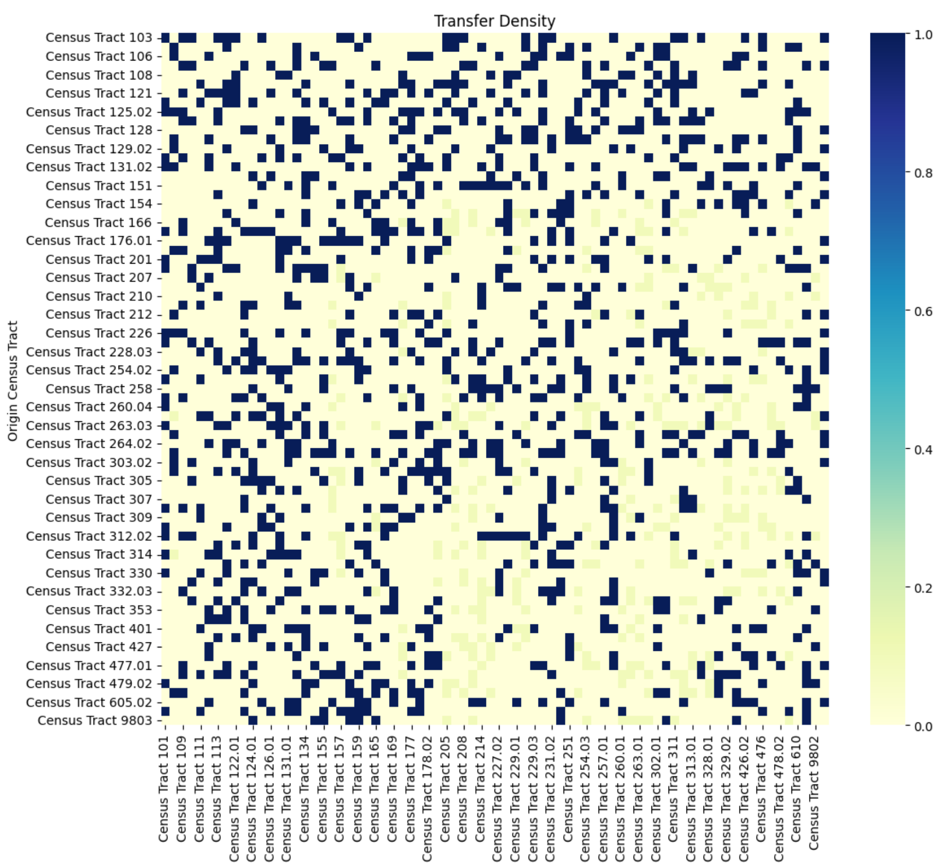

figure 4 Transfer density based on transit location

Among the 1,500 recorded trips, 1,188 were direct trips, while only 312 involved transfers. Notably, transfers tended to occur when the departure and destination routes were in close proximity. The transfer density, indicating the frequency of transfers relative to the number of trips, ranged from 0.2 to 0.5, with an average density of approximately 0.37. The 263.03 census tract had the highest proportion of transfer trips, accounting for 5.45%, followed by the 260.04 and 332.03 census tracts, each contributing 3.21%.

In San Francisco, census tracts numbered 103-180 are located in the northeast, while tracts 300-354 are situated in the southwest. The majority of transfers occurred in the northeast-to-southwest direction, suggesting a notable pattern in commuter behavior. It was observed that long-distance transfers did not constitute the majority of trips. Instead, transfers were more common within shorter distances, specifically between 3 km and 5 km. This trend indicates a preference among commuters for making transfers closer to their points of origin, likely due to the convenience and reduced travel time associated with shorter transfer distances.To get the probability of transit based on transfer location, the expression of the transfer location is based on connectivity to each census tract after normalization:

TDTPij = Transit demand probability based on transfer location from origin i to destination j

CL= connectivity level of the Transfer Station in statistical area, respectively

CLmax= highest connectivity level among all statistical area

$$TDTP_{ij}=CL/CL_{max}$$

4. Results

Transit accessibility Index

Previous research supports the importance of transfer ease and station location in determining transit demand. Studies have shown that reducing the need for transfers can significantly enhance the attractiveness of public transit (Gonzalez & Swain, 2021). Moreover, the strategic placement of transfer stations has been found to play a crucial role in optimizing transit networks and improving overall accessibility (Walker, 2012). These findings underscore the value of considering both spatial and temporal components in transit planning to better meet the needs of commuters and increase public transport usage.

In this study, I calculate the probability of a traveler choosing a station as a transfer point based on the travel time component derived from previous analyses. This calculation corresponds to the stop ID where a transfer action may occur, as estimated from the GTFS data. The probability of the transfer location component is determined by considering the station’s geographical position, helping to estimate the trip choices of Origin-Destination (OD) pairs. Typically, OD pairs with a short straight-line distance between them are more likely to have a direct connection between the origin and destination stations. This direct link is preferable as it avoids the need for a transfer, thereby minimizing station wait times and additional travel time.

The transit accessibility index in this context incorporates both the transfer location and transfer travel time components. This index is expressed through a unique value for each OD pair, representing the probability of transit demand.

$$TPij=TDRDij*TDTPij$$

TPij = Transit demand probability from origin i to destination j

TDRDij = Transfer demand probability based on transfer time from origin i to destination j

TDTPij = Transfer demand probability based on transfer location from origin i to destination j

The transportation accessibility of a single census tract is represented by the average trip probability from a single tract to every other tract, which is composed of origin-destination trips and tract-based transportation. Based on the previous component calculation, each origin-destination trip was assigned with their probability, use the average the expression is:

$$\text{Zone based accessibility}_i = TPij/\ TPij_{max}$$

$TPij_{max}$ = Maximum Transit demand probability from origin i to destination j

Zone based accessibility $_i$=Transit accessibility of the origin i

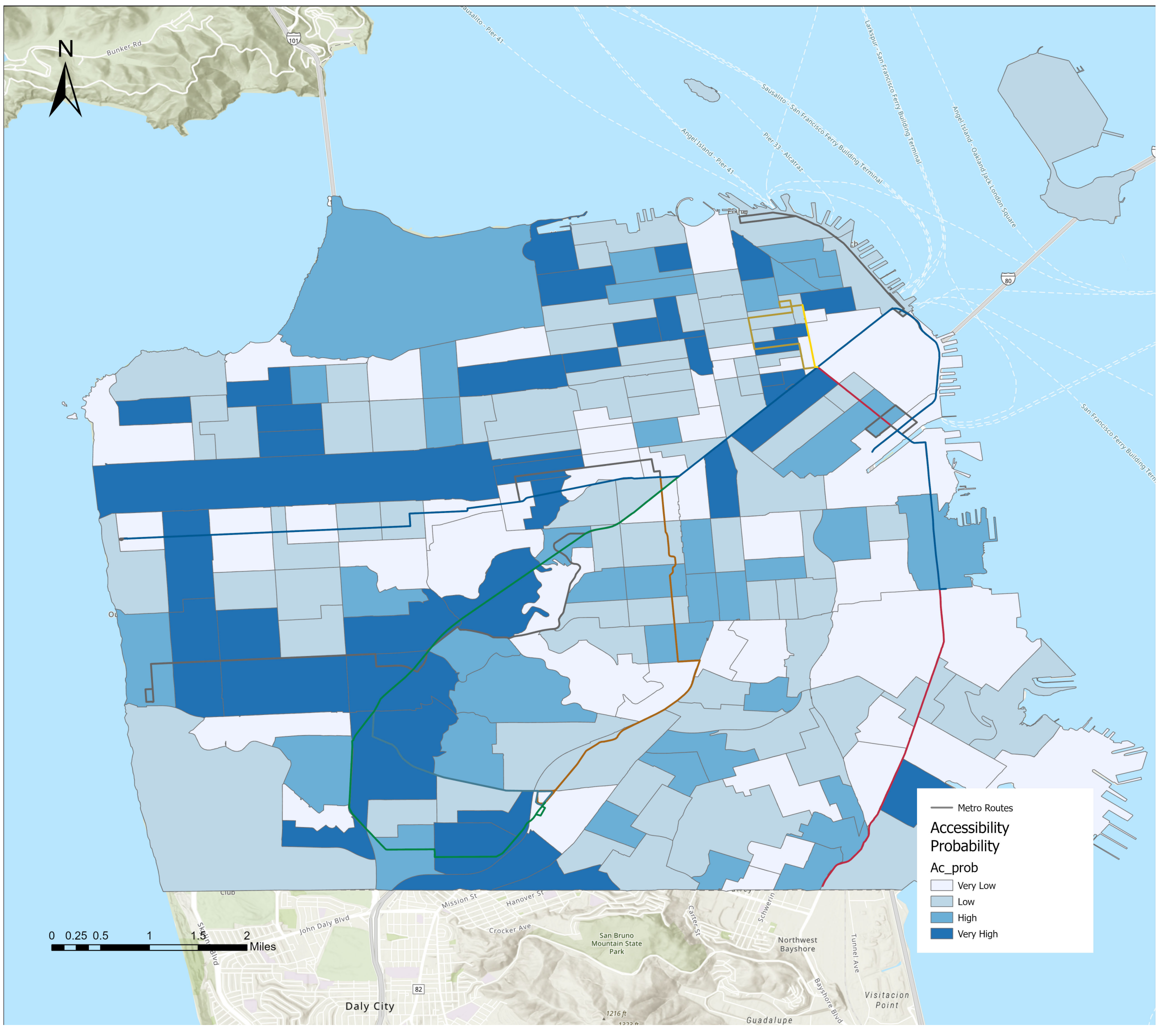

figure 5 Zone-based transit accessibility of all census tracts in San Francisco

Figure 5 illustrates transit accessibility in the San Francisco area based on census tracts, incorporating both location and travel time components. In contrast, Figure 6 focuses exclusively on the travel time component. Both figures use the quantile classification method in ArcGIS Pro to categorize accessibility levels. This method divides the data into very low, low, high, and very high categories, ensuring an equal number of data points per category. The quantiles represent ranks from the 25th to the 75th percentile, with the first quartile indicating the highest values on the map. This approach facilitates a uniform comparison across different classes by maintaining an equal number of value points per class.

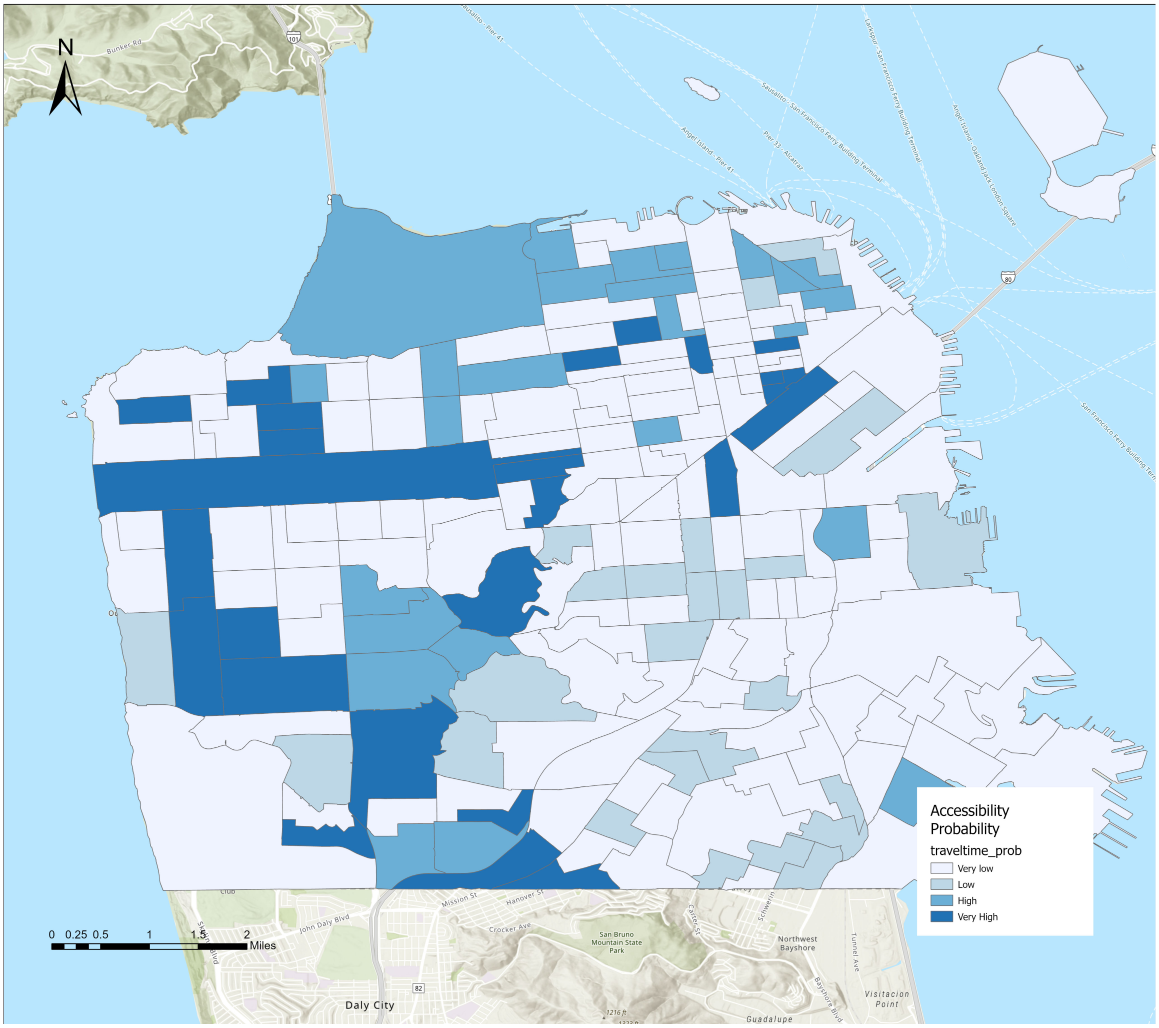

figure 6 Zone-based transit accessibility of all census tracts in San Francisco(travel time only)

The regional bus accessibility evaluation revealed that bus accessibility along the route is generally good. Notably, incorporating the transfer location factor into the accessibility calculation improved accessibility in some northeastern areas of the city, including census areas 108, 168, and 180 near Union Square, census areas 207, 210, 211, 212, and 215 in the Twin Peaks area, and census area 9305 in the Golden Gate Park area. These improvements underscore the significance of transfer stations in enhancing accessibility.

San Francisco's transportation network, characterized by a grid-like arrangement of streets and bus routes, contrasts with the ring, hub-and-spoke, or radial networks found in other cities. This grid network design, which mirrors the flow of streets and roads, affects how accessibility is evaluated. Traditional methods that rely solely on travel time can sometimes overestimate accessibility levels in certain areas. The findings indicate that accessibility is strongly influenced by the distance from the city's central business district (CBD) and the inclusion of transfer locations. When transfer opportunities are considered, certain areas exhibit higher potential accessibility, as they facilitate smoother and more efficient travel to destinations.

Figures 6 and 7 demonstrate that considering only the travel time component can lead to an underestimation of accessibility in some regions. This highlights the importance of a comprehensive approach that includes multiple factors, such as transfer stations and the network design, to accurately assess transit accessibility.

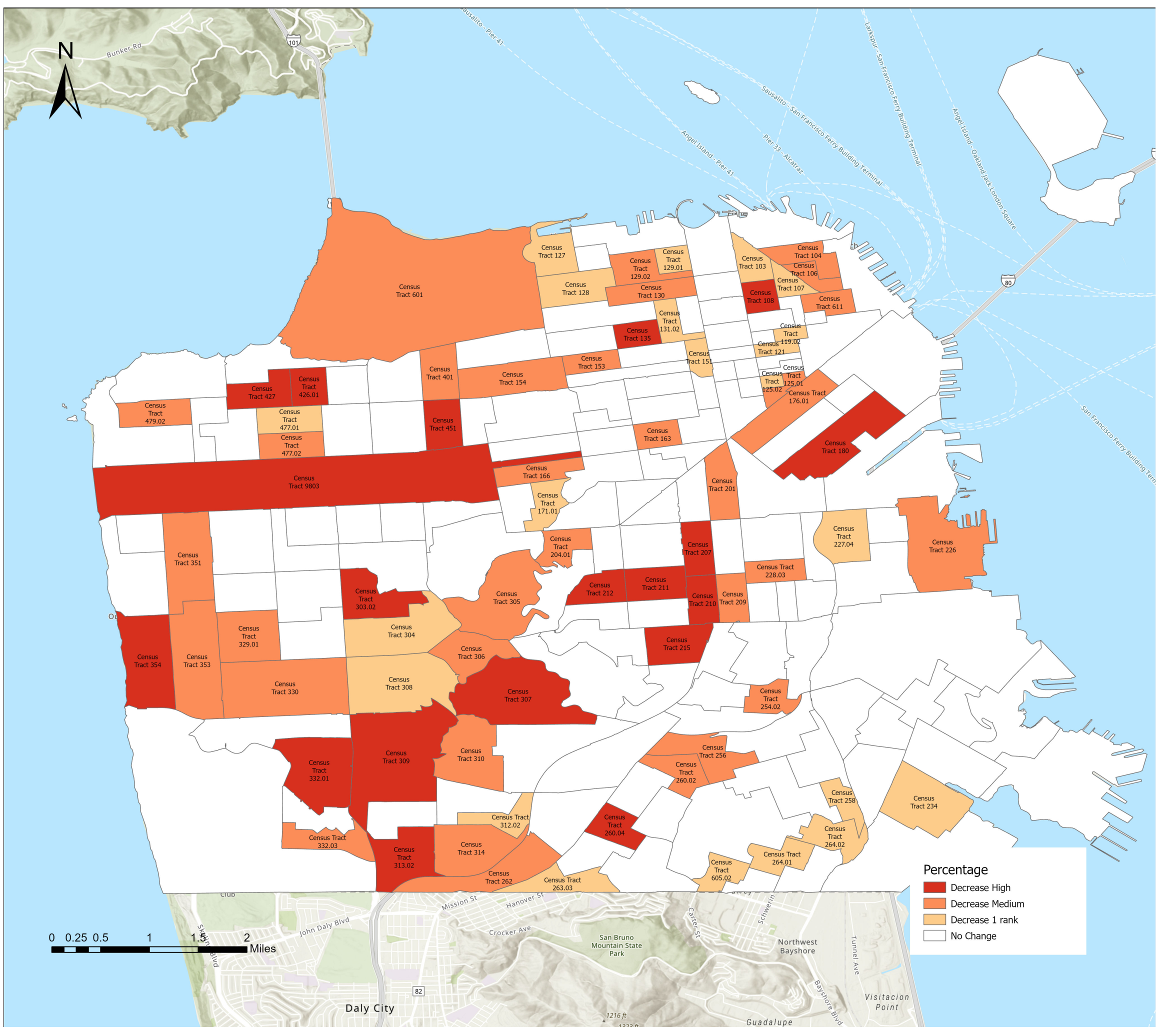

figure 7 The change in the transit accessibility level by incorporating the transfer location component

In Figure 7, the map provides a clearer depiction of how certain areas experience a decrease in accessibility when only the travel time component is considered in the calculation. The most significant decrease in accessibility values occurs in areas with good connectivity to transit routes, characterized by shorter distances to the nearest stations. These regions, often well-served by public transit, are particularly affected when the location component is excluded from the analysis.

Areas with a medium decrease in accessibility are more dispersed, primarily located around the Third-Ocean and Judah line areas. In the northern part of San Francisco, particularly in the middle-north direction, a notable decrease in accessibility is observed when the location factor is not considered. Similarly, the southern areas of the city also show a decline in accessibility under these conditions. In contrast, other areas exhibit minimal or no significant decrease, indicating that the impact of excluding the location component varies across the city.

Transit accessibility example

To explore how transfer location impact on single census tract area, here the census tract 168.0is 2 is chosen this census tract. Third-Ocean line along this area, also Duboco Church and Van-Church station is shown as the transfer stations in the metro system, which is all near this area.

in figure 8, this distribution show population with work ability from 18 to 60 age are distributed follow the tree shape, with more population distributed in 20- 40 age, which indicate that residents in this area is more likely do a commuting trip.

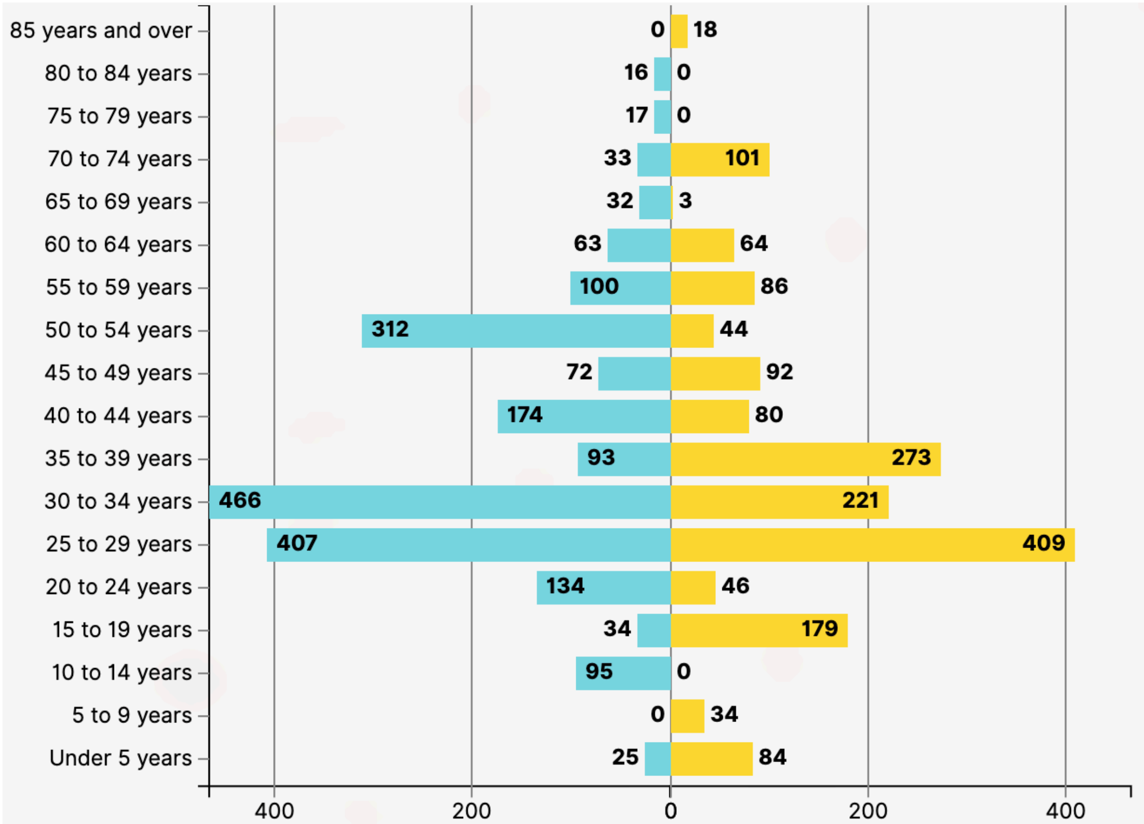

figure 8 Census Tract population distribution of San Francisco Census Tract 168.02 (Data Source: US. Census. Data)

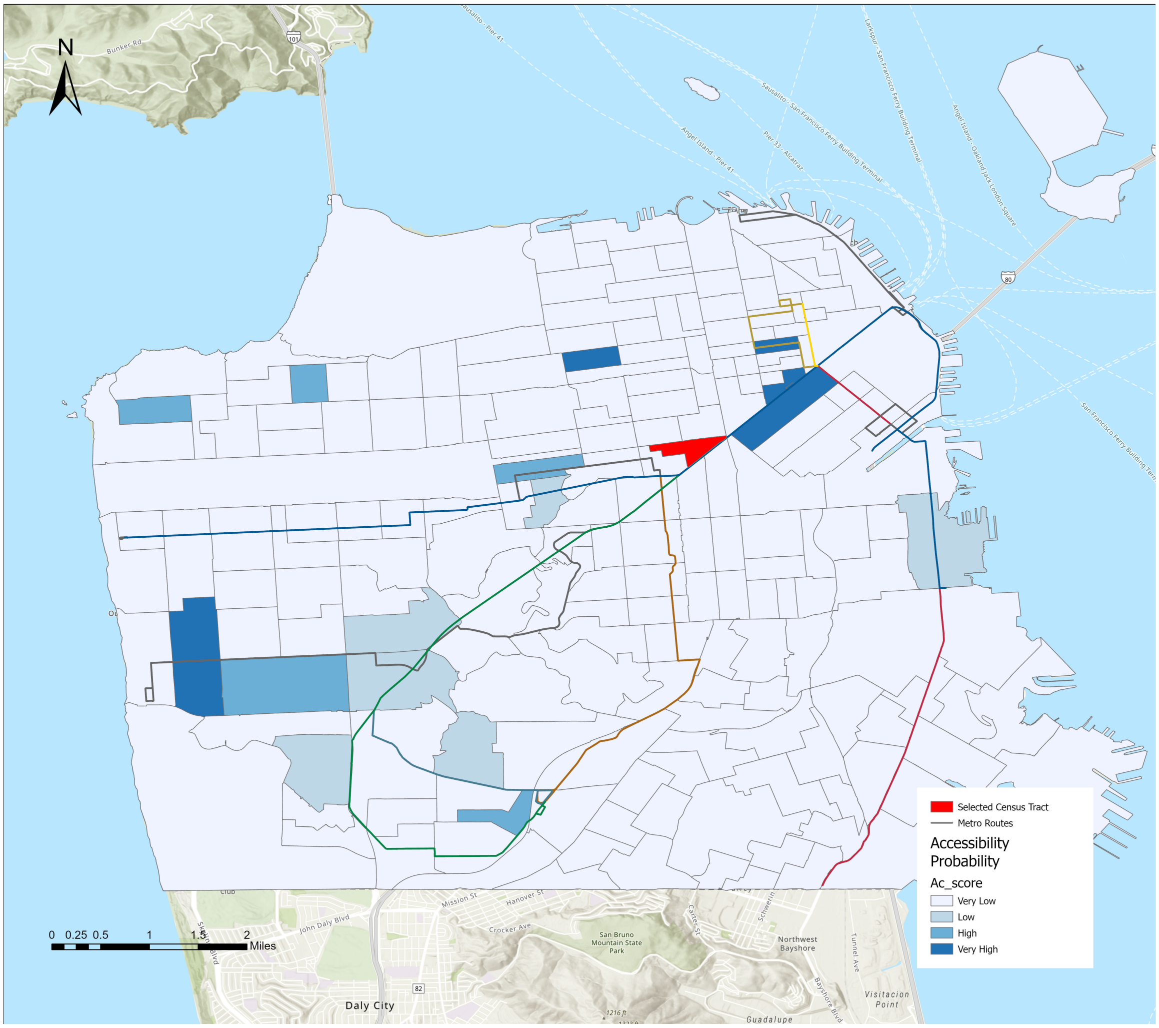

figure 9 Transit Network impacts the transit accessibility example

Census tract 168.02, situated in the Duboce Triangle area near Union Square, features a transit route along one side of the selected example area. Figure 9 illustrates zone accessibility, considering both location and travel time. In this figure, only a few census tracts demonstrate high accessibility despite the absence of routes directly through the area. Conversely, most areas lacking direct route coverage exhibit low or very low accessibility compared to other regions. Notably, people are generally willing to begin their journeys even if the station is at some distance from their origin.

Figure 9 also highlights the location of transfer stations considered in the accessibility analysis. The inclusion of these transfer locations enhances accessibility, especially in areas further from the Duboce Triangle, facilitating a broader range of travel behaviors. The metro line operates on a regular schedule, and the light rail system is unaffected by surface traffic conditions, thereby avoiding nonlinear increases in travel time. This stability in travel time is particularly crucial during peak and non-peak hours, making the light rail system an attractive option for commuters.

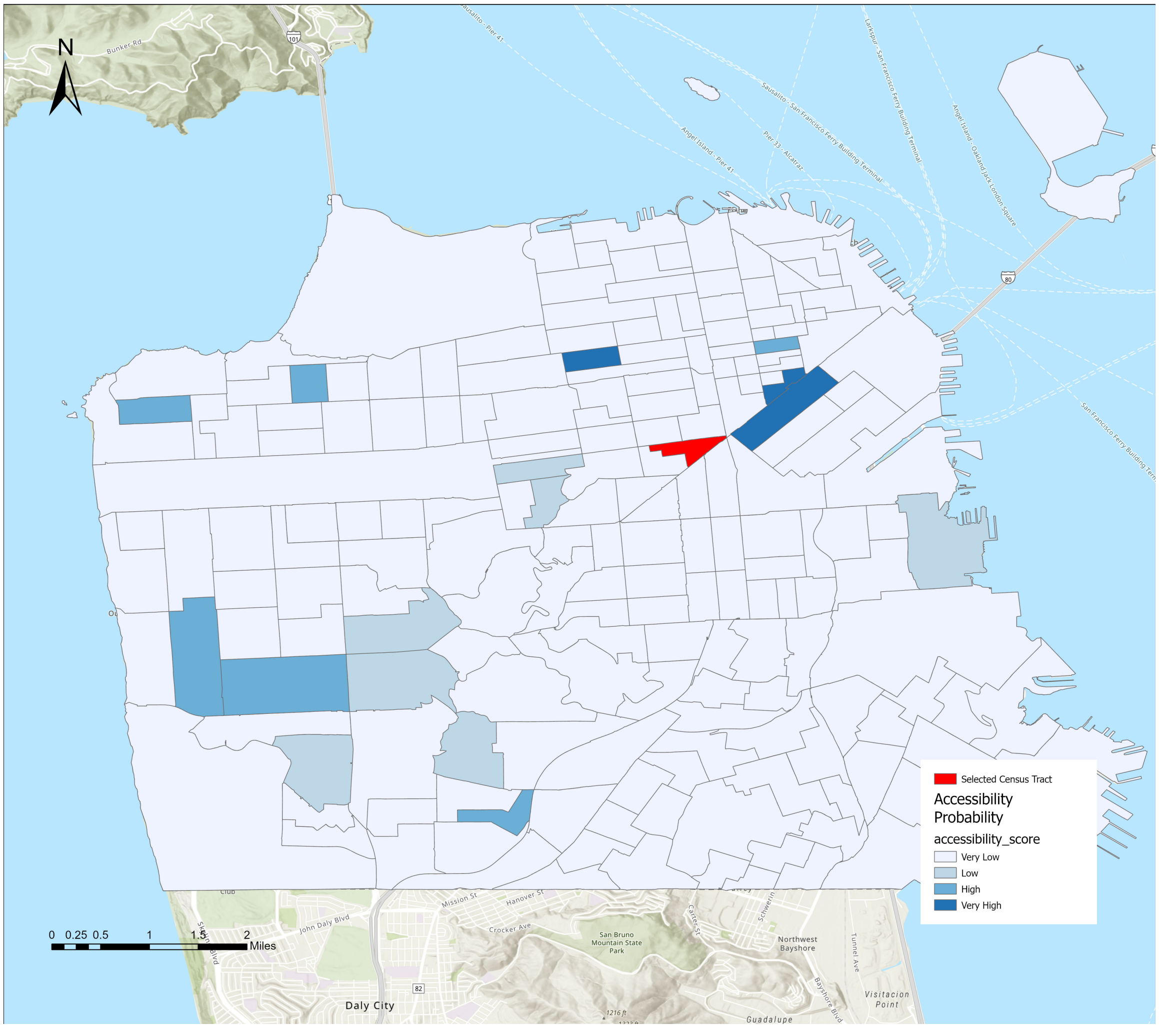

figure 10 Transit Network impacts the transit accessibility example(travel time)

In Figure 10, the location component is excluded from the accessibility calculation. The area in the southwestern direction, accessible via the Third/Ocean Line, demonstrates how travelers benefit from transfer stations distributed along this route. These stations enable seamless transfers, allowing passengers to reach census tracts such as 350 and 353, located at the terminus of the Taraval line. Figure 11 further details the reduction in accessibility for various census tracts when the location component is not considered in the analysis.

The highest levels of accessibility are observed in census tracts 176 and 159, which are situated near the selected census tract area. However, as the distance between these areas and other regions increases, there is a corresponding decrease in accessibility. This trend underscores the critical role of proximity in determining transit accessibility, highlighting the diminishing accessibility with increasing distance from key transit routes and transfer points.

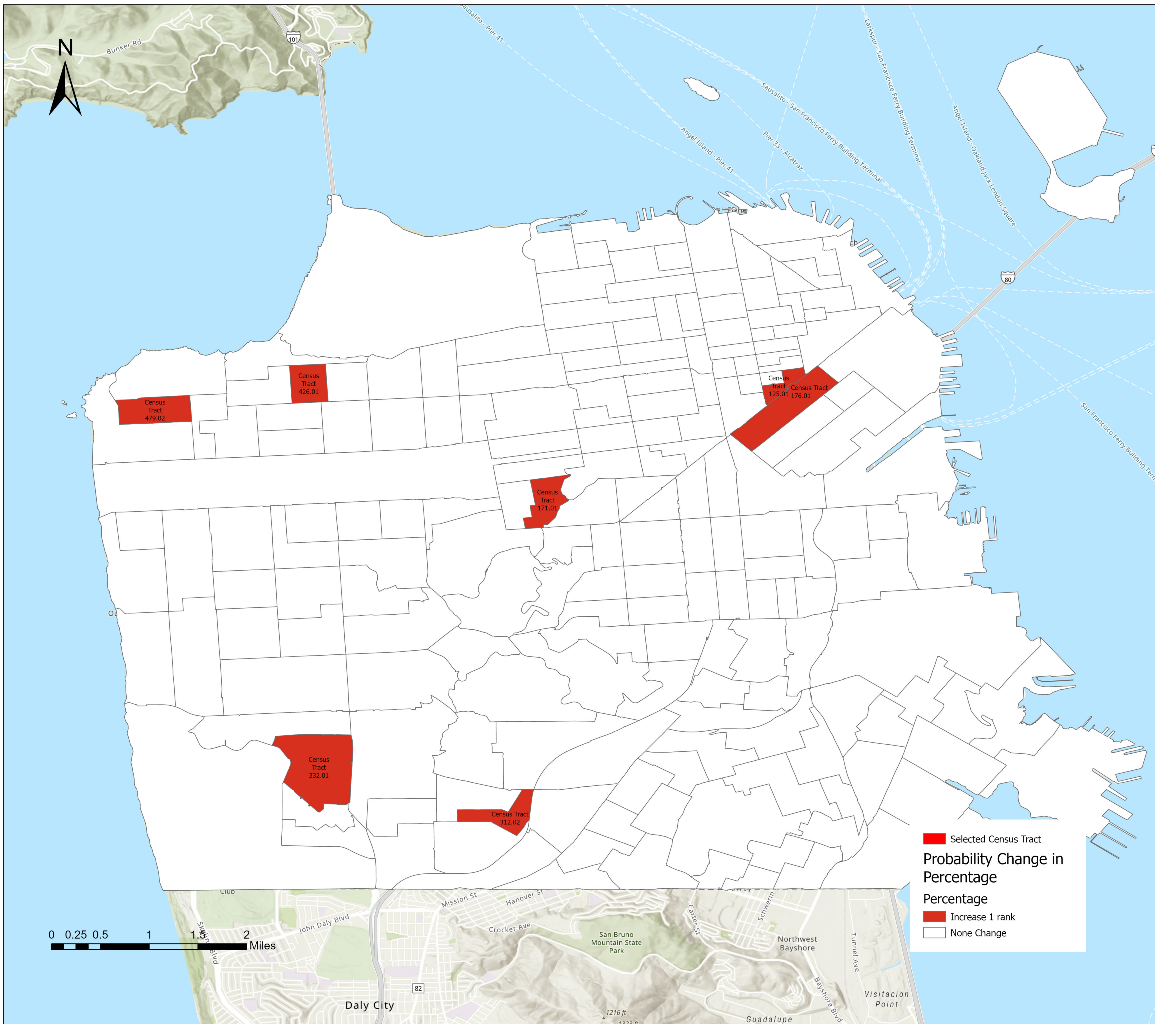

figure 11 The change in the transit accessibility level for example area by incorporating the transfer location component

5. Discussion

Implications of Findings

Based on a comprehensive analysis of travel area distribution in San Francisco, the commuting patterns of its residents predominantly follow a northeast to southwest trajectory. The northern region of the city, offering more job opportunities, exhibits a higher job-to-vehicle ratio compared to the western and southern regions, where this ratio gradually declines.

The placement of transfer locations significantly influences accessibility within a grid network, such as the San Francisco Muni metro system. The presence of well-placed transfer stations enhances network coverage and facilitates longer-distance travel between origins and destinations. A case study of the Muni metro system demonstrated that incorporating transfer locations into accessibility calculations can reveal higher actual accessibility levels in certain areas than conventional methods. Traditional measures may overestimate accessibility in regions well-served by public transport, while underestimating it in areas farther from the city center that benefit from extensive route coverage.

The strategic location of transfer stations is particularly crucial as urban areas expand. These transfer points allow travelers to extend their journeys, indicating a willingness to accept longer distances or travel times if the connectivity is robust. This is true even when the destination requires a transfer rather than being a direct trip. The role of transfer locations, therefore, becomes vital in ensuring that the public transport system meets the evolving needs of an expanding urban population, supporting greater mobility and accessibility.

Limitations of the Study

This study focuses exclusively on the Muni Metro system within San Francisco, considering only transit locations when modeling accessibility. It does not account for multimodal transit behavior, such as interactions between different forms of public transportation or private modes. Therefore, an unexplored limitation of this research is the examination of how transit accessibility varies under different transfer modes, which could provide insights when applied to a broader transportation network.

Transit behavior can also be influenced by varying time periods, such as peak hours, which can significantly impact surface bus transfers. During peak times, increased travel times and longer wait times at popular transit locations can deter individuals from choosing these stations, affecting overall accessibility. Understanding the differences between peak and non-peak hour transit scenarios could offer valuable insights into traveler behavior and preferences. Additionally, the choice of origin and destination locations may differ based on travel times, with this study primarily considering commuting patterns as a reference point.

The schedule variability within the SFMTA system, including differences between weekday and weekend services and variations between day and night schedules, also plays a crucial role. Night service frequencies, for instance, can significantly influence the decision-making process for transfer trips, as reduced frequency may limit accessibility.

The distribution of transit accessibility is further affected by the study area's characteristics. In this case, San Francisco serves as the example, where the city's natural terrain and resulting residential and job distributions create an inherent imbalance. The northeastern part of the city has a denser transportation network compared to the southern areas, leading to more frequent transport activities in regions with a dense network.

Comparative studies in cities like Brisbane, Australia, have shown that introducing location components can lower accessibility in certain areas, especially within a sparse transport network. In such contexts, outer suburban areas along bus routes may outperform inner suburban areas lacking high connectivity. This contrast highlights the importance of considering local geographical and infrastructural factors when assessing transit accessibility.

Recommendations for Future Research

The multimodality transfer behavior is more complex that the single mode transfer, such as bus to metro, metro to bus etc., how people willing to wait or take their time in transfer impacted the actual accessibility of different destinations. The actual waiting time involved with multimodality transfer behavior related to walking time between stop-to-stop transfer, and surface to underground transfer, the walking time and waiting time would added, when transfer behavior have higher travel time cost, the willingness to take the transfer would decrease, in research of transfer station choice in multimodal system, conducted in Washington, DC, the results shows that only 40% traveler s would choose the nearest station for transfer in trip, the choice of the transfer station are impacted by public transport services distance, the location of the station is important in defining the station service area, the transfer location of the station still could provide prediction of the travelers flow .

6. Conclusion

Public transportation as an crucial for equitable access to essential services such as healthcare and jobs, particularly for marginalized residents. The analysis includes developing a robust accessibility index, analyzing the spatial distribution of stations, identifying and quantifying barriers to accessibility, and comparing different accessibility models using location and travel time component. The results of the case study analysis shows that central and northern parts of the city exhibit higher accessibility, while some southern tracts show improvements needed to be taken to enhance, also the introduce of location reveals the reason of travelers' behaviors mode.

Final Thoughts

The transfer location impact in accessibility is only a single aspect that would affect travelers choice or actual ability to take a transfer trip, and also the GTFS real time data is vital to conduct the research related to the public transportation accessibility, the experiment would be enhanced if the smartcard data, for San Francisco system which called Muni card, could be available for study, the data could be more reliable in this method.

7. References

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