GETTING THERE

The Effect of First and Last Mile Infrastructure and Services on Rail Ridership

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MAPS AND TABLES

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EXECUTIVE SUMMARY

Introduction and Relevance

The first and last mile is a critical part of transportation planning; the journey to and from a transit station is as much of a part of a trip as the transit ride. This portion of planning has gotten more attention in the past decade, with a number of cities and transit agencies releasing plans that specifically address the first and last mile. This report adds to the growing attention paid to first and last mile planning.

Specifically, this report approaches first and last mile planning by looking at the connection between first and last mile infrastructure and services and ridership at rail stations in the San Francisco Bay Area. The focus on ridership was chosen as a measure of effectiveness so that the impact of first and last mile infrastructure and services could be compared. Rail ridership, however, is just part of the first and last mile question; there are other reasons a transit agency may choose to improve first and last mile infrastructure or services.

GOALS

Determine the impact of first and last mile infrastructure and services on rail ridership.

Understand the current state of first and last mile planning in the United States.

Explore the relationship between exisiting first and last mile plans and the academic literature.

The core of this report is split into two major parts: a review of existing first and last mile plans, and a statistical analysis of rail ridership at San Francisco Bay Area rail stations. The review of existing first and last mile plans covers all existing plans in the United States, and compares those plans to the findings in academic literature. The statistical analysis specifically analyzes the impact of first and last mile infrastructure and services, including bus and shuttle services, street network completeness, and bike facilities, on rail ridership. This analysis contained in this report is intended to be useful for planners as they approach new first and last mile plans, helping them better choose investments that have the greatest impact on ridership. Additionally, this report adds to the existing academic literature, finding that modes not typically covered in first and last mile analysis do have an impact on rail ridership.

Academic Literature and Planning Documents Differ

The key finding from the review of academic literature and existing first and last mile plans is that existing first and last mile plans place most of their focus on active transportation modes, while the academic literature suggests that ridership is largely driven by land use. Academic literature finds that while some active transportation related improvements do have an impact on rail ridership, the relative impact of bike and pedestrian infrastructure is much smaller than that of land use. Specifically, the academic literature finds that high-density residential, employment, and mixed-uses surrounding stations is the most predictive driver of transit ridership.

Both the academic literature and existing first and last mile plans focus primarily on active transportation modes as key station access modes. Less attention is given to bus services, although the academic literature does suggest that bus services play a part in driving rail ridership. Few first and last mile plans include bus services as a first and last mile solution.

The academic literature and planning documents also differ in their treatment of equity. A number of the existing plans include equity as a core portion of the plan, but academic research into the link between equity and first and last mile access is almost nonexistent. What literature does exist does suggest that there are important equity implications related to improving first and last mile access.

Quantitative Methodology

The statistical analysis in this report is a cross sectional study of station-level ridership at stations in two San Francisco Bay Area rail systems: Bay Area Rapid Transit (BART) and Caltrain. Station-level ridership data for stations in both systems were collected, as well as a number of control and first and last mile related variables. The control data includes demographic data about station-area populations and service data such as the number of trains that serve a station at peak hour. First and last mile variables include both active transportation mode variables, as well as variables such as bus and shuttle service.

The data was then analyzed using a linear regression model. A linear regression model was chosen as it allows for comparisons between variables across stations, estimating the number of daily riders a specific first and last mile service or piece of infrastructure adds or subtracts. In addition to the main model, two more models were run with the same variables, but limited to stations on either BART or Caltrain.

Major Findings

The model's key finding was the large impact that bus and shuttle services have on ridership at stations. Both variables were found to be highly significant. The individual BART and Caltrain models supported this result, with the impact of shuttle service being especially large and significant in the Caltrain model.

The model also strongly supports the academic literature, finding that station area jobs and housing are extremely effective predictors of rail ridership. Each additional resident or job in a station area increases daily ridership by a small, but significant amount, suggesting that ridership is ultimately heavily driven by station area land use.

Other first and last mile infrastructure and services were found to be less significant and impactful. Bikeshare was found to have a positive impact on rail ridership, but at a lower significance, and with much greater variability. The remaining first and last mile variables, including the presence of bike lanes, the provision of secure bike parking, the presence of bus terminals, and the completeness of the street network, did not show statistically significant positive relationships with rail ridership. This lack of significance is possibly due to two main reasons: it impacts a small portion of total ridership, as is the case with the bike variables, or the variable is closely related to other variables, as is the case with bus terminals and the completeness of the street network.

The Importance of Bus and Shuttle Services and Other Lessons

The key takeaway from the model and review of academic literature and existing planning documents is that bus and shuttle services should be considered as an important part of first and last mile planning in a way that they are currently not. More attention needs to be given to bus and shuttle services in planning documents and in the academic literature.

Similarly, land use is generally not considered in existing first and last mile plans, despite evidence that suggests it may be the most important driver of rail ridership. Planners must consider land use as part of first and last mile planning if the goal is to support and increase rail ridership.

This report focuses primarily on ridership as a measure of effectiveness, but there are a number of other reasons a city or transit agency might pursue first and last mile improvements, such as safety or improved trip quality. Equity is amongst those reasons. The reviewed literature suggests that first and last mile improvements has a significant impact on improving access to jobs for disadvantaged communities; combined with the analysis in this report, this suggests that equitable first and last mile access could also have an impact on ridership. Equity in first and last mile planning is not a well-studied subject, and needs to be considered in both future academic literature and first and last mile plans.

POLICY RECOMMENDATIONS

Where possible, increase bus services to rail stations.

Mandate the provision of shuttle services for housing developments and job centers not adequately served by transit.

Give greater authority to metropolitan planning agencies to be involved in the first and last mile planning process to ensure greater coordination between land use and transportation throughout a metropolitan region.

Ensure equity is considered throughout the planning process, using equity to inform and target first and last mile improvements.

Ensure that emerging technologies are regulated to improve and support equitable first and last mile access.

1. INTRODUCTION

Rail transit is an important part of urban public transit networks throughout the United States. Yet rail transit trips rarely start or stop at a station; riders travel from their origin to a station, and from a station to their final destination. Those trips, referred to as the first and last mile, are an important part of a journey, and aren't impacted by improvements to rail service, such as more frequent trains.

This report is an examination of first and last mile planning in the United States, looking specifically at how first and last mile infrastructure and services impact rail ridership. To do this, this report includes a review of relevant academic literature and existing first and last mile plans, combined with an analysis of San Francisco Bay Area rail stations. The analysis examines ridership at each station to estimate the impact of different types of first and last mile infrastructure and services on ridership.

First and last mile planning is a broad topic; this report focuses on the impact of first and last mile planning on ridership, but there are a number of other reasons a city or transit agency might want to improve first and last mile access beyond ridership, such as safety or improving the quality of access for current riders. Included in this report, however, is a brief examination of equity in a first and last mile context, a relationship that has been previously understudied by academic literature.

GOALS

Determine the impact of first and last mile infrastructure and services on rail ridership.

Understand the current state of first and last mile planning in the United States.

Explore the relationship between exisiting first and last mile plans and the academic literature.

Key Terms and Definitions

This report uses a number of terms specific to first and last mile and transportation planning. These terms are defined below.

First and Last Mile: The first and last mile is a planning term that refers to the trip transit riders take to or from a station. Transit services do not stop at every place in a city, so it's important to understand how riders access a station, and the obstacles they face when doing so. It is not always a literal mile; it can be shorter or longer than a mile. The first and last mile can be referred to as a "problem" or "challenge", with infrastructure or services referred to as a "solution".

First and Last Mile Infrastructure: This term, for the purposes of this paper, refers specifically to physical improvements or structures that relate to connecting riders to transit. An example of first and last mile infrastructure reviewed by this report is the presence of a dedicated bike lane that accesses a station.

First and Last Mile Services: This term refers specifically to non-physical services provided at or near transit stations that relate to connecting riders to transit. An example of first and last mile services reviewed by this report is the provision of shuttle service by a private employer that links the employer to a rail station.

First and Last Mile Plan: A first and last mile plan is a plan produced by a public agency, typically a transit agency or a city. These plans describe the guidelines and strategies the publishing agency intends to follow to improve first and last mile access to transit station within the area the agency provides services. Typically, these plans specifically exclude automobile access from review.

Station Access Plan: Similar to a first and last mile plan, but typically either broader or narrower in scope, focusing on a specific access mode or include significant review of automobile access modes.

Mode Choice: Mode choice refers to how somebody chooses to travel from the origin of their trip to their destination. Examples of modes are bike, single-occupancy vehicle, or bus.

Station Access Mode Choice: Station access mode choice refers to the mode transit riders use to access a transit station, specifically rail stations for this report.

Heavy Rail and Light Rail: Heavy rail and light rail refer to the types of trains that are operated on a rail network. Heavy rail typically has larger vehicles and higher passenger capacity than light rail.

Park and Ride: A service provided at many rail transit stations, park and ride lots are parking lots riders can park their cars at before taking the train to their final destination. Although not considered a type of first and last mile infrastructure for the purposes of this report, the impact of park and ride on station access and rail ridership is reviewed.

Catchment Area: For the purposes of this report, a catchment area is the area around a station that the station typically draws its ridership for. The catchment area can be defined in a variety of ways, typically based on station access mode choice. For the data analysis in this report, a catchment area of ½ mile based on the street network surrounding the station area was chosen. A more detailed explanation of why that measure was chosen is in the Methodology section of this report.

Bikeshare: Bikeshare is a service by which users can temporarily rent a bicycle for use in a specific area, usually using a mobile app. Bikeshare comes in two varieties:

Docked Bikeshare: Docked bikeshare requires users to pick a bike up at a station somewhere in the bikeshare provider's service area, and return the bike to any station at the end of their trip.

Dockless Bikeshare: Dockless bikeshare allows users to leave bikes anywhere within the provider's service area.

Scootershare: Scootershare is a service that works like dockless bikeshare, allowing users to temporarily rent an electric scooter using a mobile app. Scooters can be left anywhere in the providers service area. Due to the recency of scootershare availability, the impact of scootershare on rail ridership is not analyzed, but discussion of scootershare is included.

Peak-Hour: Peak-hour refers to the busiest commute hours in a metropolitan area, typically in the mornings and evenings.

Peak-Direction: Peak-direction refers to the direction in which most commuters travel at a specific time of say. For example, peak-direction may be into a city in the mornings and out into the suburbs in the evening.

Land Use Planning: Land planning refers to the policies that municipalities adopt to shape what uses are permitted in different parts of that municipality. For example, land use planning determines if apartment complexes are permitted in a certain neighborhood.

BART: Bay Area Rapid Transit (BART) is one of the two San Francisco Bay Area rail systems analyzed in this report. BART operates five lines, serving San Francisco, Alameda County, Contra Costa County, and the northern part of San Mateo County. BART is a metro rail service, using electrified heavy rail trains running on a regular schedule.

Caltrain: Caltrain is the second of the two San Francisco Bay Area rail systems analyzed in this report. Caltrain operates a single line, running from Gilroy in Santa Clara County, through San Mateo County to San Francisco. Caltrain is a commuter rail service, using diesel locomotive-driven trains on a schedule that prioritizes peak-hour, peak-direction service.

Relevance

Land use and transportation planning are closely linked; first and last mile planning links the two together and is an important part of both.[1] [2] Many major American cities have rail services, both heavy rail and light rail, and improving the connection between the stations in those systems to the surrounding communities could impact how those services are used. Research suggests that solving the first and last mile problem encourages public transit use.[3] Additional research also indicates that the quality of the walk to a station impacts if and how a potential rider chooses to access a station.[4] This report examines first and last mile planning more comprehensively; instead of focusing on a specific access mode, this report reviews a number of potential access modes and compares their impact.

The quality of access to and from rail stations has a major impact on rail riders using a variety of station access modes. Many cyclists use transit to extend the distance they travel by bike, treating transit as a secondary mode to cycling.[5] Transferring between transit services, such as bus and rail, can be a barrier to users; reducing transfer barriers has been shown to encourage riders to use a combination of rail and bus.[6] Bikeshare is used more frequently when the bikeshare station is located at transit station.[7] None of these examples specifically relate to the quality of service provided by a transit service, but all impact how riders interact with public transit. This report adds to the understanding of these interactions more clearly and how they specifically impact how many people choose to ride transit.

Not all transit users encounter issues of first and last mile planning; many choose to drive to transit stations and use a park and ride lot, something that has been shown to reduce emissions compared to taking a single-occupancy vehicle.[8] This report incorporates the impact of park and ride facilities on rail ridership, and compares the impact of providing park and ride

1 Park, Choi, and Lee 2013
2 Martens 2007
3 Bron, Givoni, and Rietveld 2009
4 Park, Choi, and Lee 2013
5 Flamm and Rivasplata 2014
6 Saghapour, Moridpour, and Thompson 2016
7 Ma, Liu, and Erdogan 2015
8 Duncan and Cook 2014

facilities and providing first and last mile infrastructure and service on rail ridership.

First and last mile planning has also become an increasingly important focus of transportation agencies and cities, with some agencies and cities producing plans specifically addressing the first and last mile. The Los Angeles Metropolitan Transportation Commision (Metro) produced the first plan by a transit agency that addresses the first and last mile in 2014.[9] Since then, more agencies and municipalities have produced or begun to produce their own first and last mile plans. These plans are reviewed later in this report. This report contributes to the growing interest in this topic as well as review and discuss the current state of first and last mile planning. Transportations and municipalities will be able to use this report as a starting point for their own first and last mile plans.

Beyond a review of existing literature, this report also analyzes the impact of first and last mile infrastructure and services on rail ridership. The results of this analysis will help planners target the most effective and efficient first and last mile improvements. The ridership model included in this report can help planners estimate the impact of first and last mile improvements on rail ridership, and if they choose to do so, target improvements that have the greatest impact on ridership.

More narrowly, this project looks at rail transit in the Bay Area, specifically BART and Caltrain. The analysis contained in this report will be highly relevant to both systems, as well as the cities and counties that the systems run through. Understanding the impact of first and last mile infrastructure and services on these rail services will allow planners to make targeted improvements based on an analysis of their specific systems, and the stations in their communities. The lessons learned from this report and analysis will also be more broadly applicable. BART is a heavy rail metro system and Caltrain is a commuter rail system. There are at least 29 commuter rail services in the United States and a number of heavy rail metro services.[10] Strategies that work for BART and Caltrain may be useful for similar systems elsewhere.

The analysis in this report is additionally intended to fill in a gap in the existing literature. There are a number of studies that examine specific station access modes and a number of studies that look at the quality of access mode. This report is unique in the combination of modes it considers and its connection to rail ridership. Studies on station access generally focus on a specific access mode, and don't take a comprehensive look at station access modes. Those that do connect these variables to station access mode choice, rather than connecting the variables to rail ridership.

Intended Audience

The intended audience for this report is varied. The first intended audience are planners, specifically planners that work for rail transit providers and planners that work in municipalities with rail stations within their boundaries. Bay Area planners will find this report especially relevant.

Outside advocacy groups are also likely to find this report useful and relevant. Bike, pedestrian, and transit advocacy groups and advisory committees will be able to use this report to support specific station area improvements and advocate for policies that support transit ridership.

Additionally, this report represents an addition to the academic literature, closely tying academic theory and original research with professional planning practice as it stands today. Academics and others concerned with urban and transportation planning research are also likely to find this report relevant.

This report is also intended to be a thorough introduction to the current state of first and last mile planning, explaining how the field is implementing first and last mile solutions and the evidence that supports those solutions. The report is therefore intended to be relevant for anyone that is broadly familiar with the basics of transportation and land use planning, but not familiar with the specifics of first and last mile planning.

9 Los Angeles County Metropolitan Transportation Authority and Southern California Association of Governments 2014
10 Brock and Souleyrette 2013

Structure of the Report

The remainder of the report is split into five main sections:

Academic Literature: This section reviews existing academic literature on the subject, identifying findings and themes from previous research.

Existing First and Last Mile Plans: The section reviews existing planning documents related to first and last mile planning, including a review of every existing first and last mile plan in the United States.

The Current State of First and Last Mile Planning: This section compares existing first and last mile plans and the academic literature, identifying trends and where planning documents and literature differ.

Quantitative Methodology: This section gives an in-depth explanation of the methodology behind the ridership model at the center of this report, explaining how the data was compiled and the choices made in the model.

Findings: This section reviews the results of the ridership model, and provides explanations of the results, highlighting some of the more significant findings.

Significance: This section highlights how the findings of the ridership model relate to the current state of first and last mile planning, comparing the findings of the model to existing academic literature and current first and last mile plans.

Conclusions, Policy Implications, and Further Research: This section identifies important conclusions from the analysis in the report and discusses the policy implications of those findings. The section also identifies the shortcomings of the report and suggests how future research efforts could build on the analysis found in this report.

2. ACADEMIC LITERATURE

This section reviews existing scholarly research on the topic of first and last mile planning through several different lenses. The findings from academic literature reviewed in this section are used throughout this report for comparison. This review of scholarly research is split into three sections: determinants of rail ridership, station access mode choice, and equity.

Rail Ridership

Determinants of rail ridership is a well-studied topic. Generally, studies look at ridership through at least one of three lenses: land use, demographics, or station access. Land use analysis includes the impact of residential density and employment uses on rail ridership. Demographic analysis examines the impact of demographic characteristics on rail ridership, such as household income or race, and is typically included as control variables. Station access analysis examines the quality of the trip to or from a station, and is the most directly relevant to first and last mile planning.

Of the studies that made land the primary focus, all of them found that denser uses, both in residential uses and in employment uses, correlated with higher ridership. Three studies have found that increased density around stations increases transit ridership, with ridership increasing even further with a dense mix of uses.[1 2 3] Specifically relating to employment, several studies have found that that the number of jobs in the area around a station has a major impact on ridership at that station, with one study finding that the number of jobs in a station area was the best predictor of ridership of any variable tested.[4 5] A study of Montreal's metro network went further, and found that governmental and institutional land uses specifically drove additional ridership when compared to other employment related land uses. [6]

1 Cevero 2001
2 Brons, Givoni, and Rietvald 2009
3 Kim, Ahn, Choi, and Kim 2016
4 Kuby, Barranda, and Upchurch 2004
5 Cevero 2001
6 Chan and Miranda-Moreno 2013

Although all these studies test similar variables when examining employment uses and rail ridership, they are not testing exactly the same variable. Some use the number of jobs specifically, while some use station area employment land use. Of the examined studies only one, which examines the Montreal, Canada transit system, compares both variables and found that it is employment land uses that drive rail ridership, not the number of jobs specifically.[7]

Existing literature is also relatively conclusive on the idea that bus services increase rail ridership.[8] A study analyzing ridership at Washington Metro stations found that the number of bus stops at a station is positively correlated with rail ridership. A separate study found a similar relationship between bus stops and rail ridership in an analysis of the Nanjing, China metro system.[9] The Washington Metro study found a smaller and less significant relationship between rail ridership and provision of bus services than the Nanjing, China study; this is likely due to the differences in contexts. The study of Montreal's transit system also found a small positive relationship between rail ridership and bus service at a station.[10]

The literature is more mixed on the correlation between bike infrastructure and rail ridership, although most literature supports the idea that bike infrastructure increases rail ridership. The Nanjing, China study found a positive relationship between bike parking and rail ridership,[11] while a study in the Netherlands found no significant relationship.[12] This, again, is likely due to the differences in context. An examination of the bikeshare system in Washington, DC found a small, positive correlation between rail ridership and bikeshare, as long as bikeshare stations were located at rail stations.[13]

Collectively, the examined research indicates that first and last mile infrastructure and services, such as connecting bus routes or bike infrastructure, do have a positive relationship with rail ridership. However, the examined literature also indicates that the impact of these infrastructure and services is much smaller than that of land use surrounding stations. This has major policy implications, and indicates that for many users, at least, rail use isn't determined by the quality of the access route. Rather, it appears that most people take rail transit when they can access jobs and work.

Access Mode Choice

The literature reviewed in this section is closely related to that of the first; however, the literature reviewed here does not use ridership numbers as the dependent variable, instead choosing to look at what factors make riders choose a specific access mode. These studies, therefore, largely look only at the choices of those that are already riding transit.

The first clear finding of existing literature is that land use characteristics have a significant impact on mode choice. A number of studies have found that the amount of people living close to a station has a large and significant impact on how many riders choose to walk to that station, both in international and North American contexts.[14] [15] [16] A study of Caltrain stations in Mountain View, California, found that the distance a rail station is from a rider's home impact how riders choose to access that station, with active transportation modes becoming more common the closer the rider lives to the station.[17] Another study found that the compactness of the street network around a station is a mode choice determinant.[18]

Other parts of the built environment are not consistently found to be significant predictors of mode choice. The Mountain View study found that auto-friendly streets decrease walking and biking access mode share.[19] A separate study found that low-speed roads increase bike access mode share.[20] Beyond these factors, however, the literature does not suggest a major impact of the built environment on mode share.

Mode share analysis generally focuses heavily on bike and pedestrian access, but one study has examined the impact of bus service on rail station access mode choice. This study, which examines Toronto area commuter rail stations, found that the number of bus arrivals at a rail station decreases overall walk access share, suggesting that additional bus service may act

7 Kim, Ahn, Choi, and Kim 2016
8 Ma, Liu, and Erdogan 2015
9 Zhao, Deng, Song, and Zhu 2013
10 Chan and Miranda-Moreno 2013
11 Zhao, Deng, Song, and Zhu 2013
12 Brons, Givoni, and Rietvald 2009
13 Ma, Liu, and Erdogan 2015

14 Renne, Hamidi, and Ewing 2016
15 Chalermpong and Raranawaraha 2015
16 Engle-Yan, Rudra, Livett, and Nagorsky 2014
17 Park, Kang, and Choi 2014
18 Park 2018
19 Park, Kang, and Choi 2014
20 Weliwitiya 2019

as a replacement effect, with riders choosing to ride the bus instead of walk.[21]

Emerging technologies, such as ride-hailing apps and autonomous vehicles also have the potential to alter how riders choose to access stations. A study on the potential of shared autonomous vehicles as a first and last mile solution found that shared autonomous vehicles could greatly enhance the sustainability of station access modes in suburban areas. The study, did not, however, find that shared autonomous vehicles performed significantly better than existing trip options in regards to time or cost, creating a potential barrier to adoption.[22] A report on the impact of ride-hailing apps on rail ridership in current conditions found mixed support for ride-hailing as a first and last mile solution. In particular, the report found that ride-hailing services replaced bus and light rail transit trips, but supported heavy rail trips by a small amount.[23]

One of the other clear themes of the reviewed literature is that socio-economic factors have a major impact on mode choice, although the literature doesn't always agree on how it impacts it. Two studies found that mode choice is heavily impacted by gender, age, income, and education level, with one finding that income level appeared to be the most significant predictor of mode choice among demographic characteristics.[24] [25] A separate study found that income level was not a predictor of access mode share.[26] A study specifically examining bikes as an access mode to stations in Australia, found that age played an important role in determining if riders chose to bike to a station.[27]

Equity

The connection between equity and first and last mile planning is not well studied in academic literature. Only one study was found that explicitly made the connection between first and last mile planning and issues of equity. This study examined the impact of station access mode choice on job accessibility for disadvantaged communities in San Diego, California, finding that reducing station access and egress times increase access to jobs; in particular, the study found that policies and projects that allow residents of low-income communities to bike or drive to a station greatly increased their access to low-wage jobs.[28]

The connection between transportation and equity more broadly is better studied. A study of several major Candian metropolitan regions found that low-income communities benefit greatly from improved access to jobs, especially by reducing commute times by public transit.[29] A study of low-income communities in Atlanta had similar results, finding that improved access to public transit can reduce the social exclusion of disadvantaged communities, especially in the suburbs.[30] Although not directly related to station or first and last mile access, these studies, and similar studies, suggest that improved access to transit has significant positive impacts on equity. First and last mile planning plays an important role in how and if communities can access transit.

Conclusions from the Literature Review

The academic literature indicates that first and last mile infrastructure and services do have a clear impact on rail ridership; the literature suggests, however, that certain interventions and services have a greater impact on ridership than others. In particular, station-area land use was found to be among the strongest determinants of ridership. Reviewed literature also indicates that there are strong equity implications to first and last mile planning. To determine how these lessons and findings are reflected in practice, the next section reviews existing planning documents related to first and last mile planning.

21 Akbari 2018
22 Moorthy et al. 2017
23 Clewlow and Mishra 2017
24 Meng, Memon, Wong, and Lam 2018
25 Park 2018
26 Park, Kang, and Choi 2014
27 Weliwitiya 2019

28 Boarnet et al. 2017
29 Cui et al. 2019
30 Wang and Woo 2017

3. EXISTING FIRST AND LAST MILE PLANS

Beyond scholarly research, there are a number of plans and strategies created by cities and agencies that relate to first and last mile planning. This section examines all existing first and last mile plans in the United States, as well as a number of related documents. Such documents vary greatly in scope and style. While there are a number of plans and policies explicitly about first and last mile planning, there are also documents that cover related topics; entire plans dedicated to first and last mile planning came about relatively recently, and are still rare. This section reviews some of the relevant station access related documents, followed by a review of all existing first and last mile plans in the United States.

Federal Documents

The federal government, through the United States Department of Transportation (USDOT), offers very little first and last mile planning guidance. This could suggest that first and last mile planning is not a priority of USDOT, or that the Department views first and last mile planning as a local issue.

FTA Manual[1]

The Federal Transit Administration (FTA), a part of USDOT, published the sole recent federal document on the issue, the *Manual on Pedestrian and Bicycle Connections to Transit*. Published in 2017, this document identifies very broad and high-level recommendations on how to improve station access for cyclists and pedestrians. Primarily, the manual functions as a list of considerations than a specific plan; the focus is more on broad topics than specific design or service considerations. It does not address other ways to potentially bridge the first and last mile gap beyond cycling and pedestrian access. Nonetheless, it is useful document in that it provides case studies and, more uniquely, identifies how funding can be secured for projects that improve pedestrian and bicycle connections to transit.

1 Federal Transit Administration 2017

TCRP Report 153[2]

A more in-depth analysis of station access is provided by the Transit Cooperative Research Program (TRCP) Report 153: *Guidelines for Providing Access to Public Transportation Stations*. Although not strictly a federal document, the document was sponsored by the FTA. More detailed than the FTA's manual, this 2012 document provides a more specific and proscriptive set of guidelines. At the same time, the scope of the document is broader, examining more than just pedestrian and bicycle access, but not explicitly focusing on the first and last mile.

Like the *Manual on Pedestrian and Bicycle Connections* to Transit, this report does not focus on specific design considerations, instead choosing to focus on more on the process. In essence, this document provides a method to create a process. It gives agencies guidance on how to create a process that evaluates the area around a station, identifies the station access gaps, and then addresses those gaps. A key part in the process identified in the guidelines is identifying and engaging stakeholders early on, reflecting the sometimes complicated political nature of first and last mile planning in which multiple agencies or municipalities are almost always involved.

Guidelines for Providing Access to Public Transportation Stations also includes a typology system, something that is relatively common in first and last mile plans. Typologies systems identify several different station types and provide access recommendations for each of those types. For transit systems with a large number of stations where doing in-depth access examinations of every station may be difficult or impossible, this sort of typology system is intended to streamline the planning process. The TRCP report identifies 18 separate typologies, ranging from urban commercial stations to suburban stations located in the median of a freeway. The report recognizes that stations vary greatly, and improving access to one station may look entirely different than improving access to another station.

2 Transit Cooperative Research Program 2012

Station Access and Station Area Plans

Many first and last mile planning related plans are called station access or station area plans. Not strictly first and last mile plans, these types of plans typically either have greater or narrower scopes than a first and last mile plan. Some focus on a specific type of station access, such as bike or pedestrian access, like the FTA *Manual on Pedestrian and Bicycle Connections to Transit*. Others include more than first and last mile access as part of the plan. This section examines a comprehensive station area plan that is exemplary of station access and station area plans, as well as the station access policies of the services specifically examined in this report, BART and Caltrain.

WMATA *Station Area Planning Guide*[3]

The Metropolitan Washington Area Transit Authority (WMATA) produced the *Station Area Planning Guide* in 2017. This document displays many typical traits of station access plans. A common trait of station access plans is identification of an access hierarchy. Access hierarchies designate which access modes are most important to the agency; future policy and investment is intended to encourage the access modes on the top of the hierarchy, while access modes on the bottom are deemphasized. WMATA's *Station Area Planning Guide* places pedestrian and bicycle access at the top of the hierarchy, and park-and-ride access at the bottom, although the plan does acknowledge that park-and-ride is still an important access mode for many stations.

Like the TRCP report, the WMATA plan includes a typology system, although a more limited one. WMATA's system only has three types: core stations, mid-line stations, and terminus stations. The plan separates these station types by access mode share; core stations are accessed predominately by walking, while terminus stations have a much higher automobile access mode share.

This plan does include specific design interventions, recommending design standards such as sidewalk widths and types of bike parking. For buses, the plan

3 Washington Metropolitan Area Transportation Authority 2017

goes as far as providing example layouts of what a bus facility at a rail station should look like.

WMATA's ***Station Area Planning Guide*** differs from typical first and last mile plans in two important ways. First, the plan focuses more on automobile access modes than is typical for a first and last mile plan, with sections dedicated to park-and-ride and kiss-and-ride facilities. Second, the guide also includes a section on supporting transit oriented development around transit stations, something that is not included in existing first and last mile plans elsewhere.

BART *Station Access Policy*[4]

BART, one of the two services examined in more depth for this report, does not have a first and last mile plan, or a station access plan. Instead, the agency simply has a policy, the *Station Access Policy*. This policy is much shorter and less detailed than the first and last mile plans and station area plan examined in this section. The policy lays out an access hierarchy, with priority again being given to pedestrians and cyclists, and auto access deemphasized. The policy includes a typology system with five station types that further delineates how investments should be targeted. Notably, the policy does not give any design guidelines, instead simply setting an investment agenda and outline broad access goals.

Caltrain *Comprehensive Access Plan Policy Statement*[5] and *Caltrain Bicycle Access and Parking Plan: Implementation Strategy*[6]

Caltrain, the other service examined more in-depth in this report, has two relevant documents, though neither are specific first and last mile plans. The first is Caltrain's *Comprehensive Access Plan Policy Statement*. This document is very similar to BART's *Station Access Policy*. Rather than specific design guidelines, the document outlines broad principles and identifies a station access hierarchy. The station access hierarchy differs from BART's in that transit is ranked above cycling in Caltrain's hierarchy, although the policy makes no explanation of why the hierarchy is ranked the way it is. Caltrain also identifies a typology system that prioritizes investments based on station context.

The second document that Caltrain has produced on station access is the *Caltrain Bicycle Access and Parking Plan: Implementation Strategy*. This strategy is an update of an earlier plan on the same subject, and is much more detailed than the *Comprehensive Access Plan Policy Statement*. The plan identifies specific improvements at specific stations, and identifies the relevant local government that Caltrain needs to coordinate with to implement the improvement. Beyond specific infrastructure improvements, the document also identifies potential policy changes to be considered and recommends trial periods for the policy changes. The proposed policies include lowering the cost of secure bike parking and promotion of folding bikes.

LA Metro *First Last Mile Strategic Plan*[7]

The Los Angeles County Metropolitan Transportation Authority (Metro) has prepared the most comprehensive first and last mile documents of any agency in the United States. The two documents examined in this section focus on the the heavy rail, light rail, and bus rapid transit services provided by Metro. The first document lays out a plan, while the second document provides specific implementation of that plan.

Metro's *First Last Mile Strategic Plan* lays out the agency's approach to first and last mile planning. Unlike BART and Caltrain, which only offer heavy rail service, Metro offers heavy rail service, light rail service, and both rapid and traditional bus services; many of the transit lines that feed into Metro's rail services are operated directly by Metro. The plan looks specifically at rail and bus rapid transit access, but it can also be applied to local bus routes as well.

Scope

This plan functions as a guide to create specific station-level investment and intervention plans. The document doesn't prescribe specific projects at specific stations, instead guiding planners on how to create specific first and last mile plans. It focuses

4 Bay Area Rapid Transit 2016
5 Caltrain 2010
6 Caltrain 2014
7 Los Angeles County Metropolitan Transportation Authority and Southern California Association of Governments 2014

primarily on active transportation as the key station access modes Metro wants to promote, and as a result, primarily discusses bicycle and pedestrian improvements. This emphasis on pedestrian and bicycle access is likely due to the nature of the agency, operating many different types of services.

Typology

The Metro plan does not include a typology system, likely due to the agency's intention to provide specific station-level analysis to every station on its system.

Design Interventions

The plan includes an extremely detailed tool box of specific streetscape design interventions, split into several sections:

The "Crossing and Connections" section includes street and intersection treatments such as raised crossings and scramble crossings

The "Signage and Wayfinding" section includes various signage tools, as well as a short section on smart technologies, like real time travel information, that can assist with wayfinding and provide riders information.

"Safety and Comfort" includes improvements such as landscaping, lighting, and traffic calming that increase real and perceived safety and enjoyment for travelers of all ages and abilities.

"Allocation of Street Space" includes protected bike lanes, bus lane enhancements, and rolling lanes. The

"Plug-In Components" category includes a variety of improvements such as bike share, kiss-and-ride facilities, and high-visibility bike parking. "Plug-In Components" refers to stand-alone improvements that can be made easily in a variety of contexts without significant network-level impacts.

All of the improvements listed in the toolbox include information on where they are most appropriately implemented, what kind of access barriers they address, and how they are best applied and integrated into the transit network. The toolbox is intended to match easily with the evaluation process outlined earlier in the plan, creating a comprehensive set of solutions to the issues identified in the station evaluation process.

Evaluation Process

Metro's *First Last Mile Strategic Plan* details a specific step-by-step plan to define a station area, assess that area, identifying gaps and issues in that area, and create a network of access paths for that station. The plan does not provide specific recommendations on specific stations. Rather, it is intended to provide all the necessary tools and procedures to be able to create a list of specific recommendations and improvement for specific stations.

Metro's plan identifies catchment areas it uses to define station areas, something that is not done in all first and last mile plans. For pedestrians catchment areas, Metro uses a half-mile radius from the station. For bicyclists and other forms of rolling transportation such as scooters or skateboards, Metro uses a three mile radius.

The next step in the assessment process is to overlay information gathered during the station analysis step. This process is done remotely, using existing data and software programs. By combining pieces of information, it allows Metro planners to determine where there are gaps in the station area access network and where, for example, there are safety concerns. Using these overlays, specific issues can be identified, and a walking route to examine these issues can be established.

The final step in Metro's assessment process is a site visit using the walking route created in the previous step. The core of the station visit is a scoring method. The scoring method involves rating a variety of existing conditions in three categories: safety, aesthetics, and accessibility. A score is created for each category, allowing comparisons between stations. There is also the option to add photo documentation and connect it to one of the existing condition ratings.

Once the assessment is complete, a network of access paths are laid out for the station area. This network takes into consideration both the information found in the site visit as well as information from the map overlay process. Using this information, pathway arterials and collectors are planned, as well as specific improvements and constraints. This pathway network is evaluated, and then refined through stakeholder and community input.

Unique Aspects

Much of the plan revolves around a unique concept Metro identifies as "the Pathway." This concept identifies a network of streets and paths around stations and organizes them similar to a river system or an arterial street system. Major pedestrian or bicycle access routes are identified as "arterials" and the smaller streets that feed into them are identified as "collectors." This, in effect, creates a hierarchy of streets that can be used to prioritize investment in access improvements. Arterial access routes would receive the greatest amount of investment under this plan, with collector access routes receiving less funding, resulting in arterials having the most robust pedestrian and bicycle infrastructure. Collector streets would be improved primarily to guide pedestrians and cyclists to the arterials. This system of pathways may or may not reflect the street system; an arterial street may not be designated as an arterial route under this plan. Arterial access routes may be designated on smaller streets if that street provides a safer and more pleasant access experience. Core to this pathway plan is consistent wayfinding, allowing users to identify the network and how to access the arterial access routes.

Metro *Blue Line First/Last Mile: A Community Based Process and Plan*[8]

The Metro *First Last Mile Strategic Plan* lays out a framework, with the intention to use that framework to create specific first and last mile plans and strategies for individual station areas. The first project to come out of this effort is the *Blue Line First/Last Mile: A Community Based Process and Plan*, which applies the *Strategic Plan* process to all 22 stations on the Metro Blue Line.

The Blue Line plan is an example of a first and last mile plan in action and demonstrates the process outlined in the *Strategic Plan*. Walk audits were used, using an updated *Strategic Plan* scoring method that includes an inventory of transfers and observed behaviors as scoring categories; final scores were included in the cumulative recommendations in the plan. Each station received a comprehensive evaluation, including identified strengths and weaknesses, specific critical access barriers, an identified Pathway network, and a proposed project list with estimated costs.

The Blue Line plan puts an emphasis on community outreach and equity that is not as clearly identified in the *Strategic Plan*. The Blue Line plan begins by looking at context, specifically identifying the history of redlining in the neighborhoods served by the line and the current social context. The walk audits were performed by local residents and organized by community-based organizations. 11 community events were held, and community-based organizations participated in the drafting of the final report. The report recommends partnering closely with community-based organizations and including deep institutional knowledge of project areas to ensure equitable development of first and last mile improvements.

Riverside Transit Authority *First & Last Mile Mobility Plan*[9]

The Riverside Transit Authority (RTA), the transit provider for Riverside County, California, has prepared a first and last mile plan, the *First & Last Mile Mobility Plan*. RTA primarily operates bus service- rail service in the county is heavy commuter rail operated by Metrolink, a separate agency. The plan does address first and last mile access to Metrolink.

Scope

Like the Metro plan, this is a guidance document. It does not identify specific design or service interventions at specific stations, instead outline a process with which to identify and prioritize such interventions. This plan is focused primarily on pedestrian and bicycle access to stations and stops, and is intended to be used for all transit stations serving many types of transit—from heavy rail Metrolink stations to local bus stops. Like the Metro *Strategic Plan*, this plan establishes a process to identify and evaluate station areas, and then provides ways to assess potential improvements and solutions.

Typology

The RTA plan sets six station typologies, and classifies stations and stops into them. These station types are Urban Core, Core District, Suburban, Rural,

8 Los Angeles County Metropolitan Transportation Authority 2018

9 Riverside Transit Authority 2017

Commercial District, and Industrial & Commercial. The plan then uses these typologies to recommend context- and scale-specific solutions and options for improving first and last mile access. RTA has a large service area and a variety of station types, and this typology system is intended to reflect that, categorizing a large set of stations and stops into more manageable typologies.

Design Interventions

The Riverside plan includes a toolbox of design and service interventions. The streetscape design interventions are less detailed than that of Metro, but the toolbox includes strategies on a broader array of strategies, including transportation demand management and auto access strategies.

Evaluation Process

Like the Metro plan, the RTA plan is process-based. The RTA process begins with mapping existing conditions, and then engaging the community to identify context-specific issues. Once issues and barriers have been identified, site visits are conducted. RTA uses a checklist to identify deficiencies in the station area as part of the site visit. This checklist is a list of pedestrian, bicycle, and station or stop deficiencies such missing curb ramps or lack of shelter. As deficiencies are identified, they are checked off, and marked on a map. Space is also given for additional notes. These station audits are done on a paper survey. Results from the site visits, mapping process, and outreach process are analyzed, and a second round of public outreach for potential solutions is performed. Using this information, recommendations are made and are incorporated into projects to be implemented.

Richmond, CA First Mile/Last Mile Transportation Strategic Plan[10]

The City of Richmond, a community in the San Francisco Bay Area's East Bay region, is in the process of producing a first and last mile plan, the *Richmond First Mile/Last Mile Transportation Strategic Plan*. This plan, only recently adopted, is a unique plan. Whereas the other plans examined in this section are produced by transit agencies, this plan has been produced by a city that does not operate its own transit services.

Scope

The Richmond plan is, unlike the plans examined so far, focused on specific interventions at specific stations. In particular, it looks at three major transit stations in Richmond: two BART stations, and a ferry terminal. The inclusion of a ferry terminal is also unique to this plan. The scope of this plan is wider than other plans examined thus far. Instead of a primary focus on active transportation, this plan includes topics such as paratransit and a shuttle network. The report is organized as to focus primarily on ten key projects.

Typology

The Richmond plan does not use a typology system, likely due to the small number of stations being considered in the plan.

Design Interventions

Richmond's plan forgoes a toolbox, instead recommending specific design interventions at specific places, reflecting the project-based approach of the plan. Proposed interventions include road diets, protected bike lanes, and improved pedestrian signals.

Evaluation Process

The City of Richmond chose to use a criteria-based evaluation system to identify and prioritize first and last mile design and service interventions. The plan identifies seven criteria:

1. Serves communities of concern and people in need

2. Proximity to mobility hub

10 City of Richmond 2019

3. Funding opportunities

4. Quality of service investments

5. Safety

6. City-owned location

7. Environment

Proposed interventions are scored with a point system based on these seven criteria. The ten projects identified in the report are a result of these scoring criteria.

Unique Aspects

Richmond's plan is primarily unique because it is a plan produced by a city rather than a transit agency. As a result, it is both broader and narrower than a typical plan. It examines first and last mile access to stations operated by two different providers, BART and the Water Emergency Transportation Authority, which operates the ferry service. At the same time, it provides more detailed recommendations than a plan that focus on an entire transit system could. Additionally, the Richmond plan goes into more depth on the subject of autonomous vehicles than the other reviewed plans.

Utah Transportation Authority *First/Last Mile Strategies Study*[11]

The Utah Transportation Authority (UTA), the transit provider for the Salt Lake City metro area, has published the *First/Last Mile Strategies Study*. This document differs from others examined in this section in that it blends a traditional planning document with research.

Scope

Although UTA provides bus service as well, this study is primarily focused on the heavy and light rail services offered by the Authority. Additionally, this document focuses specifically on increasing ridership. Where most first and last mile plans offer broad goals of improving first and last mile access, the UTA plan specifically identifies a metric by which to measure success. UTA emphasizes active transportation, but includes other types of station access modes as well.

Typology

The UTA plan uses a typology system, categorizing stations into six typologies: urban, multimodal, institutional, suburban, suburban non-residential, auto-dependent. With the exception of the institutional typology, which was designated based on land-use, stations were sorted into types by six variables: walk access, active transportation mode split, non-auto access mode split, availability of parking supply, population, and employment.

Design Interventions

The *First/Last Mile Strategies Study* examines several design interventions, including protected bike lanes, ADA access improvements, and improved wayfinding. UTA used a scoring system to prioritize improvements. The improvements were scored on six categories:

1. Effective in adding ridership

2. Improves safety

3. Used by peers

4. Costliness

5. Stakeholder support

6. Ease of implementation

The highest scoring improvements were crosswalk improvements, improved pedestrian signals, bike lanes, and on-site wayfinding.

Evaluation Process

The UTA study evaluation process combines the typology system and the findings from the analysis of design interventions to create recommended interventions at each station type. Certain types of interventions are designated as high priority based on station typology.

Unique Aspects

The study includes information from interviews conducted with other transit agencies, aiming to find best practices from peer agencies. Topics included current strategies, planning and prioritization, marketing, funding, monitoring, and implementation.

11 Utah Transportation Authority 2015

UTA found in these interviews that community partnerships can be assets, but are challenging to establish; that rethinking current services can be an effective way to address first and last mile challenges; and that public input is a vital part of the process.

The UTA study also includes a regression analysis that incorporates current conditions and ridership numbers at individual stations. The regression analysis found that improvements focused on stations near employment centers were more effective, and that stations with bike lanes or routes nearby saw greater ridership. The study also found a positive correlation between continuous sidewalks in the station area and ridership, although not a statistically significant level. Improved wayfinding is also identified as an element to potentially increase ridership. The findings from this regression analysis was incorporated into the scoring and prioritization of design elements.

Regional Transportation District *First and Last Mile Strategic Plan*[12]

The Denver metropolitan area transit provider, Regional Transportation District (RTD), is also in the process of creating a first and last mile plan, although it is still in its early stages.

Scope

The scope of the plan has not fully been defined yet, though it will likely have a broad scope, incorporating more than just active transportation modes. The plan will examine RTD's light rail and bus rapid transit services and stations.

Typology

RTD has defined a typology system for the future plan. There will be five core types: urban core, urban, suburban mixed, suburban residential, and rural. RTD, uniquely, has also designated six overlays to the typology system to provide further granularity. Those six types are:

1. Historically vulnerable populations: identifies areas with vulnerable communities.

2. High accessibility needs: identifies areas where users may have additional accessibility needs, such as near a VA hospital.

3. High shift/visitor variability: identifies areas with irregular commute patterns, such as a university.

4. High visitor trips: identifies an area with high visitor trips, such as a sports arena.

5. High propensity to change: identifies areas that may change rapidly, requiring more flexible solutions.

6. Parking utilization: identifies areas where parking is being used heavily, and may be a target for improved access to shift users away from single occupancy vehicle trips.

Design Interventions

RTD is currently in the process of creating a toolbox of design interventions.

Evaluation Process

RTD has not defined an evaluation process for the plan yet.

12 Regional Transportation District 2018

Agency	Focus	Station Types	System-wide or City	Typology	Design Interventions	Evaluation Process	Unique Aspects
Metro	Active transportation	Rail and BRT services	System-wide	N/A	Toolbox	Step-by-step	The Pathway; Metro Blue Line Plan
RTA	Active transportation	All services	System-wide	6	Toolbox	Step-by-step	N/A
Richmond	All modes	Rail and ferry services	City only	N/A	Specific-station level interventions	Criteria based	City-based plan
UTA	All modes	Rail services	System-wide	6	Ranked list of potential interventions	Scoring based	Research component
RTD	Not yet defined	Not yet defined	Not yet defined	5, with 6 overlays	Toolbox in process	Not yet defined	N/A

Table 3-1: Characteristics of existing first and last mile plans.

Characteristics of First and Last Mile Plans

Table 3-1 consolidates the first and last mile plans reviewed in this section, identifying the characteristics of each plan. The scope of each plan is identified, as well as the inclusion of a typology system, how design interventions are chosen, the station-area evaluation process, and any unique aspects a plan might have. Despite the relatively small number of first and last mile plans, there is a wide variety of approaches.

4. THE CURRENT STATE OF FIRST AND LAST MILE PLANNING

The first and last mile plans laid out by public agencies are somewhat divergent from the findings from the academic literature, at least when it comes from the perspective of rail ridership. There is a strong emphasis placed in many of the plans on improving the quality of pedestrian and bicycle access. The academic literature, however, found that the impact of quality of bike and pedestrian infrastructure on rail ridership is relatively minor, although it does have some impact. Less attention is given to alternative first and last mile services, such as additional bus service or shuttle service. Only one piece of reviewed academic literature examined the relationship between bus service and rail ridership in a North American context, and only as a control variable for an analysis of bikeshare.[1]

Overall, however, the literature suggests that first and last mile infrastructure and services play a relatively small role in determining rail ridership, and that the most important determinant is the amount of jobs and housing in the area around a station. This suggests that first and last mile plans should be developed alongside or include significant land use components to maximize impact on ridership.

Despite this, first and last mile plans are still potentially valuable. The literature does suggest some impact of first and last mile infrastructure on rail ridership, and the plans generally follow the findings of the literature in this respect. Furthermore, there are reasons to create first and last mile plans beyond rail ridership. Several of the plans, for example, included improved safety as a reason for improving first and last mile connections. A first and last mile plan can improve the quality of the connection for existing riders, even if an improvement doesn't necessarily draw new riders to the system. Additionally, looking strictly at ridership doesn't include the impact of changing access mode choice; improved first and last mile infrastructure may encourage a transit rider to bike to a station rather than drive, for example.

1 Ma, Liu, and Erdogan 2015

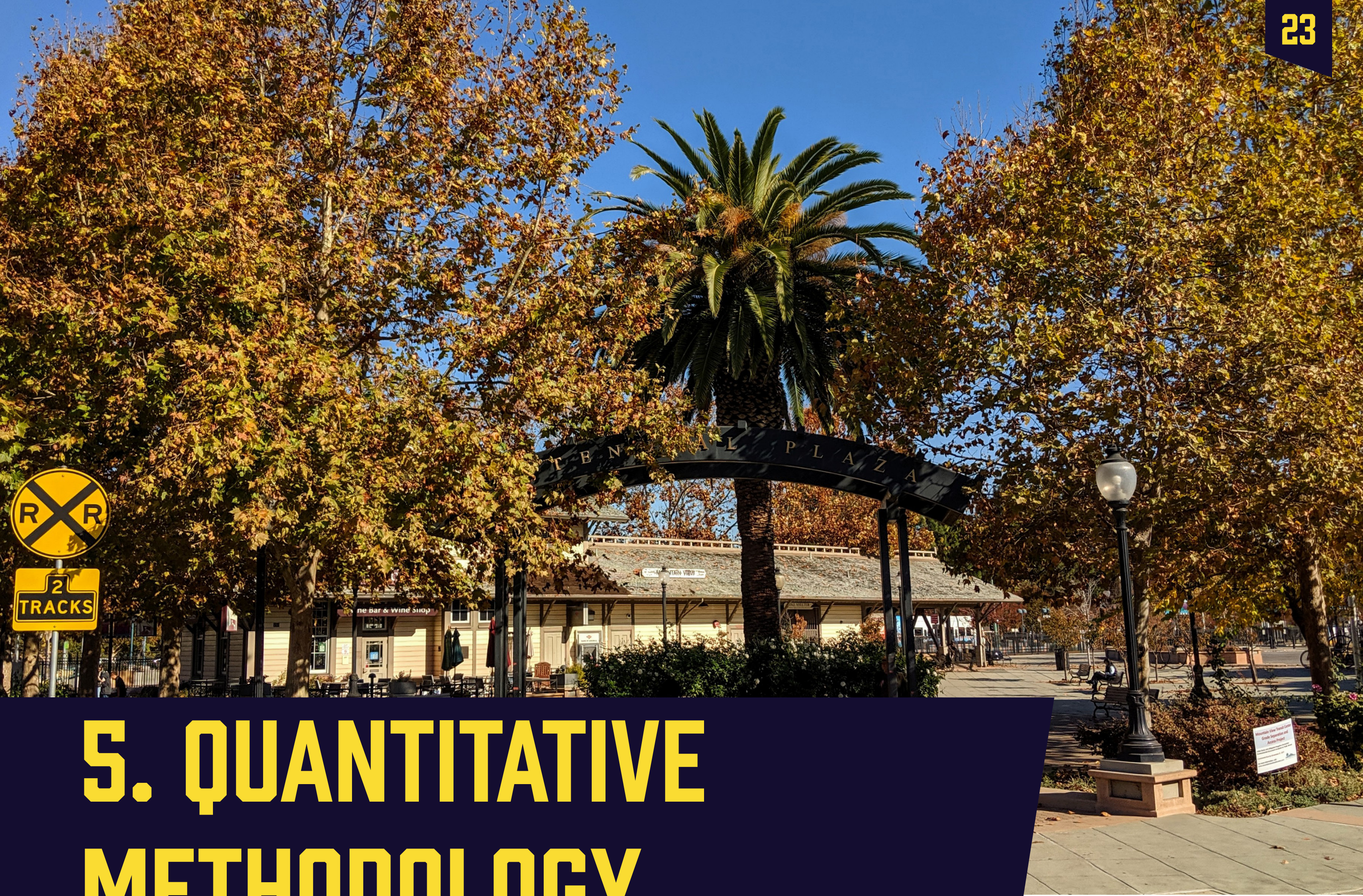
The existing first and last mile plans, as well as the body of literature, does indicate a growing interest in this topic, and provide reasons why first and last mile planning should be an important part of both land use and transportation plan. There is a clear emphasis on active transportation modes in first and last mile plans and research.

Emerging technology is mostly unaddressed by current first and last mile plans. Many of the plans recognize that transportation technologies are changing, and some include design interventions that support ride-hailing services. Only Richmod's first and last mile plan, however, provides significant policies and strategies relating to autonomous vehicles.[2] The academic literature on the subject is beginning to grow, and this could be a subject where future planning documents are heavily informed by academic literature.

On the issue of equity, the dynamic of plans not fully reflecting the literature is swapped; many existing first and last mile plans pay very specific attention to issues of equity. For example, the *Los Angeles Metro Blue Line First/Last Mile: A Community Based Process and Plan* explicitly identifies equity as a driving force behind the report, and weaves issues of equity throughout the report and process.[3] The topic, however, is largely unaddressed by academic literature. This could be a result of the difficulty in effectively quantifying the impact of first and last mile improvements on issues of equity, or the attention given to first and last mile planning is a relatively recent phenomenon; all first and last mile plans reviewed in section were published after 2014.

First and last mile planning is clearly becoming an increasingly important part of planning practice and literature; it's not clear, however, what makes an effective first and last mile intervention. To that end, a quantitative methodology was developed, detailed in the following chapter.

2 City of Richmond 2019
3 Los Angeles County Metropolitan Transportation Authority 2018



5. QUANTITATIVE METHODOLOGY

The core of this report is a cross sectional study that compares station-level first and last mile traits with station-level ridership using a linear regression model, determining what impact first and last mile infrastructure or services have on rail ridership.

This section will explain the variables chosen for the model, how and why those variables were chosen, the creation of the model, and an explanation of what variables were chosen to be in the model.

The Stations and Systems

This paper looks at two heavy rail systems in the San Francisco Bay Area: Caltrain and Bay Area Rapid Transit (BART). The two systems were chosen due to a shared geographic context and the availability of detailed station-level ridership data.

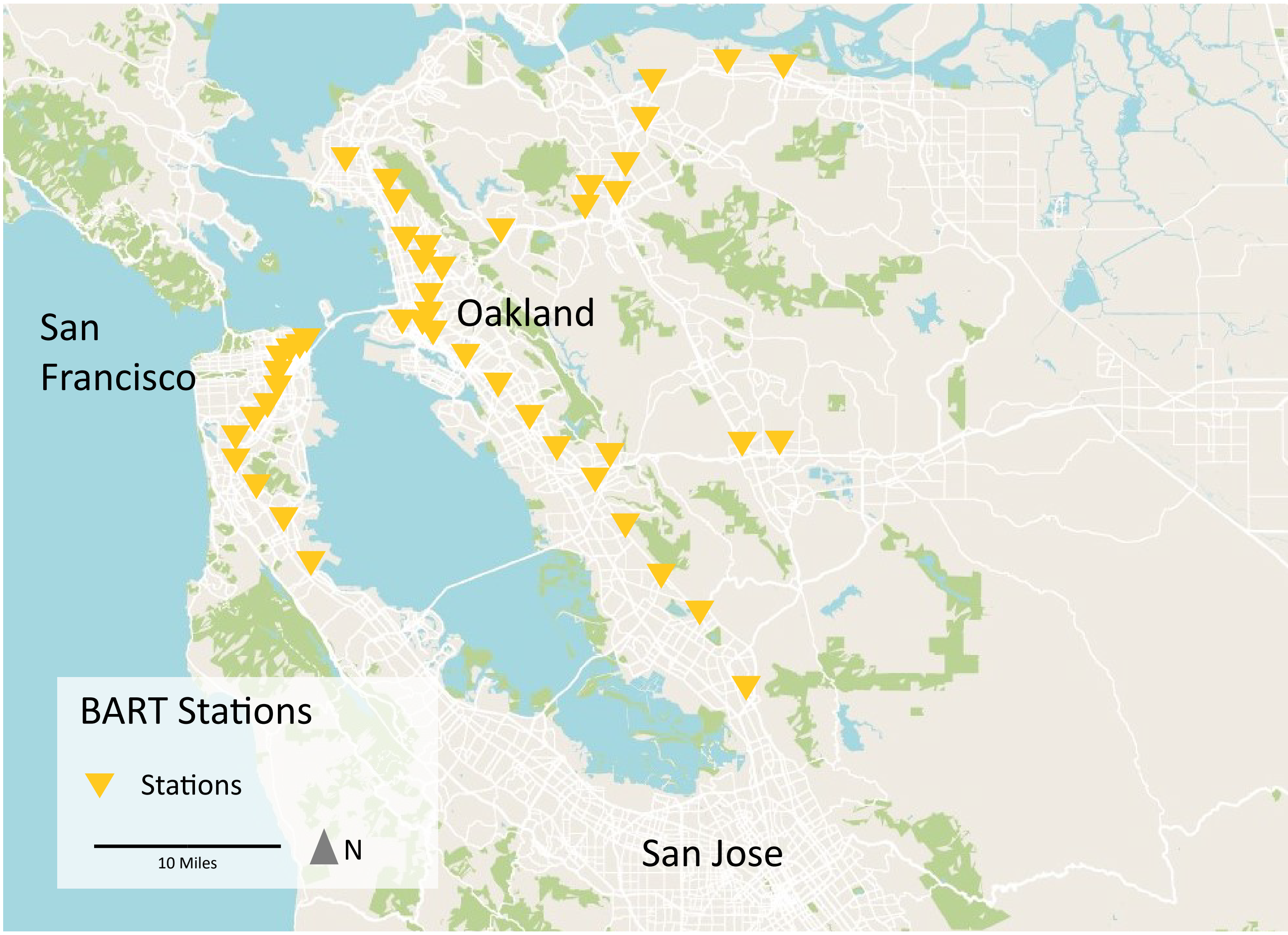
In total, 72 stations are analyzed for this model. Of those, 28 are Caltrain stations, 43 are BART stations, and one, Millbrae, has both Caltrain and BART service. For the purposes of this analysis, Millbrae Station is considered a single station served by both Caltrain and BART.

Map 5-1: Caltrain stations.

Caltrain Stations

All Caltrain stations that receive regular weekday service are included in the analysis. Broadway and Atherton stations, which both receive service on weekends, were excluded, as was Stanford Station, which only receives services for special events. Stations south of San Jose Diridon Station, which only receive peak-hour, peak-direction service are included in the analysis. The complete list of included Caltrain Stations is below. Map 5-1 is a map of included Caltrain stations.

- 22nd Street
- Bayshore
- Belmont
- Blossom Hill
- Burlingame
- California Ave.
- Capitol
- College Park
- Gilroy
- Hayward Park
- Hillsdale
- Lawrence
- Menlo Park
- Millvrae
- Morgan Hill
- Mountain View
- Palo Alto
- Redwood City
- San Antonio
- San Bruno
- San Carlos
- San Francisco
- San Jose Diridon
- San Martin
- San Mateo
- Santa Clara
- Sounth San Francisco
- Sunnyvale
- Tamien



Map 5-2: BART stations.

BART Stations

All mainline BART stations are included in this analysis. This analysis excludes the two stations served solely by eBART, a diesel multiple-unit rail service, on the Millbrae-Antioch line. The analysis also excludes the San Francisco International Airport and Oakland International Airport Stations. The complete list of included BART stations is below. Map 5-2 is a map of included BART stations.

12th Street	El Cerrito del Norte	North Berkeley	Union City
16th Street	El Cerrito Plaza	North Concord/Martinez	Walnut Creek
19th Street	Embarcadero	Orinda	Warm Springs/South Fremont
24th Street Mission	Fremont	Pittsburg/Bay Point	West Dublin/Pleasanton
Ashby	Fruitvale	Pleasant Hill/Contra Costa	West Oakland
Balboa Park	Glen Park	Powell Street	
Bay Fair	Hayward	Richmond	
Castro Valley	Lafayette	Rockridge	
Civic Center/UN Plaza	Lake Merritt	San Bruno	
Coliseum	MacArthur	San Leandro	
Colma	Millbrae	South Hayward	
Concord	Montgomery Street	South San Francisco	

Variable	Predicted Impact	Year Data Collected	Source
Caltrain	Negative	2019	Caltrain Website
No. Trains (Peak Hour)	Positive	2019	BART and Caltrain schedules
Median Income ($)	Negative	2019	ESRI Community Analyst
Population	Positive	2019	ESRI Community Analyst
Employment	Positive	2019	ESRI Community Analyst
Catchment Area (Sq. Miles)	Positive	2019	ESRI Community Analyst
Car Ownership (% with no car)	Positive	2019	ESRI Community Analyst
Bus Lines	Positive	2019	BART and Caltrain Websites
Shuttle Connections	Positive	2019	BART and Caltrain Websites
Parking (Hundreds)	Positive	2019	BART and Caltrain Websites
Bikeshare Dock	Positive	2019	Baywheels
Lockers	Positive	2019	BART and Caltrain Websites
Dedicated Bike Lanes	Positive	2019	Google Maps
Bus Terminal	Positive	2019	Google Earth

Table 5-1: Variables included in the full model and their predicted relationships.

The Variables

A total of 16 variables were collected for analysis. Table 5-1 lists all of the variables included in the model and their predicted relationship with ridership.

Ridership	
Mean	6557.26
Standard Deviation	8053.019
Minimum	78
Maximum	43823

Table 5-2: Descriptive statistics for the ridership variable

Ridership

The dependant variable for the analysis, ridership counts the number of people that chose to ride BART or Caltrain at each station in the system. The model will determine each included variable's impact on total ridership on each station, estimating how many riders each additional unit of the variable will add or subtract from the final ridership. This analysis is concerned about access trips to stations, and only station access trips are included in the model. For typical weekday commuters, this will include the home-to-station trip as well as the work-to-station trip, and therefore analyze the impact of first and last mile infrastructure and services on both trip types. Table 5-2 includes has the descriptive statistics for this variable.

Caltrain

Caltrain's ridership numbers come from the annual ridership reports produced by the agency. At the time of this writing, the Caltrain 2018 Annual Passenger Count was the most recently published set of data. A full census of ridership, the count was conducted in February 2018. The data break down is extremely detailed, recording the number of people that board Caltrain on each train at each station, as well as the number of bikes that were brought on the train. This analysis uses the total weekday boardings at each station.

BART

BART's ridership numbers are sourced from monthly ridership reports released by the agency. This process is automated, tracking the number of people that pass through the faregates at each station. The data includes both station access and egress, as well as station pair data, which counts, for every station, how many people that access that station and leave the system at every other station in the system. As this report is primarily concerned with station access, this analysis uses the number of riders that access each individual station on a weekday. To control for changes in travel patterns and other time effects, data collected in February 2018 is used.

Station and Service Variables

The Caltrain and BART variables are included to control for differences between the two systems, such as differences in price and fare structure, train amenities, and train capacity. Only one of the two variables, Caltrain, is included in the model, as with the exception of Millbrae station, the two variables are mirrors of each other. The third variable, the number of peak hour trains, measures the level of service at each station.

Caltrain

This variable indicates that the station is a part of the Caltrain system.

BART

This variable indicates that the station is a part of the BART system.

Number of Trains, Peak Hour

This variable counts the number of trains that leave each station in one hour during peak hours on a weekday. For both Caltrain and BART, this information was sourced from publically-available timetables, and all trains scheduled in both directions between 7am and 8am were counted for each station. As the analysis only counts departing trains, terminus stations in both directions have comparatively fewer trains. This variable is meant to control for higher ridership due to higher levels of service.

Demographic Characteristic Variables

These variables measure a variety of demographic characteristics that are used to control for different environments surrounding stations. Each variable is measured in a half-mile catchment area surrounding the station, based on the street network surrounding the station.

A half-half mile catchment area was chosen as it is the standard catchment area used for determining station area characteristics in academic literature, and based off an analysis by Robert Cevero. A network based approach was selected based on the same analysis and to exclude populations that, even if they live close to the station, are unable to conveniently access the station.

All data for these variables are sourced from Esri's Community Analyst software. This software was chosen as it allows for a standardized station area analysis, rather than the irregularly sized census-block level data that the American Community Survey uses. Data from Esri's Community Analyst software is based off of American Community Survey Data, mixed with Esri's own data and projection. Esri then uses a set of proprietary algorithms to provide demographic estimates in a user-defined area. In this case, the areas defined were created using the software, which can create a catchment area based on a half-mile walk on the existing street network.

For one station, Warm Springs / South Fremont, the Community Analyst software indicates that nobody lives or works within a half-mile of the station, and as such, no demographic data is included for this station.

Median Income

This variable measures the median income of residents within a half-mile of the station based on the street network surrounding the station. The variable is meant to control for any differences in travel patterns between income groups.

Population	
Mean	6232.917
Standard Deviation	7300.515
Minimum	0
Maximum	43067

Table 5-3: Descriptive statistics for the population variable

Population

This variable measures the number of people that live within the half-mile catchment area of the station. This controls for the impact of residential density on ridership numbers. Table 5-3 includes has the descriptive statistics for this variable.

Employment	
Mean	12751.43
Standard Deviation	34919.817
Minimum	0
Maximum	210508

Table 5-4: Descriptive statistics for the employment variable

Employment

This variable measures the number of workers within the half-mile catchment area of the station. This controls for the impact of having a high density of jobs in the areas surrounding stations. Table 5-4 includes has the descriptive statistics for this variable.

Car-Ownership

This measures the percentage of households without access to an automobile within the half-mile catchment area of each station, controlling for the difference in travel patterns that these households may have.

Pedestrian Variable

A single variable is included to measure the quality of pedestrian access to each station.

Catchment Area

This variable simply measures the total area, in square miles, accessible within a half-mile walk of the station. This measures the completeness of the streetwork, and accounting for any major barriers in the station area, such as an impassable freeway. This variable is based on the catchment areas as defined by Esri's Community Analyst software.

Bus and Shuttle Variables

Three variables are included relating to buses and shuttles.

Bus Lines	
Mean	8.597
Standard Deviation	7.957
Minimum	0
Maximum	38

Table 5-5: Descriptive statistics for the bus lines variable

Number of Bus Lines

This variable counts the number of bus lines that serve each station. All lines operated by a transit operator that have regular weekday service are included. Night- and weekend-only lines are not included. For above-ground stations, all lines that stop at or adjacent to a station are included in the analysis. For below-ground stations, such the BART stations in downtown Oakland and San Francisco, all bus lines that stop within a block of any station entrance are included.

The information for this variable was sourced from publicly available information; Caltrain provides a list of all bus lines that provide service to each station, and BART provides maps that indicate what bus lines stop within the vicinity of every station. Table 5-5 includes has the descriptive statistics for this variable.

Shuttle Routes	
Mean	1.278
Standard Deviation	1.886
Minimum	0
Maximum	10

Table 5-6: Descriptive statistics for the shuttle route variable

Shuttle Routes

This variable counts the number of shuttle lines that serve each station. This variable is included to determine how providing shuttle services impact ridership on BART and Caltrain. For the purpose of this analysis, a shuttle route counted if it offers regularly scheduled weekday service and meets one of the following criteria:

Is operated by a private entity, such as a corporation, or an association of private entities, such as through a transportation demand management (TDM) service.

Is operated by a semi-public entity, such as a university or medical center.

Is operated by a public entity, such as a city, and offers free rides, as is the case for San Jose's DASH shuttles and Oaklands' Broadway shuttle.

Data for this variable was collected from publicly available information. Caltrain provides lists of connecting shuttle services for every station, and BART includes shuttle services on the routes of bus maps near stations. Table 5-6 includes has the descriptive statistics for this variable.

Bus Terminal

This variable indicates if a station has a bus terminal located at the station. For this analysis, a station is considered to have a bus terminal if it has a space for bus pick-up that is removed from surrounding streets and has at least two bus bays. This variable determines if providing a centralized, off-street site for buses has an impact on rail ridership.

Data for this variable was collected by analyzing Google Earth satellite imagery of each station.

Park and Ride Variables

Two variables, both variations on the same data, are included in this analysis. Only one of the two variables is included in the final model.

Number of Parking Spaces (Hundreds)

This variable counts the number of spaces available at park and ride facilities at each station, provided either by Caltrain or BART. Both services provide information about the number of parking spaces available in park and ride lots at each station on their websites. Due to the large number of spaces at many stations, the total number of stations was divided by 100, to measure the impact of adding an additional 100 spaces on ridership.

Park and Ride Facilities

This variable indicates whether a station has park and ride facilities, regardless of the number of spaces. This was included to determine if simply offering park and ride facilities has an impact on ridership.

Bike Variables

Four variables relating to bike facilities and services are included in this analysis. Two variables, like in the park and ride variables, are variations on the same data.

Bikeshare

This variable indicates if the station has a bikeshare station located at or adjacent to the station. For this analysis, bikeshare stations operated by Bay Wheels, formerly FordGoBike, are included. The presence of bikeshare stations are included in the model to determine if providing such facilities impacts ridership.

Data for this variable came from publicly available information provided by Bay Wheels. Dockless bikeshare, such as the service provided by Lime, is not included in this analysis, due to the low-level of availability at the time the ridership data was collected by BART and Caltrain.

Secure Bike Parking Capacity

This variable measures the number of secure bike spaces available at each station, either in bike lockers provided by BART, Caltrain, or other local agency, or in a bike station, a staffed bike storage facility, such as the one at Caltrain's San Francisco Station. Secure bike parking is included in the model to indicate if providing riders a safe place to store their bikes impacts the number of riders.

The data for this variable is from publicly available data on BART and Caltrain's websites.

Secure Bike Parking

This variable indicates if a station offers secure bike parking, regardless of how much capacity it offers. This is intended to determine if simply offering secure bike facilities has an impact on ridership.

Dedicated Bike Lanes

This measure indicates whether a station can be accessed by dedicated bike lanes. Any station that has a dedicated bike lane that directly serves the station or runs adjacent to the station and connects to a bike network is considered to be accessible by dedicated bike lanes. Any station that requires bike riders to ride in mixed traffic with automobiles to access the station is not considered to have dedicated bike lane access. In addition, any station that has dedicated bike lanes adjacent to the station, but those lanes end within a half-mile of the station are not considered to have dedicated bike access. This variable is included in the model to determine if providing direct, dedicated bike access to a station impacts ridership.

The data is from an analysis of satellite imagery and bike network data provided by Google Maps.

The Model

This analysis uses a multiple linear regression model. A linear regression model was chosen as it measures the impact of multiple variables on a single dependent variable. A linear regression provides an estimate on the magnitude of each variable's impact on ridership at an individual station. For example, a transportation planner will be able to use the results of the model to predict how many additional riders adding a new bus line to a station will add.

This analysis includes three main models: the full model, and two-system specific models.

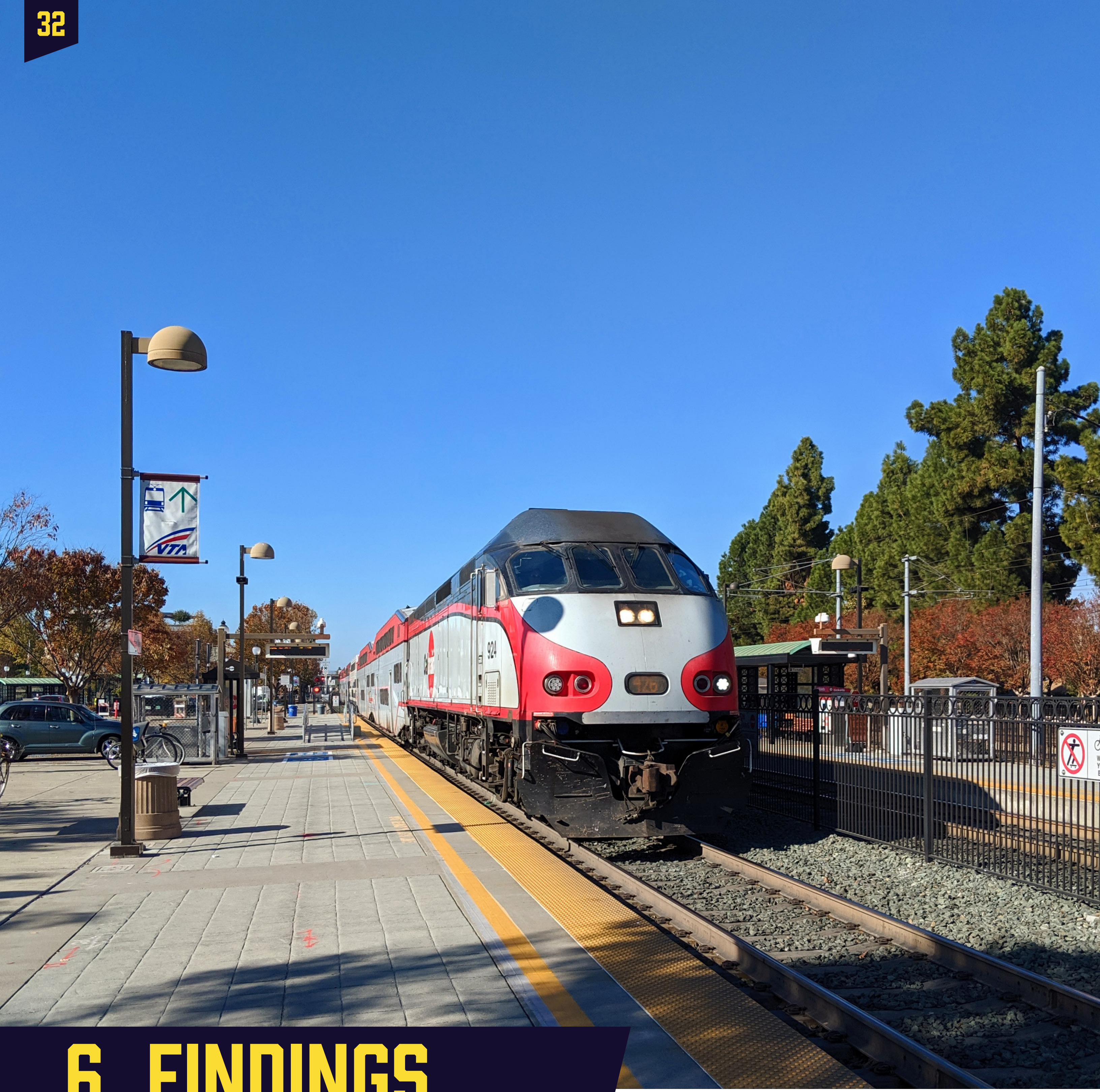
The Full Model

This model analyzes all included variables on all BART and Caltrain stations. The full model is the primary analysis tool for this report, and is used to draw the broadest conclusions about the impact of first and last mile infrastructure and services on rail ridership. The full model includes the following variables:

Caltrain	Employment	Shuttle Connections	Secure Bike Parking
Number of Trains	Catchment Area	Bus Terminal	Dedicated Bike Lanes
Median Income	Car Ownership	Parking (Hundreds)	
Population	Bus Lines	Bikeshare Dock	

The System-Specific Models

There are two system-specific models: one for BART and one for Caltrain. Both models include all the same variables as the full model, minus the Caltrain system indicator, but only include the stations from their respective rail systems. The purpose of these models is to compare them to the full model and to one another. Including this comparison allows analysis of how individual first and last mile infrastructure and services impact the systems differently.



6. FINDINGS

The Full Model

This model analyzes all included BART and Caltrain stations. This model has an R square of .959. Table 6-1 includes the model result.

Variable	B (Std. Error)
Constant	35.359 (1717.384)
Caltrain	-100.389 (1142.873)
No. Trains (Peak Hour)	95.597** (44.288)
Median Income ($)	.013** (.006)
Populations	.270*** (.070)
Employment	.137*** (.013)
Catchment Area (Sq. Miles)	-6713.768** (2682.641)
Car Ownership (% with no car)	.330 (.539)
Bus Lines	211.374*** (59.172)
Shuttle Connections	341.600*** (127.236)
Parking (Hundreds)	29.674 (51.863)
Bikeshare Dock	1297.429* (769.370)
Lockers	-64.589 (988.443)
Dedicated Bike Lanes	542.927 (601.541)
Bus Terminal	523.610 (631.997)
R Square: .959	*: Significant at 90%
Adjusted R Square: .948	**: Significant at 95%
	***: Significant at 99%

Table 6-1: Results of the full model.

Significant First and Last Mile Variables

The first major finding of the model is the impact of bus and shuttle service on ridership. Both variables have a significant effect on ridership at a 95% confidence interval. For each additional bus line, the model predicts an additional 211 daily riders on average, and for each additional shuttle route, the model predicts an additional 342 riders on average. This suggests that additional bus and shuttle services offer access to jobs and housing beyond the station area.

An unexpected result, the model also finds a significant negative effect of the completeness of a street network on rail ridership, with a 95% confidence interval. For each additional square mile of land accessible by walking within a half mile of a station, the model predicts that 6713 fewer daily riders will use the station. This counterintuitive finding may be the result of how well jobs and population capture ridership. In other words, an extensive street network may only provide ridership benefits as it increases access to jobs and housing. As the station catchment area gets larger, so does the number of jobs and housing in the station's catchment area. Meanwhile, ridership at stations with poor street networks may be driven more by park and ride or bus.

Of the bike-related variables, only bikeshare was found to have a statistically significant impact on rail ridership, albeit at a 90% confidence interval and with a relatively large standard error. This suggests that the impact of bikeshare docks varies widely across stations.

Significant Demographic, Land Use, and Service Variables

The strongest relationships found by the model were between rail ridership and the jobs and population within a station area. Both variables were found to be significant at a 95% confidence interval. For each additional resident of a station area, the model predicts and additional .27 daily riders, on average. Employment was found to be similarly significant to population, with each additional station area job adding approximately .137 daily riders. This reflects the literature review, which found that station area land use was the most significant driver of rail ridership, and was an expected result.

Median income was also found to have a significant impact on rail ridership, at a 95% confidence interval. For each additional dollar in median income, the model predicts .013 additional daily riders. This is likely a reflection of the number of affluent and job-rich communities that BART and Caltrain serve.

The number of trains during peak hour does have a significant impact on rail ridership at a 95% confidence interval. The model predicts that each additional train serving a station at peak hours adds approximately 96 daily riders. This in an expected result; it's unsurprising that more frequent service drives additional ridership. The impact is relatively small, however, most likely a result of stations with a large number of station area jobs and population receiving the most frequent service.

Non-Significant Variables

Bike infrastructure was largely not found to be a statistically significant driver of ridership. Offering secure bike parking was not found to have a significant impact on rail ridership. This may be because of the relatively small numbers of secure bike parking offered compared to total ridership; most stations with secure bike parking have fewer than 40 spaces available, compared to hundreds or thousands of daily riders. Dedicated bike lane access, meanwhile, was found to have a positive, but non-statistically significant impact on rail ridership. This could be the result of a similar reason, that the number of people that bike to a station is few enough that it's difficult to come to a statistically significant conclusion. The result could also be driven by the variance in quality of bike lanes not captured by this variable, such as changes in elevation, traffic quantity, or shade.

Bus terminals were found to have a positive, although non-statistically significant impact on rail ridership. This is likely because, with a few exceptions, stations with bus terminals also have a high number of bus lines that serve them.

The differences between Caltrain and BART services do not have a significant impact on ridership at a station. This could stem from many key differences being covered by other variables, such as the number of trains per hour, or from the wide variability in ridership numbers at stations in both systems.

The percentage of households without a car within a station area was not found to be a significant predictor of rail ridership. This is an unexpected result, but could be that car-ownership rates are generally high at all stations, and the variance simply too small to make a statistically-significant conclusion.

The number of parking spaces at a station does not have a significant effect on rail ridership, according to this model. This may be the result of large differences between the number of parking spots provided at each station combined with the difference in station area contexts. For example, it may be the case that parking is a more significant driver of ridership at suburban stations.

BART Model

The BART Model analyzes BART stations using the same variables as the full model. Only significant results and results that differ from the full model are discussed here. The R square for this model is .979. Table 6-2 lists the results of the model.

Variable	B (Std. Error)
Constant	4103.303* (2106.314)
No. Trains (Peak Hour)	81.459* (35.641)
Median Income ($)	.002 (.007)
Populations	.202** (.078)
Employment	.135*** (.013)
Catchment Area (Sq. Miles)	-5579.432* (2826.833)
Car Ownership (% with no car)	.247 (.514)
Bus Lines	203.756*** (52.749)
Shuttle Connections	265.196* (134.931)
Parking (Hundreds)	12.204 (41.585)
Bikeshare Dock	514.063 (915.095)
Lockers	-1501.069 (1381.868)
Dedicated Bike Lanes	-30.279 (751.728)
Bus Terminal	-72.880 (784.814)
R Square: .979	*: Significant at 90%
Adjusted R Square: .971	**: Significant at 95%
	***: Significant at 99%

Table 6-2: Results of the BART model.

Significant First and Last Mile Variables

Bus and shuttle services were once again found to be significant drivers of ridership. Bus service was once again found to have a significant impact on rail ridership at a 95% confidence interval, and an estimated impact of 204 additional daily riders per bus line. Shuttle connections were also found to have an impact on ridership at BART stations, although only at a 90% significance level. The estimated impact is also lower compared to the full model, with an estimated 265 additional daily riders for each shuttle connection. The differences may be a result of BART's more urban service compared to Caltrain, which primarily serves suburban communities; riders may be less likely to need to take a shuttle or bus to their final destination.

Significant Demographic, Land Use, and Service Variables

The BART model also shows a strong correlation between land use and ridership, with both the population and employment variables found significant at a 95% confidence interval, and with relatively similar estimated impacts to the full model.

As reflected in the full model, the number of trains per hour at peak hours has a significant impact on ridership at a 95% confidence interval. The BART model also found a similar relationship between catchment area and ridership as the full model.

Non-Significant Variables

Unlike the full model, bikeshare was not found to be a statistically significant driver of ridership. This suggests that the impact of bikeshare is likely greater for Caltrain than it is for BART, and may indicate that BART stations are generally less bike-friendly than Caltrain stations.

Median income was not found to be significant in the BART model, suggesting less of a correlation between median income and ridership on BART compared to both systems or Caltrain.

Variable	B (Std. Error)
Constant	-970.116 (2256.954)
No. Trains (Peak Hour)	-121.346 (238.980)
Median Income ($)	.019 (.011)
Populations	.337 (.231)
Employment	.254** (.113)
Catchment Area (Sq. Miles)	-7167.022 (5341.910)
Car Ownership (% with no car)	.589 (1.401)
Bus Lines	396.598 (252.566)
Shuttle Connections	471.352** (200.648)
Parking (Hundreds)	-511.222 (384.404)
Bikeshare Dock	1119.338 (1153.457)
Lockers	343.803 (1340.446)
Dedicated Bike Lanes	1517.088 (927.455)
Bus Terminal	125.971 (1010.462)
R Square: .864	*: Significant at 90%
Adjusted R Square: .746	**: Significant at 95%
	***: Significant at 99%

Table 6-3: Results of the Caltrain model.

Caltrain Model

The Caltrain model analyzes Caltrain stations using the same variables as the full model. As a whole, the results from this model were less significant, likely due to the smaller station sample size. Only significant results and results that differ from the full model are discussed here. The R square for this model is .864. Table 6-3 lists the results of the model.

Significant First and Last Mile Variables

The number of shuttle connections serving a station was to be statistically significant at a 95% confidence interval. The approximate impact of an additional shuttle connection, 471 daily riders, was also much higher than in the full or BART models. This suggests that a shuttles provide Caltrain riders with a valuable link. The result may have to do with the nature of the area Caltrain serves; there are a number of very large employers near Caltrain's route, but they are significantly removed from the stations. The number of bus lines serving a station was not found to be statistically significant, but the estimated impact of an additional bus line on daily ridership was much higher than the other two models. The lack of significance here may be a result of the smaller sample size.

Although not statistically significant, the presence of dedicated bike lanes at a station was found to be almost statistically significant at a 90% confidence interval. Dedicated bike lanes were also found to have a much greater positive impact on ridership in the Caltrain model, with stations that have dedicated bike lane access having 1517 more daily riders, on average. This could be an indication that Caltrain's station areas are generally more friendly to bikers than BART's station areas.

Significant Demographic, Land Use, and Service Variables

Employment is one of only two variables that were found to be statistically significant at a 95% confidence interval in the Caltrain model, the other being shuttle service. The approximate impact of an additional station area job was found to be similar across all three models.

Non-Significant Variables

Unlike the full and BART models, population was not found to be statistically significant, although the estimated impact is relatively similar. Median income was found to be nearly statistically significant at a 90% confidence interval, with a similar small positive correlation between median income and ridership as the full model.

Bikeshare was not found to be statistically significant in this model. This is unexpected, as the variable was found to be significant in the full model, but neither the Caltrain nor BART models. This may mean that the impact is variable enough across stations that a greater sample size is needed to determine significance.

7. SIGNIFICANCE

This section discusses the significance of the findings of the quantitative models, including how those findings reflect current planning practice and lessons from academic literature. There are four major findings discussed in this section.

Land Use Drives Ridership

The analysis contained in this report, as well as the reviewed literature, indicates that land use is the key driving determinant in rail ridership; the more people and jobs near a station, the more people use rail transportation. The correlation found between rail ridership and population and employment in this report is relatively strong, with each ten additional jobs or residents adding between 1 and 3 additional riders. The findings largely reinforce what was already known.

Yet, despite this correlation, land use is generally not given much attention in first and last mile plans published by transit agencies and cities. This is, in some ways, understandable; land use planning is generally defined by plans and documents much larger in scope, such as general plans and zoning codes. First and last mile planning, however, is one of the key bridges between land use and transportation planning, and the analysis contained within this report indicates that first and last mile planning alone is not enough to drive people to take transit.

The literature and results of the analysis suggest that most people take rail transit when they can access their homes or jobs easily. First and last mile planning can make that access trip more convenient, but if an agency's goal is to encourage more people to take transit, land use planning must be incorporated with first and last mile planning; even if the access route to transit is great, people do not take transit unless it goes somewhere useful.

For cities producing their own first and last mile plans, land use can be incorporated into, or aligned with, first and last mile plans relatively easily. The Richmond first and last mile plan, for example, does include some land use policies, although they are a relatively small part of the overall document.[1] For transit agencies, which frequently span multiple municipalities with land use authority, it is more difficult. Nonetheless, the evidence indicates that agencies should work closely with the municipalities in their service areas to develop land use strategies.

Beyond just encouraging denser, mixed use development around stations, land use strategies could be integrated with first and last mile plans in creative ways. For example, the LA Metro first and last mile plan identifies key pedestrian and bicycle access pathways.[2] Increased densities could be focused on those access paths, rather than a broad station area upzoning. This would limit development to the areas where riders would have greatest access to, supporting greater first and last mile improvements.

Bus Services are Key

A key takeaway from the analysis in this report is that providing bus and shuttle services does have an impact on ridership; the correlation was both relatively large and statistically significant. Typically, first and last mile plans focus more heavily on active transportation access modes, but the evidence found here suggests that bus and shuttle modes are important first and last mile access modes too.

The impact of bus routes on rail ridership is perhaps the most important lesson from the analysis; the impact is clear and positive, and is likely more feasible than land use changes. Many transit agencies that operate rail service also offer bus service, so organizing bus service to better serve rail stations requires less interagency cooperation. The two agencies examined in this report, BART and Caltrain, are exceptions to this, although Caltrain partially administered by SamTrans, the transit operator for San Mateo County. For cities, some cities operate their own transit service. For example, Union City, in the San Francisco Bay Area, operates its own bus service that complements the BART service that runs through the city.

1 City of Richmond 2019

2 Los Angeles County Metropolitan Transportation Authority and Southern California Association of Governments 2014

The literature supports the analysis made in this report. One of the pieces of research reviewed in this report also found that the number of bus stops at a station impacted the number of rail riders.[3] A second study, in a Chinese context, found the same relationship.[4] Many of the first and last mile plans reviewed in this report, however, do not cover bus service as a first and last mile solution. This results of the models from this report as well as the academic literature suggest that bus service should be considered as a potentially very important first and last mile solution.

There are some limits to bus services, however. The analysis in this report did not examine the quality of bus services that connect with rail stations; it's likely that aspects of the bus route, such as frequency or ridership, change the impact of adding an additional bus route to a station. Bus routes need to go somewhere, so transit agencies and cities need to understand what would make for a successful bus route before adding additional services. Cities and transit agencies should identify areas with high concentrations of jobs and housing that are currently underserved by bus service, and connect those areas to rail transportation.

One additional challenge with bus routes as a first and last mile issue is that bus stops require access routes of their own. While a bus network can more completely cover an area than a rail network, riders still need to get to and from the bus stops. Adding bus routes as a first and last mile solution can clearly help, but it also moves the first and last mile problem from a rail station to a bus stop. Some existing first and last mile plans include bus stop access, and the results of the models in this supports further inclusion.

Shuttles Have a Major Impact

One of the most interesting results of the models in this report is the importance and impact of shuttle service on rail ridership. Little attention has been given to shuttle services in existing literature; none of the literature reviewed for this report examined shuttle services. Yet, the analysis in this report indicated that each additional shuttle route that serves a rail station has a larger impact than each additional bus route.

3 Ma, Liu, and Erdogan 2015

4 Zhao, Deng, Song, and Zhu 2013

Shuttle routes should therefore be included as a valuable first and last mile connection.

As a policy option, encouraging shuttle service has a number of advantages. First, it has little to no capital and upkeep costs for cities and transit agencies; of the shuttles services included in this analysis, most are organized and run by private organizations rather than public agencies, although there are some exceptions to this rule. Second, shuttle services can be incorporated into existing private transportation demand management programs, not requiring the creation of new operators or services. Additionally, there may be benefits to encouraging private entities to participate in regional transportation solutions, such as helping create a level of civic engagement and ownership in these private organizations. The downside to shuttle services is that they require cities and transit agencies to work with private entities to create services; agencies cannot create their own services.

A major caveat with the impact of shuttle services is the unique context of the San Francisco Bay Area. The three models suggest that the impact was greatest on Caltrain, which runs through an area in which there are a number of very large employers that are not adjacent to the rail line; Caltrain runs through the historic center of many of the communities it services, while many of the large tech sector employers are located in giant office parks adjacent to the bay, and away from those historic cores. This suggests that the lessons from this analysis in relation to shuttle services are especially relevant to rail systems in similar contexts. However, the same relationship was found in the BART model, though with a smaller impact and less significance. BART has a more varied context than Caltrain, suggesting that the shuttle service is still relevant in other contexts, just less so.

Bikes and Pedestrians

Most first and last mile plans focus heavily on bike and pedestrian access. However, the analysis in this report found that the bike and pedestrian variables were less impactful than many of the other variables. As already noted, the models suggest that the number of jobs or residents within walking distance is a much stronger determinant than specific factors that impact the quality of an access trip.

The evidence for pedestrian infrastructure is especially small. The completeness of the street network seems to primarily be impactful only as far as it increases access to the number of jobs or homes from a station. This suggests that improving street network completeness should only be considered as a policy to increase rail ridership if and only if those improvements increase access to major employment or residential centers.

The analysis found a clearer correlation between bike infrastructure and services and rail ridership, although still not an outstanding one. In particular, it does appear that bikeshare does have an impact on rail ridership, although the variance for this impact was found to be quite high. This evidence supports the conclusions of the literature review in this report, and suggests that bikeshare should be encouraged as a potential first and last mile solution. The other bike variables were found to be less significant, although the Caltrain model did find a positive correlation between ridership and direct dedicated bike lane access, suggesting that in a context similar to Caltrain's, creating dedicated bike lanes may also be a first and last mile solution.

8. CONCLUSIONS, POLICY IMPLICATIONS, AND FURTHER RESEARCH

First and last mile planning is an increasingly important part of land use and transportation planning. This section reviews the analysis and findings contained in the report, and discusses the policy implications of those findings, as well as identifies avenues for future study.

Conclusions

This report reviewed existing first and last mile scholarly research, reviewed and compared all existing first and last mile plans in the United States, and includes a quantitative analysis of the impact of first and last mile infrastructure and services on rail ridership in the San Francisco Bay Area. This report specifically examined first and last mile planning through the lens of ridership, attempting to determine which first and last mile infrastructure and services are most effective at driving rail ridership.

The key findings from this analysis are:

There is a disparity between the findings in the academic literature, supported by the quantitative analysis in this report, and existing first and last mile plans on the topic of land use. Academic literature and the quantitative analysis suggests that one of the strongest determinants of rail ridership is land use, specifically the amount of housing and jobs near stations.

Bus and shuttle services are an important and underutilized first and last mile solution. The quantitative analysis in this report found that both bus and shuttle services had a significant positive relationship with rail ridership, while the review of first and last mile plans found that few plans considered bus and shuttle service as a key solution. Academic literature also does not adequately address bus and shuttle service as a first and last mile solution, with few papers including such services as variables.

The quantitative analysis in this report found only light support for walking and biking first and last mile infrastructure as a driver of rail ridership. Of tested variables, only the provision of bikeshare was found to have a significant, positive relationship with rail ridership. Meanwhile, active transportation modes were found to typically be the main focus of first and last mile plans.

This report is unique in its comparisons between existing first and last mile plans and a quantitative analysis of first and last mile infrastructure; it links policy with a quantitative measure of efficacy that can be used for future planning efforts. The analysis here has a clear and immediately relevant impact for the San Francisco Bay Area. Much of the findings contained in this report were based on an analysis of the San Francisco Bay Area's BART and Caltrain rail systems. The findings listed here can be used to improve first and last mile access on both systems, especially for underserved communities throughout the Bay Area.

This report is simply part of a broader picture, however; encouraging rail ridership is simply one part of first and last mile planning. The literature review indicated that there are important equity implications to first and last mile planning, but it is an extremely understudied topic. The analysis contained in this report can and should be used as a stepping stone to better understand how first and last mile planning can be used to increase equity in American transit systems. First and last mile planning offers an incredible opportunity to better connect low-income communities with high-quality opportunities.

Policy Implications

The findings from this report suggest that there are a number of important factors planners and policymakers should consider when approaching first and last mile planning. Five important implications are listed below.

Improve Bus Services

The clearest policy implication is that bus and shuttle services should be an important part of first and last mile analysis. Bus and shuttle services have the advantage of being in line with the typical scope of first and last mile plans, as well as being more directly impactful. Improved bus services, in particular, should be appealing to transit agencies; it's quicker to add a new bus route or alter an existing one than it is to wait for new, transit-oriented development, and transit agencies have more power to accomplish the task.

Mandate Shuttle Services

Cities and counties should consider implementing laws that make the provision of shuttle services mandatory for housing developments and job centers greater than a certain size that are not adequately served by existing transit routes. The analysis contained in this report indicates that people do use shuttles as a first and last mile solution, and that shuttles have a significant impact on ridership. The findings from the analysis of Caltrain, which is removed from many of the largest employers in the area it serves, give especially strong support to such a policy.

Coordinate Land Uses and Remove Barriers

A city or agency approaching first and last mile planning with a primary or secondary goal of increasing ridership or providing more equitable access to jobs or amenities would benefit from considering how to densify land uses around a station. Adding more housing to station areas show a particularly dramatic impact. Changing land uses, however, can be politically difficult and impacts can be slow. To capitalize on the impact of jobs and housing in a station area, the analysis also indicates that cities and agencies should identify and remove barriers that separate major housing developments or job centers from rail stations. Removing barriers may be more politically acceptable than dramatic changes in land use.

Increase Involvement from Metropolitan Planning Organizations

The difficulty of connecting land use planning with first and last mile planning suggests that first and last mile planning should be done by regional authorities. Transportation planning, especially first and last mile planning is a difficult task; first and last mile planning requires the coordination of multiple agencies and municipalities. Transit agencies typically do not have land use authority, and must work with a number of cities and counties to create transit-supporting land uses or build infrastructure outside of stations. This variety of planning authorities can additionally cause unequal distribution of first and last mile improvements. Richmond, California, for example, has a first and last mile plan, but it is the only community served by BART that does. Existing metropolitan planning organizations in the United States could be given greater authority to be involved in first and last mile planning by creating a formal role for such organizations in first and last mile planning, ensuring that land uses around stations are transit-supportive. Greater involvement from regional planning organizations would also ensure that first and last mile goals and policies are consistent throughout a metropolitan area.

Consider Equity Throughout the Planning Process

The literature reviewed in this report indicated that first and last mile planning does have an important equity impact. Combining the lessons learned from the analysis in this report with the lessons from the literature suggests that first and last mile infrastructure and services could play an important role in both increasing low-income communities' access to jobs and rail ridership; improving the quality and speed of first and last mile access for low income communities, such as through additional bus lines, could provide better access to the jobs that drive ridership.

Closely involving metropolitan planning organizations in first and last mile planning could also have a dramatic effect on equity. While most first and last mile plans already pay a great deal of attention to equity, metropolitan planning organizations, due to their regional nature, may be able to better identify and target disadvantaged communities regionally. This report creates a model by which the efficacy of equity-focused first and last mile solutions can be measured, as well as a starting point for the types of first and last mile infrastructure and services would be most effective in increasing access to jobs and amenities for these communities.

Prepare for Emerging Technologies

Transit agencies and municipalities should also implement policies that respond to and regulate new technologies in the field of transportation to ensure they support equitable first and last mile access. Emerging technologies, such as ride-hailing apps, autonomous vehicles, and scootershare could potentially have a major impact on how or if people choose to access rail stations. While these developments could improve first and last mile access, they could also have an overall negative impact on rail ridership. The analysis in this report can be used as a model to evaluate the impact of such technologies on rail ridership. A ridership model based off of this report would, for example, determine if a well-used scootershare service actually caused more people to access a rail station, or if it is largely used by those that would have otherwise biked or walked to a station. Technologies that fail to support first and last mile access could then be regulated in such a way to ensure there is no negative impact on rail ridership.

Further Research

This report focuses almost exclusively on the relationship between first and last mile planning and rail ridership. Rail ridership, however, is only a part of first and last mile planning; there is much more in the field still to understand. First and last mile planning is becoming increasingly important, and understanding the impact and relative effectiveness of different first and last mile policies is going to be increasingly valuable.

Additional research should be done into modes other than rail. The impact of first and last mile infrastructure and services on bus ridership is also important; not all cities have rail transit services, but most have bus services. In this report, bus transportation was evaluated as a first and last mile solution, but bus lines still require first and last mile access of their own. An analysis of different levels of bus services could be especially enlightening, examining the different impacts of first and last mile services on bus rapid transit routes as opposed to local or express bus routes. Further analysis could even be done to determine if improving first and last mile access to bus routes that serve rail stations has an impact on rail ridership.

There are also other important considerations in regards to first and last mile planning beyond rail ridership. The first is quality of access. A public agency may want to improve the quality of access for existing riders, even if those improvements have little or no impact on ridership. Further research could be done on what specific improvements are most associated with riders perception of the quality of their station access trip, such as mid-block crossings or protected bike lanes. Part of quality of access includes safety. Public agencies have a strong interest in increasing the safety of riders, and improving first and last mile infrastructure may be part of that. Additional research could determine if improving first and last mile infrastructure has a significant impact on the safety of riders, either perceived or actual.

The other important consideration is the impact of improved first and last mile services on access mode choice. The analysis in this paper does not examine how improved first and last mile infrastructure may influence existing riders to alter how they choose to access a station. Further research could determine if, for example, adding bikeshare causes riders to choose to bike to a station instead of drive to that same station. Cities and transit agencies could see benefits by increasing non-automobile station access modes. If fewer people drive to a station, park and ride lots could be converted to transit oriented development. A reduction in non-automobile access mode share may also help public agencies meet greenhouse gas reduction targets.

This report also does not examine the impact of two important emerging technologies related to the first and last mile on rail ridership. The first emerging technology is the growth of transportation networking companies, such as Uber and Lyft. Due to the cross-sectional nature of the analysis contained in this report, such services were not considered; all stations included in the analysis are in areas served by ride-hailing apps, and as such, there is no way to determine the impact of such apps. However, ride-hailing apps provide a potentially alluring solution to the first and last mile problem. To accurately measure the impact of theses services on rail ridership, a longitudinal analysis could be done of several station, examining the change in rail ridership following the introduction of such services. A study even more specifically aimed at how public agencies can solve the first and last mile challenge could look at the effectiveness of providing subsidized rides to a rail station.

The second emerging technology is the rise of scootershare. Scootershare provides a potentially effective alternative station access mode, allowing users to reduce the amount of time it takes to access a station. This report does not analyze the impact of scootershare on rail ridership due to current limitations in the data set. Ridership data analyzed for this report was collected by the respective agencies in February 2018, about the same time the first scootershare services were rolled out in the San Francisco Bay Area. Once more recent data has been released, an analysis of the impact of scootershare on rail ridership can be completed; unlike ride-hailing services, scootershare services are not available at every station analyzed for this report. Additional research can be done on scootershare to determine its impact on station access modeshare, as well; it’s possible that scootershare creates a replacement effect. Riders that use scootershare to access a station may have used another access mode prior to the introduction of scootershare.

There is much more to study in relation to first and last mile planning; this report is a starting point for future first and last mile planning efforts.

REFERENCES

Akbari, Saidal. "Empirical Models of Transit Demand with Walk Access/Egress for Planning Transit Oriented Developments around Commuter Rail Stations in the Greater Toronto and Hamilton Area." *Journal of Transport Geography* 68, (2018).

Bay Area Rapid Transit. *BART Station Access Policy*. Oakland, CA: Bay Area Rapid Transit, 2016.

Boarnet, Marlon G., et al., "First/Last Mile Transit Access as an Equity Planning Issue." T*ransportation Research Part A: Policy and Practice* 103 (2017): 296–310.

Brons, Martijn, Moshe Givoni, and Piet Rietveld. "Access to Railway Stations and Its Potential in Increasing Rail Use." *Transportation Research Part A: Policy and Practice* 43, (2009).

Caltrain. *Caltrain Bicycle Access and Parking Plan: Implementation Strategy.* San Mateo, CA: Caltrain, 2014.

Caltrain. *Comprehensive Access Plan Policy Statement*. San Mateo, CA: Caltrain, 2010.

Cervero, Robert. "Walk-and-Ride: Factors Influencing Pedestrian Access to Transit." 3, no. 4. J*ournal of Public Transportation* 3, (2001): 1.

Chalermpong, S., and A. Ratanawaraha. "How Land Use Affects Station Access Behaviors of Bus Rapid Transit Passengers in Bangkok, Thailand." *Transportation Research Record* 2533 (2015): 50–59.

Chan, Sabrina, and Luis Miranda-Moreno. "A Station-Level Ridership Model for the Metro Network in Montreal, Quebec." *Canadian Journal of Civil Engineering* 40, no. 3 (2013): 254–262.

City of Richmond. *First Mile/Last Mile Transportation Specific Plan*. Richmond, CA: City of Richmond, 2019.

Clewlow, Regina R. and Gouri S. Mishra. *Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States*. UCD-ITS-RR-17-07, Institute of Transportation Studies, University of California, Davis (2017).

Cui, Boer, Geneviève Boisjoly, Ahmed El-Geneidy, and David Levinson. "Accessibility and the Journey to Work through the Lens of Equity." *Journal of Transport Geography* 74, (2019).

Engel-Yan, Joshua, Malvika Rudra, Christopher Livett, and Rebecca Nagorsky. "Strategic Station Access Planning for Commuter Rail: Balancing Park-and-Ride with Other Modes." Edited by Joshua Engel-Yan. *Transportation Research Record* 5, no. 2419 (2014): 82–91.

Flamm, Bradley, and Charles Rivasplata. "Perceptions of Bicycle-Friendly Policy Impacts on Accessibility to Transit Services: The First and Last Mile Bridge." Mineta Transportation Institute, San Jose State University. San Jose: Mineta Transportation Institute (2014).

Federal Transit Administration. *Manual on Pedestrian and Bicycle Connections to Transit*. Report no. 0111. Washington, DC: Federal Transit Administration (2017).

Ji, Yanjie, Yingling Fan, Alireza Ermagun, Xuening Cao, Wei Wang, and Kirti Das. "Public Bicycle as a Feeder Mode to Rail Transit in China: The Role of Gender, Age, Income, Trip Purpose, and Bicycle Theft Experience." *International Journal of Sustainable Transportation* 11, no 4. (2017): 308–317.

Kim, Dohyung, Yongjin Ahn, Simon Choi, and Kwangkoo Kim. "Sustainable Mobility: Longitudinal Analysis of Built Environment on Transit Ridership." *Sustainability* 8 no.10 (2016).

Kuby, Michael, Anthony Barranda, and Christopher Upchurch. "Factors Influencing Light-Rail Station Boardings in the United States." *Transportation Research Part A: Policy and Practice* 38, (2004).

Larsen, Jacob, Ahmed El-Geneidy, and Farhana Yasmin. "Beyond the Quarter Mile: Re-Examining Travel Distances by Active Transportation." *Canadian Journal of Urban Research* 19, no. 1 (2010): 70–88.

Lin, Ting. "Spatial Analysis of Access to and Accessibility Surrounding Train Stations: A Case Study of Accessibility for the Elderly in Perth, Western Australia." J*ournal of Transport Geography* 39, (2014).

Los Angeles County Metropolitan Transportation Authority, and Southern California Association of Governments. *First Last Mile Strategic Plan*. Los Angeles, CA: Los Angeles County Metropolitan Transportation Authority, 2014.

Los Angeles County Metropolitan Transportation Authority. *Blue Line First/Last Mile: A Community-Based Process and Plan*. Los Angeles, CA: Los Angeles County Metropolitan Transportation Authority, 2018.

Ma, Ting, Chao Liu, and Sevgi Erdoğan. "Bicycle Sharing and Public Transit." 2534. *Transportation Research Record: Journal of the Transportation Research Board* 2534 (2015): 1–9.

Meng, Meng, Abdul Ahad Memon, Yiik Diew Wong, and Soi-Hoi Lam. "Impact of Traveller Information on Mode Choice Behaviour." *Transport* 171, no. 1 (2018): 11–19.

Moorthy, Aditi, Robert De Kleine, Gregory Keoleian, Jeremy Good, and Geoff Lewis. "Shared Autonomous Vehicles as a Sustainable Solution to the Last Mile Problem: A Case Study of Ann Arbor-Detroit Area." *SAE International Journal of Passenger Cars: Electronic & Electrical Systems* 10 no. 2 (2017): 328–336.

Park, Keunhyun. "The Impacts of Built Environment Characteristics of Rail Station Areas on Household Travel Behavior." *Cities* 74, (2018).

Park, Sungjin, Junhee Kang, and Keechoo Choi. "Finding Determinants of Transit Users' Walking and Biking Access Trips to the Station: A Pilot Case Study." *KSCE Journal of Civil Engineering* 18, no 2. (2014): 651–658.

Regional Transportation District. F*irst and Last Mile Strategic Plan PPAC Meeting #*3. Denver, CO: Regional Transportation District, 2018.

Renne, John L., Shima Hamidi, and Reid Ewing. "Transit Commuting, the Network Accessibility Effect, and the Built Environment in Station Areas across the United States." *Research in Transportation Economics* 60 (2016): 35–43.

Riverside Transit Authority. *First & Last Mile Mobility Plan*. Riverside, CA: Riverside Transit Authority, 2017.

Transit Cooperative Research Program. *Guidelines for Providing Access to Public Transportation Stations*. Report no. 153. Washington, DC: Transportation Research Board, 2012.

Utah Transportation Authority. *First/Last Mile Strategies Study*. Salt Lake City, UT: Utah Transportation Authority, 2015.

Wang, Kyungsoon, and Myungje Woo. "The Relationship between Transit Rich Neighborhoods and Transit Ridership: Evidence from the Decentralization of Poverty." *Applied Geography* 86 (2017).

Washington Metropolitan Area Transportation Authority. *Station Area Planning Guide. Washington*, DC: Washington Metropolitan Transportation Authority, 2017.

Weinstein Agrawal, Asha, Marc Schlossberg, and Katja Irvin. "How Far, by Which Route and Why? A Spatial Analysis of Pedestrian Preference." *Journal of Urban Design* 13, no. 1 (2008): 81–98.

Weliwitiya, Hesara. "Bicycle Train Intermodality: Effects of Demography, Station Characteristics and the Built Environment." *Journal of Transport Geography*. 74, (2019).

Zhao, Jinbao, and Wei Deng. "Relationship of Walk Access Distance to Rapid Rail Transit Stations with Personal Characteristics and Station Context." *Journal of Urban Planning & Development* 139, no. 4 (2013): 311–321.

Zhao, Jinbao, Wei Deng, Yan Song, and Yueran Zhu. "What Influences Metro Station Ridership in China? Insights from Nanjing." *Cities* 35, (2013).