Next-Generation Transit System Design During a Revolution of Shared Mobility

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A Research Report from the Pacific Southwest Region University Transportation Center

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16. Abstract
Ideally, public transit, by moving more people using fewer vehicles, serves as a backbone of a transportation system. However, most transit systems in the United States suffer from low ridership and high operating costs, thus they provide a significantly compromised mobility service to the transportation system users. Under current transit system design principles, such as service area requirements, inefficiencies in resource use are almost inevitable. Given the opportunities brought by new mobile technology and the environment of mobility as a service, current transit system design principles need to be reevaluated and redefined to enable transit to serve as a backbone in the transportation system. In this seed-grant project, we evaluated whether building an integrated multimodal public transportation system via reallocation of transit resources is financially feasible and environmentally sustainable. We also conducted an in-depth review of related literature and discussed other concerns regarding an integrated system. Based on the results from our case study and review of other recent studies, we draw an optimistic conclusion about an integrated service system where public and private mobility service providers coexist.

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TABLE OF CONTENTS

List of Tables

List of Figures

About the Pacific Southwest Region University Transportation Center

The Pacific Southwest Region University Transportation Center (UTC) is the Region 9 University Transportation Center funded under the US Department of Transportation's University Transportation Centers Program. Established in 2016, the Pacific Southwest Region UTC (PSR) is led by the University of Southern California and includes seven partners: Long Beach State University; University of California, Davis; University of California, Irvine; University of California, Los Angeles; University of Hawaii; Northern Arizona University; and Pima Community College.

The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education, and technology transfer aimed at *improving the mobility of people and goods throughout the region.* Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

U.S. Department of Transportation (USDOT) Disclaimer

Disclosure

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Abstract

Ideally, public transit, by moving more people using fewer vehicles, serves as a backbone of a transportation system. However, most transit systems in the US suffer from low ridership and high operating costs, thus they provide a significantly compromised mobility service to the transportation system users. Under current transit system design principles, such as service area requirements, inefficiencies in resource use are almost inevitable. Given the opportunities brought by new mobile technology and the environment of mobility as a service, current transit system design principles need to be reevaluated and redefined to enable transit to serve as a backbone in the transportation system. In this seed-grant project, we evaluated whether building an integrated multimodal public transportation system via reallocation of transit resources is financially feasible and environment sustainable. We also conducted an in-depth review of related literature and discussed other concerns regarding the system. Based on the results from our case study and review of other recent studies, we draw an optimistic conclusion about an integrated service system where public and private mobility service providers coexist.

Next-Generation Transit System Design During a Revolution of Shared Mobility

Executive Summary

Most transit systems in the United States face challenges of low ridership and high operating costs. In part, this is because transportation systems are operated by governments, which must respond to the demands of the majority of residents. As a result, service area coverage is an important design criteria in current transit agency practice. Our analysis, based on Santa Clara Valley Transit Agency's data, shows that system efficiency may be compromised when such coverage requirements are imposed as hard constraints in transit system design.

To address the challenge of integrating public and private mobility services to improve overall system efficiency, in this seed-grant study, we focused on reevaluating and redefining the role of public transit and its design principles in the new context of technology and shared mobility. Specifically, we evaluated the feasibility of an integrative system where public and private mobility services coexist to relax the conventional service coverage requirement of a transit system, so that public transit resources can be reallocated more efficiently. Feasibility was measured by cost (including user cost and agency cost), social equity (impact on different user groups), and environmental benefit (measured by energy and emission savings per person-mile-traveled). We used the transit system of Santa Clara County as a real-world case to study feasibility.

Our results are based on the following assumptions: (1) Transit demand is static and known; (2) Developing a business model that accommodates strong public-private partnership is possible; (3) Shared mobility services are easily accessible to transit users. The Santa Clara Valley Transit data revealed:

- Average transit ridership ranges between 0 to 116 people per vehicle trip across all transit routes, with most of the low ridership routes being operated to satisfy demand of low density areas.
- The average operating cost ranges between a few dollars to more than 70 dollars per passenger trip, with more than 78% of the routes exceeding an operating cost threshold of $7.39 (equivalent to a three-mile Uber service price in the area).

Based on these results and a detailed look into some specific routes and alternative routes in the neighboring areas, we conclude that building an integrated multimodal public transportation system in Santa Clara County by reallocating existing transit resources is financially feasible and environmentally favorable. On the other hand, there are still obstacles raised from legal, political, and equity concerns. An in-depth review of recent studies and existing successful practices in some cities suggest that these barriers may be overcome through better coordination and cooperation among different service providers in the system.

1. Introduction

Ideally, by moving more people using fewer vehicles, public transit can significantly reduce greenhouse gas emissions and energy consumption in the transportation sector and alleviate road congestion. Thus, it plays an important role in improving the sustainability of transportation systems.

However, most public transit systems in the United States face challenges of low ridership and high operating costs. In part, this is because transportation systems are operated by governments, which must respond to the demands of the majority of residents. Current transit agency practice and literature related to transit system design indicates that the typical evaluation criteria for transit planning and operations are coverage of service area, user costs, operating costs, and service quality (Sinha, 2003; Fan and Machemehl, 2006; Zhao and Zeng, 2007).

By examining real data from Santa Clara Valley Transit Agency (VTA), we found that some rarely used bus stops and routes were kept in the system mainly to fulfill the service area coverage requirement. Our mathematical analysis, as well as some empirical evidence, show that system efficiency may be compromised when service area coverage requirements are imposed as hard constraints in transit system design. Relaxing such constraints has long been considered socially unacceptable because there are individuals and communities largely relying on transit.

A typical issue causing low transit ridership is the “first mile, last mile” problem, given that placing stops at every origin and destination is financially impossible (Giannopoulos, 1989; TCRP., 1996). Many transit agencies have attempted to resolve this problem with special shuttles. However, shuttle services also face problems in terms of cost and ridership, leading to low and sporadic adoption of paratransit modes (Golden, Chia, Ellis and Thatcher, 2014; Enoch and Potter, 2016). At the same time, the development of mobile intelligent devices, like smart phones, has made low-cost ride-sharing accessible in most urban areas. While transit agencies have been trying to improve the level of service, competition from ride-sharing companies have driven a decline in national transit ridership (Tyree, 2017).

Unfortunately, many of the criticisms of transit—such as empty buses, unreliable and infrequent service, and heavy government subsidies—have been valid for many years. There are cultural, psychological, and land-used related factors causing low demand for transit, which would take much longer to change than transit design and are beyond the expertise of the PI and the scope of the proposed research. On the other hand, we envision that, with its advantage of scale, public transit ought to play a major role in the new environment of mobility as a service. The key ingredient calling for and driving this transformation is technology, which is changing the way people move around and interact with cities by giving them the ability to request, track, and pay for trips with mobile devices. From a system design viewpoint, can we do better to integrate public and private mobility services and to improve the efficiency of the overall system?

To address this question, in this seed-grant study, we focused on reevaluating and redefining the role of public transit and its design principles in the new context of technology and shared mobility. Specifically, we evaluated the feasibility of an integrative system where public and private mobility services coexist to relax the conventional service coverage requirement of a transit system, so that the public transit resources can be reallocated more efficiently. Feasibility was measured by cost (including user cost and agency cost), social equity (impact on different user groups), and environmental benefit (measured by energy and emission savings per person-mile-traveled). We used the transit system of Santa Clara County as a real-world case to study feasibility.

2. Research Design

We analyzed financial feasibility based on operating data, including ridership and fiscal data, from the Santa Clara Valley Transportation Authority (VTA). Financial feasibility was analyzed by mathematical and theoretical comparison between the existing public transportation system and a model of an integrated, multimodal public transportation system. Feasibility in terms of equity, legal, and political concerns was assessed through an in-depth review of existing studies and empirical evidence.

3. Financial Feasibility Analysis

3.1. Datasets

Most of the results reported in this study were obtained based on statistical analysis of the data described in Table 1.

Table 1. Datasets and sources.

Dataset	**Source**
Adopted Budget Fiscal Year 2016-2017	Provided by Santa Clara VTA
Ridership Data	Santa Clara VTA website
Transit Routes Map	Santa Clara VTA website

3.2. Assumptions

Our investigation of the feasibility of an integrative system combining shared mobility services and public transit was based on the assumptions described below.

3.2.1. Static and known transit demand

We used existing transit demand as a fixed known input parameter in the feasibility analysis. We are aware that an introduction of ride sourcing services to the system may change travelers' travel behavior in terms of trip rates, mode choice, and route choice, thus changing the actual travel demand. For example, if, for each trip combining public transit and shared mobility, part of the trip happens in private cars, then comfort will be increased. At the same time, ride-sharing apps on mobile devices can enable easy access to shared mobility services so that people can replace the original low frequency transit with shared mobility, leading to reduced waiting time and improved flexibility, accessibility, and reliability. If the extra cost of using ride-sourcing services is covered by some subsidy mechanism, we can expect an increase in transit demand. However, with this seed grant alone, we did not have the time and resources that would be needed to build a full-scale endogenous behavior model in the feasibility study. Therefore, we used existing transit demand to quantify the system users, and then conducted a sensitivity study to test how deviation from this assumption may affect the conclusions.

3.2.2. Developing a business model that accommodates strong public-private partnership is possible

Another assumption is that it is possible to develop a financial mechanism to redistribute revenues among shared mobility and public transit. We assume public transit operators can develop and use such a mechanism to compensate target passenger populations to minimize the inconvenience caused to them by removing a transit route. Although this paper does not delve in depth into the design of this mechanism, considering the capability of mobile devices nowadays, we are optimistic that this assumption is implementable. In further support of this assumption, an existing practice in Seattle demonstrates combines UBER and the transit system (Clugston, 2017).

3.2.3. Easy accessibility to shared mobility service

This paper assumes that after a transit route is removed, the transit system can maintain its level of service by compensating passengers for the usage of shared mobility services in the originally covered area. However, many of the selected candidate routes for removal, where there is less demand for public transportation, are located in remote areas where there may not be enough supply capacity of shared mobility services. Therefore, after removing those transit routes, passengers in these areas may not be able to access shared mobility, so that the level of service may be reduced. One possible approach to address this would be for shared mobility companies such as UBER to offer drivers bonuses to serve these areas. However, in this model we did not assume such expanded service and an exploration of its financial sustainability was beyond the scope of this study.

3.2.4. Origin and destination are transit stops

Due to the lack of actual origin and destination (OD) information, we assume that each trip begins or ends at the first and last transit stops where passengers board or get off.

3.3. Financial Feasibility Analysis Procedure

A threshold for low average ridership was set at 16.95 passengers per vehicle trip. This value was calculated based on the average bus fuel economy, 2.33 mpg, the average private car fuel economy, 25 mpg, and the average ridership per private car trip, 1.58 passengers per vehicle trip (Lowe, Aytekin and Gereffi, 2009; Foxall, 2016). As we seek to improve environmental sustainability, we do not want to simply gain financial efficiency at a cost of more environmental damage. To lower GHG and other related emissions, we sought to achieve a high overall fuel economy per passenger, that is, 25 mpg × 1.58 / 2.33 mpg = 16.95 passengers per vehicle trip.

The threshold for large cost per rider was set to be $7.39 per trip (equivalent to a three-mile Uber service price in the area). In this research, we consider possible removal of a transit route with low ridership, whose demand is then covered by combining private mobility services and nearby transit routes with sufficiently high ridership.

To meet the criteria of having a nearby alternative transit routes, a given transit route, X, had to have other routes within 3 miles of its frequently used origins and destinations. This maximum of 3 miles was determined based the corresponding additional cost ($7.39) of connecting riders of route X to an alternative transit route by a shared mobility service.

The step-by-step procedure for evaluating the financial feasibility of an integrated, multimodal system with public transit and private shared mobility is shown in Table 2.

Table 2. Feasibility analysis procedure.

Steps	**Details**
Statistical Analysis of Raw Ridership Data	Calculate the total, average, and variance of on and off ridership at each stop Obtain rider volume of each transit route
Filtering transit routes	Criteria are: Low average ridership (< 16.95 per trip) High cost per rider (> $7.39 per trip) Availability of alternative transit routes within 3 miles
Manually observe and select candidate transit routes for removal	For example, if most riders get on board in the first or last few stops of a transit route, the demand is more concentrated at both ends. This kind of route can be more easily replaced by transporting passengers using shared mobility to nearby alternative transit routes.
Calculate the operating cost saved by removing part or all of the transit route.	Calculated based on fiscal data from Santa Clara VTA
Calculate the number of riders that need to be subsidized for shared mobility costs to maintain the level of service of transit system for this group of passengers.	
Calculate the maximum amount of compensation that could be provided to each rider for each trip.	

3.4. Results

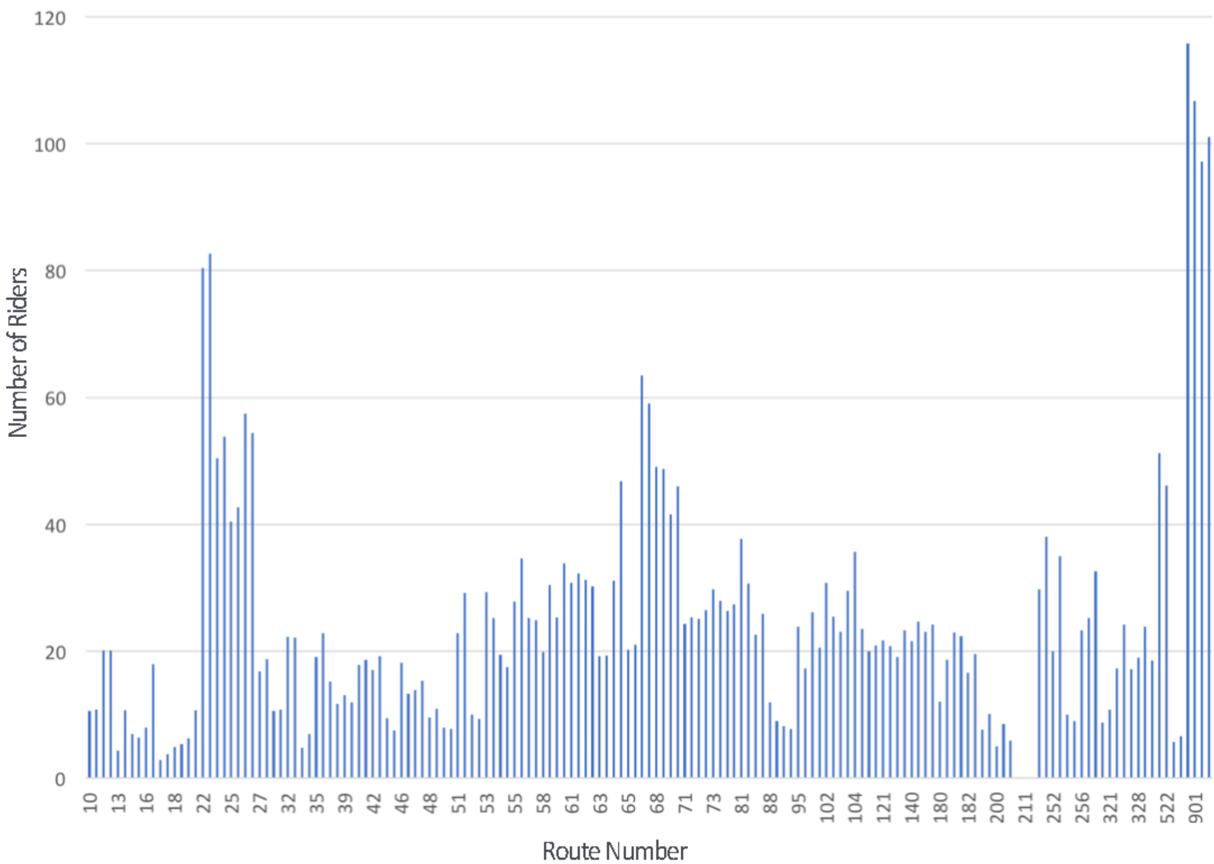
The overall ridership performance of all VTA routes in Santa Clara County is summarized in Table 3.

Table 3. Overall ridership performance of VTA operated transit routes.

Item	**Results**
Maximum ridership per vehicle trip	115.79 (carried by line 901)
Average ridership per vehicle trip	24.32 (with standard deviation of 19.34)
Range	0–115.79

Figure 1 shows the average ridership of all transit routes in Santa Clara County.

Figure 1. Average ridership of transit routes.



As can be seen from Figure 1, the average ridership of each transit routes varies significantly. From manual observation on locations of each route and description of routes by Santa Clara VTA, we found that most of the routes with low ridership are operated to satisfy demand of lower density areas.

With the analysis procedure described in Section 3.3, we identified a set of transit routes with low ridership and high average cost per rider. There were about two dozen such routes. Table 4 presents detailed information on 7 representative routes.

Table 4. Seven representative routes.

Transit Route	Average Ridership (passengers per vehicle trip)	Gross Cost per Rider	Gross Cost Saved per year, if removed	Route Type*	Nearby Alternative Transit Route
46	13.61	$8.00	$229,438	Local	66, 70, 71, 180
52	9.34	$9.18	$346,173	Local	40
900	6.15	$12.63	$1,282,159	Light Rail	Not available
321	9.76	$12.63	$21,088	Limited	60, 104, 902
185	8.92	$63.57	$56,082	Express	32, 68, 104, 522, 902
17	3.33	$22.78	$155,010	Community	14, 68
200	4.97	$26.96	$28,207	Other	104, 902

** See Section 3.5 for an explanation and examples of different route type.*

Figure 2 shows the average cost per rider of the routes with low ridership (below 16.95 passengers per vehicle).

Figure 2. Average gross cost per rider for routes with low ridership (below 16.95 passengers per vehicle).

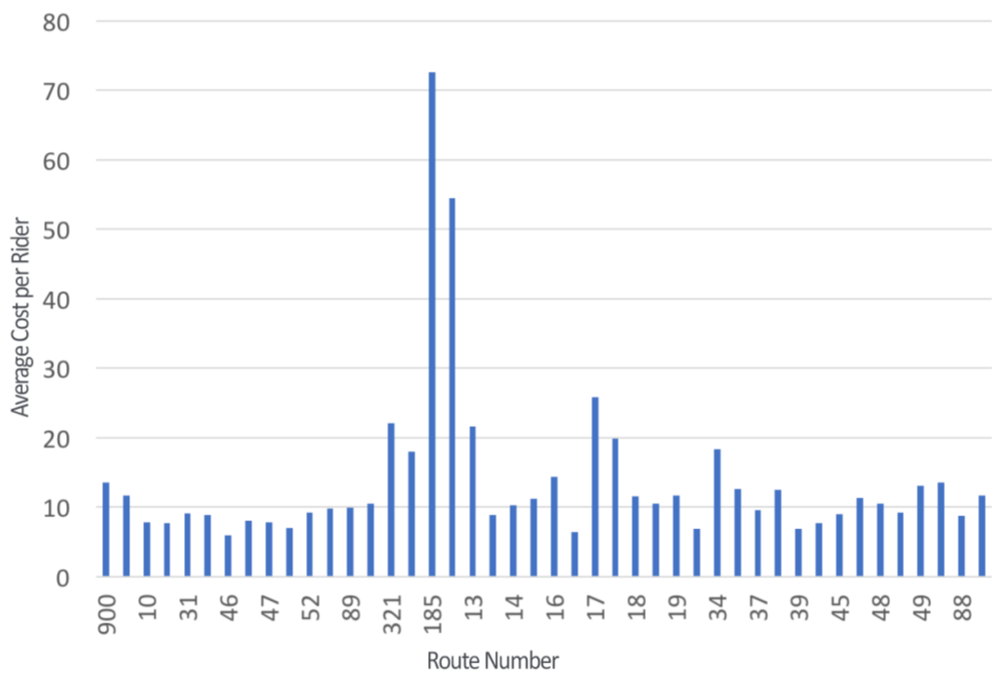


Table 5 summarizes the ridership performance by route types.

Table 5. The ridership performance by route types.

	All	Number (%) of low-ridership routes*	Number (%) of large–average cost routes**	Number (%) of low-ridership & large–average cost routes*number (%)
All routes	72	27 (38%)	56 (78%)	25 (35%)
Core routes	18	0 (0%)	6 (33%)	0 (0%)
Local routes	17	8 (47%)	13 (76%)	6 (35%)
Community routes	16	13 (81%)	16 (100%)	13 (81%)
Express routes	13	3 (23%)	13 (100%)	3 (23%)
Light rail	3	1 (33%)	3 (100%)	1 (33%)
Limited routes	4	1 (25%)	1 (25%)	1 (25%)
Other	1	1 (100%)	1 (100%)	1 (100%)

**Low ridership indicates the average ridership is below 16.95 passengers/vehicle trip*
***Large average cost indicates the average cost per passenger trip is over $7.39*

We next explored the possibility of reallocating saved transit funds to subsidize shared mobility trips of up to 3 miles for target passenger populations. As can be seen from Figure 2, the average cost per rider of most routes can accommodate shared mobility trips of up to 5 miles. If the budget for all of the routes shown above were pooled, more would be available to subsidize each shared mobility ride on average. Therefore, there is great financial potential to support the creation of an integrated multimodal system as we envision.

Figure 3 is a map showing the transit routes mentioned above, with different colors indicating the maximum amount of subsidy for every rider who has been using the routes.

Figure 4 shows what other alternative routes can be accessed within 3 miles of stops of lower ridership routes. As can be seen from the map, within 3 miles, there are many routes available as alternatives.

Figure 3. Routes with low ridership and high rider cost.

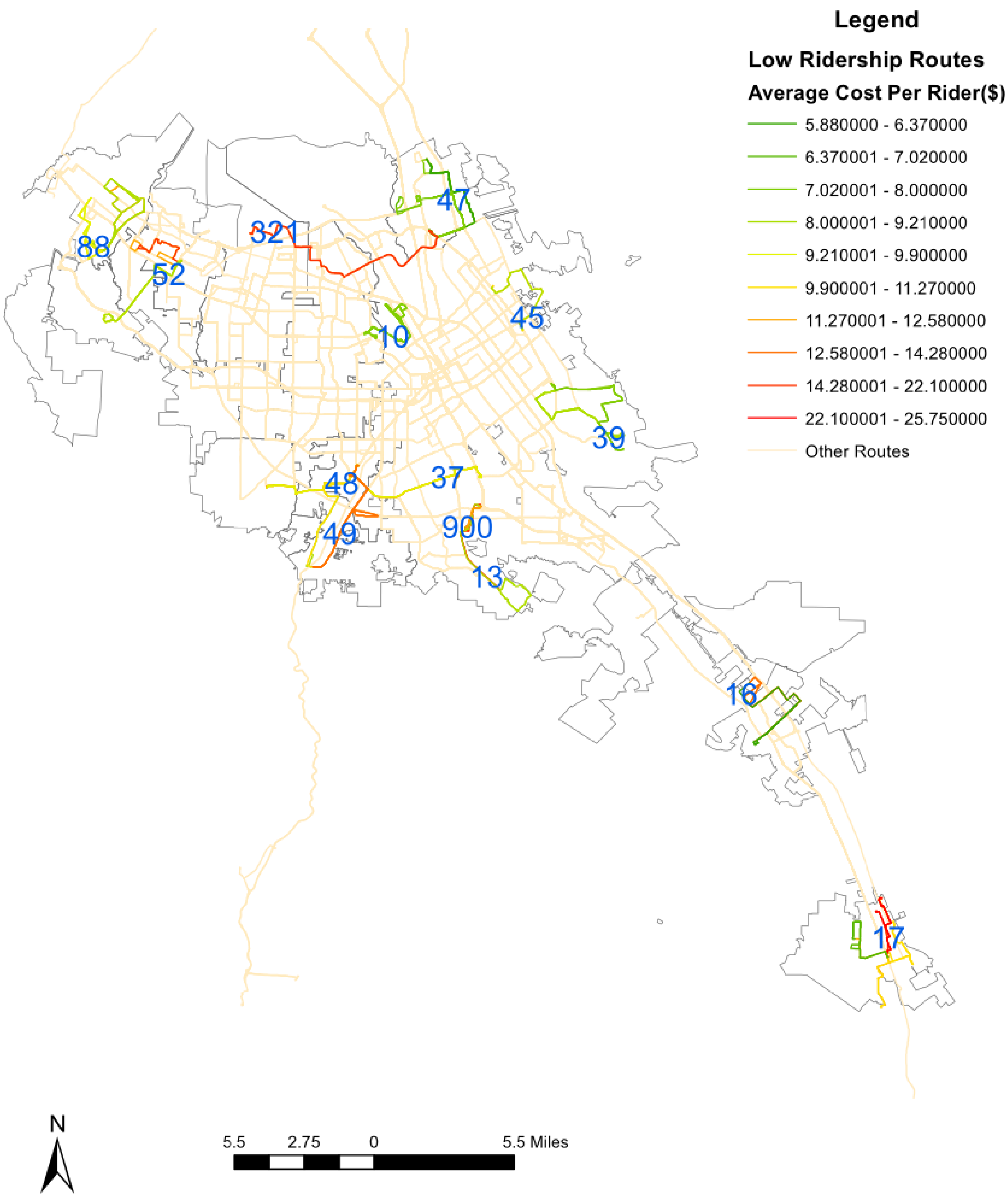
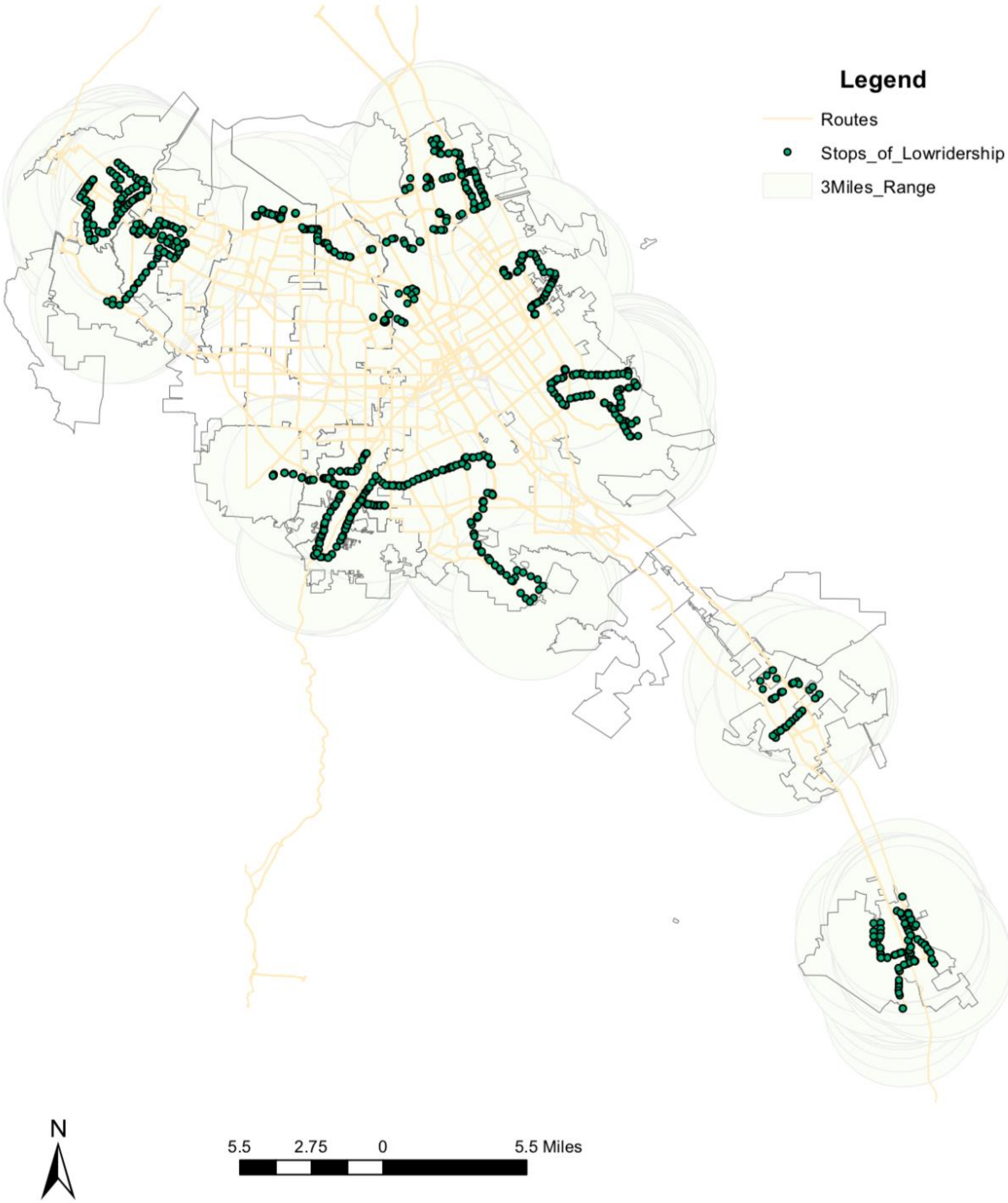


Figure 4. Alternative routes within 3 miles of low-ridership routes.



3.5. Detailed Analysis of Typical Bus Routes

The following analyses are provided here as representative examples of the financial feasibility analysis performed on all the transit lines considered for removal.

3.5.1. Route 46 (Local route)

Santa Clara VTA operates numerous bus lines that operate on most major thoroughfares throughout Santa Clara County. Those lines are called “local routes.”

As a local route, Route 46 has an average ridership not much below the low-ridership threshold (16.95 passengers per vehicle) and an average rider cost ($8.00) not much above the large cost threshold. However, most of coverage of Route 46 can be covered by Routes 66, 70, 71, and 180. In addition, the entire length of Route 46 is about 6.5 miles, which translates into a ride-sourcing cost of about $9.80. Based on the average cost of $8.0 per rider trip, combining ride-sharing with Routes 66, 70, 71, and 180 could satisfy the current demand on Route 46.

The majority of local routes face a problem of high cost, but considering their ridership situation, most of them are actually operating well in terms of a trade-off between environment sustainability and cost efficiency.

3.5.2. Route 321 (Limited route)

This type of route basically operates on weekdays only, mostly during peak hours. These routes operate via expressways to provide semi-express service to business parks in Sunnyvale and Milpitas.

The purpose of Limited routes is justifiable, but the ridership and cost of Route 321 do not match its purpose. Route 321 is the only route among all Limited routes that suffers low ridership and large cost. Based on the nature of the route, and the fact that coverage of Routes 60, 104, and 902 overlap most of its coverage, it would be financially feasible to replace Route 321 with a combination of ride-sourcing services and other transit routes.

3.5.3. Route 900 (Light rail)

Light rail routes are intercity routes operated in conjunction with other agencies.

Due to the short length of Route 900, which is about 1.2 miles, we cannot find other suitable alternative routes for it. Considering the average cost per rider is $12.63, it can be well replaced by subsidized ride-sourcing option.

Route 900 is the only one among all light rail routes that suffers lower ridership and poor cost efficiency. Though the other two light rail routes may have cost efficiency issues, their riderships are high, making them suitable for continuation.

3.5.4. Route 185 (Express route)

Express routes mostly operate during weekday peak hours only. These routes operate in two patterns: AM commute and PM commute. The AM commute operates towards business parks, Downtown San Jose, or the Fremont Bay Area Rapid Transit (BART) stop; the PM commute operates from these locations.

Most express routes are operating well in terms of ridership, though their cost efficiency could be improved. Route 185 and two other express routes are suffering from low ridership and large costs. For each of these three routes, there are a couple of other transit routes that can work as alternatives if connected with ride-sourcing services. Due to their large average cost ($63.57 per rider for Route 185), it is financially feasible to replace them with integrated services.

3.5.5. Route 17 (Community route)

Community routes are those operated by VTA mainly to serve lower-density communities, in which regular transit services do not justify such operations, because of area geography or low ridership.

As a community route, Route 17 is relatively short. Considering the high average cost per rider, which is $22.78, and the short range of the route, it could be replaced with subsidized private mobility services. On the other hand, Routes 14 and 68 could satisfy most of the demand covered by Route 17. The analysis and feasibility of removal of most of the other community routes are same as Route 17.

3.5.6. Route 200 (Light rail shuttles)

This type of shuttle mainly operates to and from light rail stations around San Jose. These services use shuttles instead of regular buses, thus the fuel economy is better, about 8 vehicle miles per gallon. In terms of environmental concerns, the average ridership of Route 200 makes to private cars. The average cost per rider trip is $26.96, which is much more expensive than most ride-sourcing services, like UBER. The service range of Route 200 is about 9.8 miles in total, which would cost an UBER rider about $13.95. Thus, replacing Route 200 with ride-sourcing would be financially feasible and preferable.

3.5.7. Core routes

Core routes belong to the local route category, except that they cover key transfer points, including Downtown San Jose, several Caltrain stations between Palo Alto and Gilroy, and most light rail stations. Some of them also provide connecting services to other transit agencies, including AC Transit, Dumbarton Express, Monterey-Salinas Transit, and SamTrans. Most core routes are cost efficient.

3.6. Relevance to Sustainable Transportation

Ideally, transit systems can significantly reduce GHG emissions. If a bus is fully loaded, with a fuel economy of 2.33 vehicle miles per gallon and capacity of 50, the equivalent fuel economy is about 117 passenger miles per gallon, which is much higher than the average fuel economy of private cars, 25 mpg, with only one passenger in a vehicle (Lowe, Aytekin and Gereffi, 2009; Foxall, 2016). However, in the VTA system, about 1/3 of transit vehicles are running with their average ridership less than 16.95. This translates to 39.49 passenger miles per gallon. On the other hand, privately owned vehicle trips carry an average of 1.58 passengers (Lowe, Aytekin and Gereffi, 2009), translating to 39.5 passenger miles per gallon, which is expected to be even higher with an increase in pooling by ride-sourcing companies. Therefore, in the case of Santa Clara county, replacing about 1/3 of their transit routes with integrated ride-sharing would not only be economically advisable, but also environmentally favorable if ride-sharing increases.

3.7. Summary

As demonstrated by the case study results above, building an integrated multimodal public transportation system in Santa Clara County by reallocating existing transit resources is financially feasible and environmentally favorable.

4. Feasibility Analysis Regarding Other Concerns

Although the financial feasibility and sustainability benefits are promising, there are other barriers—including legal, political, and social concerns—to building such an integrated multimodal system. In the following discussion, we analyze the feasibility of overcoming those obstacles based on an in-depth review of relevant studies.

4.1. Legal Concerns

Ride-sourcing companies, such as UBER, hire drivers without offering them formal employment. This kind of business model makes drivers independent contractors who can be provided with incentives but cannot be subject to employment conditions. This raises several difficulties for ride-sourcing companies obtaining contracts supported by federal funds to provide paratransit services (Murphy, 2016; Cunningham, 2016).

According to (Nelson/Nygaard Consulting Associates, et al, 2007), for any party contracted by public transit agencies to provide mobility services, drug and alcohol tests are required. This requirement would be difficult to fulfill with ride-sourcing services because of the independent nature of their drivers.

Accessibility with regard to riders with disabilities is also a concern, given that ride-sourcing companies do not have fleet-level accessibility accommodations. According to the relevant Code of Federal Regulations (49 CFR 37.77):

> …a public entity operating a demand responsive system for the general public making a solicitation after August 25, 1990, to purchase or lease a new bus or other new vehicle for use on the system, shall ensure that the vehicle is readily accessible to and usable by individuals with disabilities, including individuals who use wheelchairs.

Replacing transit routes with ride-sharing would likely require that the ride-sharing vehicles comply with this regulation. Examples of transit and paratransit VTA vehicles that comply with this regulation are shown in Figure 5. In addition to the challenge of ride-sharing services using accessible vehicles, there are difficulties in educating and occupationally training drivers to help load/unload passengers with impaired mobility and secure their wheelchairs properly (Murphy, 2016).

Figure 5. General ADA accommodations provided by VTA vehicles.

All the legal issues mentioned above are under litigation in several jurisdictions in the U.S. Since the social and environmental benefits of integrating ride-sourcing with transit are considerable, as are the potential profits for ride-sourcing companies, the ride-sourcing companies, the government (including the court and public transit entities) and the general public are likely to make an effort to reach an agreement eventually. As technologies advance at their own pace, we envision that the transportation world is going to go through a major technological transformation. Any party who is not making a deliverable effort to keep up with such changes is likely to lose their market share. Since there are mutual benefits gained by all parties, we are optimistic that a better integrated system will form given better coordination and fair revenue sharing mechanisms among parties.

4.2. Political Concerns

As mentioned in Section 3.2, we assumed availability of ride-sourcing services throughout the area. However, this is certainly not the case in reality. Since ride-sourcing drivers are not employees, they provide services based on their own interest and, potentially, on available incentives, instead of requirements of employment. If the incentives provided by ride-sourcing companies are not attractive enough, low density communities may have a lack of sufficient ride-sourcing supply to meet the level of service desired. Some existing practices in major cities in the U.S. show promise to overcome this issue (Salzberg, 2017). By providing riders incentives to use ride-sourcing services to connect from their origin/destination to transit stations, ride-sourcing companies can increase rider demand in low density areas, which would in turn provide drivers with more incentives to serve those areas. Cooperation between transit agencies and ride-sourcing companies, such as a current pilot program in Seattle (Clugston, 2017), demonstrates a way that ride-sourcing agencies can maintain or improve level service in an integrated system.

In sum, even though the level of service required may be challenging, there is potential, even with existing practices, to integrate public transit and private mobility services.

4.3. Equity Concerns

According to (Neff and Pham, 2007), lower income earners are more likely than higher income earners to use public transit. The impacts of integrating ride-sourcing with transit on the level of service to different demographic groups may vary significantly. This raises equity concerns.

One issue affecting equity is raised the availability of communication technology. The development of mobile devices has significantly improved rider experience among all kinds of modes and trip purposes, and at the same time has significantly increased the use of transit modes (Ferris, Watkinsand Borning, 2011; Windmiller, Hennessy and Watkins, 2014; Gooze, Watkins and Borning, 2013). In addition, technological innovations have also opened opportunities for building an integrated multimodal public transportation system. However, to create such a system to meet equity requirements, designers must consider the methods that various groups of residents use to access information about public transit and other mobility options.

According to Windmiller et al. (Windmiller, Hennessy and Watkins, 2014), certain demographic groups, especially the elderly and low-income earners, tend to not own smartphones, and therefore they are not able to access transit information via mobile devices. At the same time, smartphone ownership has been increasing in these groups and other electronic devices have been developing for better accessibility.

We expect that transit agencies and ride-sourcing companies, with a foundation in strong public-private partnerships, will be able to accommodate certain demographic groups. They may achieve this through new systems for requesting, tracking, and dispatching vehicles and by conducting outreach activities.

5. Conclusion, Discussion, and Future Research

Based on our analysis of Santa Clara county and a review of the relevant literature, we conclude that an integrated multimodal public transportation system would be financially feasible and environmentally sustainable. Such an integrated system would likely improve rider experiences and the level of service, while increasing flexibility, availability, and reliability. However, obstacles remain, such as those related to legal, political, and equity concerns. Nonetheless, our review of the research literature and successful practices in some cities suggest that these barriers may be overcome through coordination and cooperation among entities in the system.

Several questions beyond the scope of this study remain. For example: What subsidy strategy could increase benefits to transit riders and/or improve the performance of the system? A more in-depth investigation on this question would require complex modeling that could capture the interactions among multiple entities, e.g., a transit agency, private ride-sourcing services, and riders. Another question is whether an improved, integrated system would remain financially feasible given that it would lead to greater demand and, therefore, a need for larger subsidies. Further study of such dynamic demand may lead to research on optimal operating strategies for transit agencies and ride-sourcing companies. Multi-agent simulation of a multimodal transportation system could provide insight into its potential benefits and costs to society.

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Data Management

Products of Research

The data that were collected and used for the study are listed below.

Data	Availability
Adopted Budget Fiscal Year 2016-2017	Provided by Santa Clara VTA staff
Ridership Data	Available on the Santa Clara VTA open data portal website: http://data.vta.org/datasets/ridership
Transit Routes Map	Available on the Santa Clara VTA open data portal website: http://data.vta.org/datasets/76e215d0bca14dcca1406427858455fe_14/data

Data Format and Content

The files for budget (Adopted Budget Fiscal Year 2016-2017) and ridership data are in excel format. The files for transit route map are in arcGIS system format. The budget data provides information on transit operating cost for various types of buses. The ridership data provides rider counts on each segment (between stops) of a transit route at a specific time. Upon aggregation, one can retrieve information about the average ridership information for each transit route. The transit route map depicts all routes operated by VTA and their stops. This allowed us to identify potential communities (residential areas) that might be impacted by removal or change of an existing transit route.

Data Access and Sharing

The ridership data and the transit map are all available at the website of Santa Clara VTA for public access. The budget data can be retrieved from VTA upon request for research usage.

Reuse and Redistribution

The raw data published on the VTA website are available for access by the general public. The budget data and the analysis results produced from this study can be made available upon request for research and education purposes only.