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Article

A Quantitative and Qualitative Analysis on the Improvement of Public Transportation in Santa Clara County

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Abstract: This research investigates the possibilities of improving Santa Clara County's public transit system using various modalities of public transit service. In the recent past, many individual projects have been pursued, funded, and constructed on the county's transit network, yet as a whole failed to attract significant ridership. The county's fundamental issue of car-dependency and congestion remains and is worsening. Previous research has established plans for specific routes, corridors, or modalities of transit, but a comprehensive analysis and proposal by a third party outside of the transit operator for future public transportation service and development in the county has not yet been laid out. We review contemporary and historical literature on the topic, public transportation guides and best practices, and the unique situation in Santa Clara County which has contributed to its current congestion and overall transportation challenges. We compare three feasible modalities for future construction and expansion and the ways in which this could impact ridership. From the results of our data and general concepts in the literature, we propose a solution combining a greatly expanded bus rapid transit system and improvements to current bus and light rail networks, particularly in time-competiveness, route linearity, and zoning. Through these improvements, we aim to produce a proposal where transit service that is more time-efficient and ultimately better fits the diverse needs of the Santa Clara County community. We hope that we may outline a possible method to significantly increase ridership while decreasing environmental impact, congestion, and maintaining cost-effectiveness, both in the future construction and operation of transit. We recommend further study with regards to BRT construction in addition to a continuation and expansion of projects to improve the efficiency and potential ridership of existing bus and light rail routes.

Keywords: public transportation; mobility; sustainability; urban development; social science; engineering

1. Introduction

Santa Clara County

Santa Clara County needs great transportation. It is the most populous county in the San Francisco Bay Area [1] with 1.9 million residents, and is a core part of a major metropolitan area where many large firms' offices are located, especially in the technology industry. With the population and wealth of such a large, diverse, and well-connected area, convenient and time-effective transportation for a wide variety of trips and residents should be a priority—yet hundreds of thousands of commuters, 75% of the employed population [2] sit in traffic on the county's roadways every day.

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Public transit and alternate mobility methods are an unpopular option: transit's mode share is just 7%, and bicycling is only 2%, both far less than working at home, at over 15% [2]. Heavy congestion, measuring in the thousands of vehicle-delay hours per road segment, and lengthy rush hours, with both the morning and evening peak lasting up to 4 hours, are consistently present according to pre-pandemic data [3]. Even after the pandemic, despite a noticeable lessening of congestion on most routes, several of the same freeway segments as pre-pandemic [4] still suffer from the most severe traffic. To combat this problem, the City of San Jose aims to increase the modality of public transit for commuters from to 35% by 2050 [5], a highly ambitious five-fold increase in ridership percentage. Additionally, for those who cannot drive, whether for health, financial, or many other reasons, mobility is noticeably constrained by the current transit situation [6]. In order to relieve congestion, reduce environmental impact, improve mobility access, and ensure a promising future for the county's communities, public transportation service and utilization must be improved.

Little recent literature has discussed a dilemma which the county faces: which modalities should its public transit operator concentrate on expanding and optimizing to increase its positive impact, given that the present situation is unsustainable? In the recent past, the Santa Clara Valley Transportation Authority or henceforth VTA, has been expanding and improving portions of its standard bus, bus rapid transit (BRT), and light rail (LRT) networks [7–9]. In order to reduce inefficiency and increase ridership, we aim to provide some commentary and suggestions regarding the implementation of a multimodal solution to this problem.

It is understood that VTA, as with any transit agency, has many operating constraints. Therefore, the solutions that we propose should comply with all regulations set in place by federal, state, and regional oversight agencies as well as public transportation best practice. Additionally, the proposal should be socially, fiscally, and environmentally feasible to construct during the next decade and responsible to operate and expand after its initial launch.

This paper aims to understand the unique situation which Santa Clara County and San Jose is in with regards to transportation development and integration. We explore the unusual locations of past commercial and residential developments and how this relates to low transit ridership in the present. To rectify this, we propose several possible solutions and consider the positives and negatives of each idea; we compare these solutions and reference results from other metropolitan areas in order to provide a feasible final plan to improve transit ridership which aims to maximize the positive properties of each proposed solution while mitigating drawbacks associated with them.

2. Background Information

This section discusses the problems currently associated with the county's transportation system and the developments that led to the current challenges with ridership, farebox recovery, and missed targets. We explore the VTA's current service offerings, their effectiveness, and the ways in which the agency also connects outside of the county. Finally, we discuss the projects that VTA has been involved in, their efficacy, both historically and in the present, and the agency's management behind their decisions.

2.1. Transportation Development and Implementation

The county's present infrastructure was developed during the "highway era" of the 1950s-70s [10], and therefore, almost every transportation system in the county is built to maximize driving speed. When the county's freeways were built, it was believed [10] that automobiles could provide the mobility needed for the future. This would turn out to not be—the problems associated with dependence on automobile traffic, from congestion to air pollution and the amount of land dedicated to roads, would prove to be stumbling blocks for the sustainable development of the area [10]. The county, as previously mentioned, experiences significant congestion above the Bay Area average [11].

Due to the spread-out nature of industrial, commercial, and residential zones [12,13], providing service for commuting and daily necessities, which represent the vast majority of transit ridership [14] for most transit operators, is difficult to achieve by running lines into a downtown hub, as is common in significant "transit cities" such as San Francisco and Boston [15,16]. In Downtown San Jose, there are only about 36,000 jobs—a half to an eighth of the amount of employment positions in the downtowns of other cities of comparable [13]. Housing is often located in low- to medium-density suburban neighborhoods [1, 13] while employment is decentralized in corporate campuses and office parks, resulting in long commute times, especially on transit and in certain areas [17]. Finally, the county also imports a significant portion of its workforce [18], principally from the Alameda and San Mateo counties. The success of public transportation in the city hinges on effective network planning and unique solutions to challenges few other cities face.

Nevertheless, there is hope for revitalizing downtown San Jose and hence also the transit utilization that comes with it. Transit-oriented developments of both residential and commercial nature are being built along corridors centered on downtown [19]. When the density of employment facilities, such as the facilities being developed in central San Jose, increases in the area immediately around a major transit stop, transit ridership will correspondingly increase [13]. The agency, with some network alterations, is poised to capture this demand given the heavy congestion around the entire Bay and their significant service in the area [1,20].

2.2. Introduction to Ptublic Transit

The SCVTA, or simply VTA, is the government-operated public transportation operator for Santa Clara County; beyond this, the agency also performs road upkeep and development [21]. The agency's operating costs primarily come through a sales tax measure as well as state and local grants, while operating revenue from fares, advertising, and road pricing make up a small minority [22].

In its public transportation division, the agency operates two types of vehicles: light rail and motor bus. VTA operates a variety of services consisting of 3 Light Rail Transit (LRT) lines, 5 rapid bus routes, 20 frequent bus routes, and 21 local bus routes, along with others not detailed by this paper. These services are defined by different operational characteristics, as outlined below [23,24]:

- Light Rail Routes: Mostly standard light rail transit, with a mix of street running and grade-separated operation. 15 min peak headways.
- Rapid Bus Routes: Classified as a “BRT-lite” system (BRT in the US), these routes operate limited-stop service with 15-min peak headways. Their alignments typically run parallel to other high-ridership frequent bus routes.
- Frequent Bus Routes: Operating as standard bus services, these have short stop spacing and peak headways of 15 min.
- Local Bus Routes: Sharing the same closely spaced stops as frequent bus routes, these routes have longer peak headways of about 30 min.

Other routes include highway express buses [24], ACE commuter rail shuttles [23], and demand-response Paratransit [24]. Due to the relatively low ridership these routes have compared to core VTA routes [25], the research here will not discuss the implementation of these in great detail.

2.3. Longer-Distance Connections

In the Bay Area as a whole, there are 27 transit operators, none of which have greater than a 50% share of all transit ridership, making the Bay Area one of the few major metropolitan areas in the United States to lack a single principal transit operator which captures more than half of rides [26]. Necessarily, these operators, having all sorts of different jurisdictions they operate under from cities to counties and lacking a pronounced leader agency, have different standards for what different types of routes and services are called. For example, on VTA, ‘express’ indicates a highway bus that makes point-to-point trips with a few stops at each end or occasionally in the middle [27]. However, on Muni, San Francisco's primary transit operator, express operation indicates a line that does not necessarily deviate from the normal routing or use higher-speed roadways [7,28] but skips large numbers of stops stops to provide faster service to the most heavily-utilized segments or stations. This type of conflicting branding confuses potential customers [26], possibly already overwhelmed by the number of operators and variety of services. Even worse, the relative lack of coordination causes gaps in service or duplicate services in some areas on parallel routes [26], and fares and their structures are unstandardized throughout—this matter is especially of importance to low-income individuals, who are currently discouraged on cost grounds to travel with multiple operators, despite the possibility of a faster and more convenient trip [26].

Complementing VTA in Santa Clara County, particularly for travel outside of the county or through larger swathes of it, are a pair of rail operators, CalTrain (Peninsula Joint Powers Authority/JPBX) and BART [29,30]. In addition, VTA also has connections with AC Transit of Alameda County and with SamTrans of San Mateo County at a few major transfer stations. Although connections are often inconvenient, especially when untimed, they are still a necessary part of public transportation in the Bay Area and around the world, especially when making longer-distance trips across local or regional borders such as city or county limits; 50% of all transit trips in the U.S. involve such a transfer [14].

Even with the number of operators and the difficulty of aligning transfers, service types, and fares, VTA still has the potential to provide effective local service trips within the county while providing convenient and seamless connection opportunities for longer-distance travelers, as is done in London and Seattle [26].

2.4. Present State of the System

A transit system is a multifaceted network that cannot be judged by a single metric. It may be highly efficient at moving people but suffer from high operating costs and accident rates, or be safe and comfortable but low ridership due to poor land use and route planning. Hence, we consider a variety of factors that are important to the customer, the transit operator, and the taxpayer alike. We begin from the most consumer-facing and subjective, variable metrics and move our way towards the agency-wide issues such as the bottom line and the feasibility of constructing new extensions.

One's transit experience starts even before stepping on the vehicle. From the walk to the station and wait there, riders consider the time and conditions which they subject themselves to on their way to the stop. VTA generally has stations located along many arterial roads, and many stations have bus shelters and adequate signage. Headways are mixed, but most routes usually run every 10 to 30 min [23] at peak times on weekdays and longer outside of them [24], with shorter waits possible on a few corridors with duplicate routings on specific sections [22]. Delays, while improving, are still somewhat frequent, affecting over one in five buses and about one in ten light rail trips [31]. VTA's reliability and headways are still in need of improvement, as studies have demonstrated that riders value waiting time more than onboard time, especially when station facilities are relatively lacking [32] as is the case at some bus stops. Lastly, VTA's network coverage of some areas is limited.

That is little comfort for subsets of VTA's ridership demographic. Like most US transit agencies, VTA carries significant populations of disadvantaged residents, such as low-income and car-deficit families and the elderly; despite the overall wealth of the area, there remain a sizable portion who struggle to get by, especially with the high prices of doing business and living in the Bay Area. For low-income residents, many households may own fewer vehicles than licensed drivers [33]. These individuals often *cannot* drive for necessary trips [33]; to go places further than possible with walking or bicycling, these individuals are forced to utilize transit to at least some extent. About 7.5% of the county's population is under the poverty line—over 135,000 people [34], in addition to the 65+ population of approximately 290, 000 [34]. Nevertheless, a solid majority of senior citizens in San Jose are still dependent on their personal vehicles [6], demonstrating the need for a stronger public transit network; low-income residents, who also must commute in addition to travel for personal reasons, are likely even more strained if the household has a deficit of vehicles relative to drivers.

A criticism of VTA has been land use efficiency [12], as many VTA routes operate through low-rise housing, office parks, and strip malls. Many suburban lines are not time-competitive with automobile traffic, often operating relatively indirect routes. Some lines have point-to-point average speeds comparable to bicycling [7]. BRT and LRT are also ineffective; only a few miles of BRT infrastructure exists in the county [8], all of it in San Jose, and while these sections are relatively heavily ridden [35], the majority of the "Rapid" routes, even on the most congested sections of road, lack dedicated right-of-way and therefore are still impeded by traffic. TSP does mitigate this problem to an extent, but more steps need to be taken.

In addition to the arguments mentioned above about VTA's ineffectiveness at transporting passengers, the agency also operates a costly system for the taxpayer. In FY2024, the agency's operating cost was about $470 million, with labor costs representing approximately 70% of that figure, while total revenue from fares—

excluding advertising and other means of profit but including paratransit fares—was only $25 million [22], representing a farebox recovery ratio of approximately 5.5%. Total revenue was only about $36 million in this same year, representing a loss of approximately $448 million [22]. In 2019, when VTA's farebox recovery ratio was approximately 9%, nearly double what it is today, the agency's practices were already criticized by a Santa Clara Grand Jury for financial mismanagement and the worst financial statistics among ten peer agencies of similar size and operational area [36]. VTA has not identified a holistic plan to significantly increase its overall economic efficiency, and therefore, the post-pandemic fiscal deficits may cause services on many lines to be lessened or completely cut, as BART is threatening to do with its own funding crisis [29]. This would be a bleak future for the agency as well as transportation as a whole in Santa Clara County.

2.5. The State of VTA's Future Projects and Their Management

A competent transit agency requires a well-run and well-informed board, preferably with experienced transit professionals. After all, this board controls the agency's budget—an enormous purse of public funding, contributing billions to major projects such as the BART extension [37] and Eastridge light rail extension [38] in addition to project selection and realizing efficient service for an area with millions of people [39]. Unfortunately, there have been many criticisms of the board's governing structure and the results of its decisions, from overarching project management to station placements [12, 36, 37, 39]. These criticisms come from auditors, juries, and riders, and while VTA has taken some feedback into account in recent years [36], they still reject some important recommendations to improve transparency and lengthen terms, citing stability concerns [36, 39]. Without a reconsideration of decision-making processes and methods along with a reorganization of the board, VTA may continue to struggle with low ridership and inefficient use of its public funding while not producing the level of service that it has the potential to provide.

3. Possible Solutions

In this section, we discuss the potential ways in which we could go about pursuing our goal of improving transportation in the county. We propose many plans, even outside of improving public transportation, and give reasons why such plans are relatively unviable given the state of the current network. We then turn our attention to three major modes of transit which VTA could pursue: improving their current bus network, building a bus rapid transit (BRT) system, or improving and expanding the light rail (LRT) network. We compare the advantages and disadvantages of each in the particular application of Santa Clara County given the unique characteristics and challenges present.

3.1. Solutions Other Than the Improvement of Transit

In this section, we consider and briefly analyze solutions outside of expanding and improving public transportation. Here we consider many of the possible solutions that could decrease congestion and increase mobility. However, several proposals have undesirable side effects that may outweigh their main goal of improving transportation, and some are simply unfeasible at the present time. Therefore, it is important for us to eliminate such proposed solutions.

In 2020–2021, during the COVID-19 pandemic, many workplaces shifted the majority of their operations to a remote platform. However, through the following years up to the present day, increasing numbers of workplaces required their employees to return to the office, and even those which did not demand a full return required at least a "hybrid" model of at least some days in office [40] Fortunately, vehicle-hours of delay in Q4 2024 at 60 mph in Santa Clara are still nearly 25% lower than in Q4 2019, some of it attributable to this work pattern change, but have increased since Q4 2023 [3, 4]. This demonstrates that those who have switched to partial remote employment have done so since the pandemic's beginning and further commute congestion relief from remote employment is unlikely. If anything, congestion will only slightly increase year-on-year if past trends continue to hold [4].

Living near one's job is another method of reducing vehicle travel-miles and congestion, but in many major employment hotspots in Santa Clara County, particularly on the Peninsula, it is currently infeasible to build an adequate amount of housing given the large number of positions and land use patterns [41]. Due to the resulting affordability difficulties in these areas [42], the notion of living closer to work will continue to be financially difficult in the near future for many employees. Even with the long commutes as they are, over 60% of renters spent over 30% of their income on housing in 2022 [43], representing a significant cost-burden. If the adequate number of units for the number of employment positions were constructed in areas requiring them, ignoring current zoning and other restrictions, the current road infrastructure of those areas may be overwhelmed by the number of commuters, even if a lesser percentage drove alone, as we have anecdotally seen in a few areas of Palo Alto, Mountain View, and other Peninsula cities with large numbers of employment facilities.

Another related proposal is to encourage employees to walk, bike, or carpool during commute hours in order to reduce freeway and arterial congestion, as this removes cars from the roadway. However, due to the aforementioned long distances and the safety challenges of bicycling along high-speed, high capacity roads with many intersections and unprotected bike lanes, only 6.7% of residents utilize bikes to reach a destination at least once a week [44]. Carpooling is already encouraged in the county, with free or discounted use of HOV/express/carpool lanes when multiple people are in the car—exact regulations vary by freeway [45]. Despite these efforts to incentivize the practice, distances between multiple coworkers' housing may be long due to low density: 61% of residents live in single-family homes of some type [43], which makes picking up coworkers potentially inconvenient and time-consuming. Therefore, some other solution in addition to or instead of housing changes and alternative commute methods is needed.

One could even propose to keep VTA in its current state or remove transit entirely, as the agency spends over $400 million per year [31] to serve relatively few people. Many citizens rarely utilize public transportation anyway [33,46]. Nevertheless, previous research demonstrates that even a moderately ineffective public transit agency is far better for congestion, the environment, and as a social service than none at all, and that improving public transit ridership by a small amount compared to the number of total person-miles traveled has an outsized impact on the reduction of freeway and arterial congestion [46].

Public transportation strikes offer a view into a complete transit shutdown, and while the data observed is not fully representative of the long-term effects, as residents would adapt to the new reality and the long-term effects would be less severe, it gives a good glimpse into the hidden necessity of public transit [46]. During the LA Metro Strike in 2003, where the system shut down for several weeks, the car-centric city of Los Angeles had an overall freeway congestion increase, in terms of vehicle-minutes of delay per vehicle-mile traveler, by over 45 per cent, and on all freeways paralleling major transit lines, over 60 per cent, with the most extreme cases of congestion increase exceeding 100 per cent increase in the morning peak hour [46]. While transit has a minimal effect on total vehicle-miles traveled, it has a larger-than-expected effect on total congestion despite this when heterogeneity in roadway conditions during peak hour are considered [46]. A traveler aiming to utilize the most congested corridor at the most congested time for that corridor is most likely to take public transportation. This traveler, if they were to utilize their personal automobile instead, would also have an outsize impact in terms of their contribution to the increase in congestion, as a single vehicle added to an already-congested flow of traffic increases delay much further than a single vehicle added to a roadway where traffic is flowing smoothly. Therefore, even a small number of commuters switching to public transportation during peak-hour roadway conditions can have a large impact on the many drivers, who will now enjoy a freer-flowing roadway [46].

Even though San Jose has different traffic patterns from Los Angeles, it can be assumed [46] that similar negative impacts can be expected from removing transit in Santa Clara County and around the Bay, a large urban area. BART meltdowns in 2025 [47] also demonstrated the importance of transit for congestion alleviation, with significantly heavier traffic when these situations occurred, even if only for a few hours. On the positive side, it is also conversely possible to expect significant improvements in roadway traffic conditions with additional public transit service paralleling the most heavily trafficked stretches of road.

Additionally, we must also consider the social role that public transportation serves to low-income and senior communities thanks to its low cost and lack of barrier to entry. Poor public transit service, especially in areas where these populations are concentrated, has a disproportionate impact on these populations' mobility [33]. Hence, when considering both the interests of the rare transit rider and the average driver as well as the wellbeing of the whole community at large, transit service in Santa Clara County cannot possibly be removed.

In recent times, the deployment of ride-hailing services and autonomous vehicles as taxis, particularly in the Bay Area, has raised some questions about public transit's future [33]. However, transit offers a low price for many solo trips that no current provider can come close to equaling, and may be time-competitive with driving in some areas given a well-designed network. Additionally, these services do not solve the problem of congestion: ride-hailing services travel on the same roads as all other commuters, and therefore also continue to contribute to traffic congestion so long as they are mixed with human drivers. Some areas and routes in the county may lack the necessary infrastructure for self-driving coverage at all. While these services may be a good option for some areas lacking sufficient density for effective transit service and as a last-mile complement to transit service, it cannot replace public transportation because of transit's low cost, energy efficiency, congestion alleviation, and capacity per land area. In addition, self-driving vehicles are similarly affected by traffic as standard vehicles, making trip times just as long as driving during congested hours. Meanwhile, transit on dedicated rights-of-way is unaffected by such traffic. In the end, transit is here to stay—but it is up to those here in the present to find solutions for a better transit system into the future.

3.2. Improving Time-Competitiveness on the Present Network

This solution aims to improve the speed and efficiency of the current route network by altering route alignment, stop spacing, and availability and timing of connections; it does not involve constructing any major new infrastructure beyond new stops and transit signal priority on heavily-used portions of the network.

Such an improvement scheme possesses many advantages. First of all, it is by far the most affordable of the new plans: a VTA plan to roll out over 35 new bus shelters, 57 benches, and 17 bus pads, among other amenities representing a sizable portion of the cost of at least 15 high-quality bus stops cost $6.7 million [20]. Under VTA's current stop spacing guidelines, this number of stops will cover 3–5 miles of standard bus right-of-way while representing only a fraction of the per-*mile* costs of BRT and LRT—about $25 million and $200 million respectively. For more information on general cost estimates, see section 3.3. Additionally, the cost of maintenance of the public roads which buses operate over is also untaken by the public as a whole through taxes rather than by the agency alone. In any case, the construction and maintenance costs of a bus system are much lower than other modes requiring dedicated guideway infrastructure.

This implementation also provides benefits to the most routes and in the least time if considered system-wide. New bus stops and similar bus infrastructure on a given route take only 4–5 years from initial planning to completion [20], which is much faster than other modes [8, 9]. Accordingly, more parts of the network can receive updated routes, stops, and minor enhancements such as TSP and bus pads [20, 48] where deemed necessary which would contribute to greater ridership, convenience, and time-competitiveness. Routings and the amenities on offer at stops could also be adjusted to better serve the needs of more elderly and low-income neighborhoods in sections where such bus lines already exist.

This plan is perhaps also the most effective of our three proposals for potential integration with other systems of all types due to the possibility for subtle but important changes on a widespread portion of the network. Timed transfers with faster modes of transit such as regional and commuter rail—with the capability to adjust for future stops—have a major positive time impact on connecting trips, and positive progress on this front is continuing to be made [49]. Additionally, VTA may choose to improve its network with express services similar to the existing DB and express buses; corporate-sponsored freeway service has the possibility of time-competitiveness by way of utilizing HOV lanes, but VTA has not experienced success with express service [50]. This is perhaps due to fierce competition from private operators such as WeDriveU and Hallcon [51,52] who offer more comfortable motorcoaches rather than transit buses. Bikeshare through Bay Wheels may also be installed near downtown bus stations for convenient urban mobility [53], especially given the somewhat expansive network of bike lanes in the city [54]

However, low spending to cover a wide area usually comes with its major downsides: with this plan, the situation is no different. A major issue of the current VTA system is poor time-competitiveness with automobile traffic, despite heavy congestion [1]. Most lines, especially ones outside of the "Rapid" scheme and light rail, are slow due to long routings [7] and many stops, with scheduled trip times on certain routes nearly doubling rush-hour driving times in more suburban areas with freeways, despite congestion. This plan would do relatively little to address this core issue; even if plans to increase speed on bus routes were taken, such plans would come with other difficult trade-offs, as we will explore next.

When average bus service speeds need to be increased without dedicated right of way, there are relatively few options to increase time-competitiveness: operate on a higher-speed road, with fewer stops, or a combination of both. VTA's installation of transit signal priority through its TRIPS program [55] has a commendable impact, but given the gaps of over 100% between scheduled bus speeds and driving average speeds on some routes, the 7.5–15% improvement we can expect with TSP outside of a BRT package is unlikely to significantly improve ridership [56] although local results may vary. To save time, larger roads or removing stops may also be used. However, faster, wider roads generally have fewer safe intersections where passengers can conveniently access major destinations on both sides of the road. Removing stops, while effective on sparse sections of local roads for faster service, will also increase last-mile distances for some riders—if their primary use stop is removed, they are forced to utilize the closest remaining stop, which will always be a longer distance away from their destination than the current one.

Many neighborhoods in San Jose and its surrounding regions are converting less-dense single family homes into multifamily dwellings in order to "up-zone" areas, therefore partially rectifying the region's severe housing crisis [13,57] and hundreds of thousands of employment opportunities are in the valley to stay. With these large numbers of people needing to travel and freeways and arterials already above their capacity in many stretches [4]. VTA needs the capability to expand into a larger, faster transit network with the mode it chooses to concentrate on rather than addressing the problem as it comes—with the rate that transit construction is performed, it will be too late by the time the new system is complete. An improved bus system like the one proposed here could easily handle the passenger loads today, but with increasing congestion, more and more passengers could possibly turn to a well-built transit system. Capacity on core segments without a light rail link in the future may be lacking, resulting in crowding and general system degradation. While VTA can increase capacity and frequency by adding headways on many routes at once, this would significantly increase the amount of vehicles, operators, and maintenance personnel required, both of which are important contributors to VTA's labor cost. In turn, labor represents about 70% of the agency's transit operating cost [22], making shorter headways on multiple routes a costly preposition to operate. Alternatively, fewer commuters may turn to transit because of the bus system's inevitable longer journey times. Neither option are positive outcomes for VTA or the residents of the county.

3.3. Bus Rapid Transit

This solution aims to construct a small but expandable bus rapid transit (BRT) network across the congested areas of 2–3 major arterial corridors throughout the county. The specified system would ideally be closer in nature to a "full BRT" system, as specified by Vincent [58] rather than a Rapid bus or "BRT-lite" system, which is more akin to a hybrid between full BRT and a standard bus. To an extent, Rapid bus service already exists in the county with the Rapid 523, Rapid 522, Rapid 500, and Rapid 568. The Rapid routes are an excellent foundation from which to build full BRT. This plan involves the construction of enhanced level boarding stations, transit/carpool lanes in most areas, off-board fare collection similar to the light rail, and 7.5 to 10-min peak headways. These improvements exist on top of current Rapid bus service guidelines such as longer stop spacing of 1–2 stops per mile [24] and transit signal priority, which may be upgraded to a cloud-based system to reduce cost and increase implementation practicability on a wider portion of the network [59]. It is worth noting that VTA attempted a BRT in the past, but the project did not go through to completion, with only the Santa Clara-Alum Rock BRT coming close to a BRT standard [60].

In terms of balancing economics and potential for speed, ridership, and capacity, BRT seems very attractive given the current conditions in Santa Clara County—limited budget due to low system ridership, residential and commercial areas along a few major arterial corridors, nearly a million residents in the largest city and a large, widespread urban area with many inner suburbs but not enough density for rail [61]. If BRT is built and operated to a high standard, it can achieve sufficient returns on investment: for example, Cleveland's 6.6-mile, $200 million Euclid Avenue BRT, branded as the RTA HealthLine, inaugurated in 2009 and carries over one million riders per year along Cleveland's "main street" [62]. Alameda county's $232 million [63], 9.5-mile Tempo service carries over 4 million riders per year [64], almost as many as VTA's *entire* light rail system. Even the rapid, "BRT-lite" bus lines such as the 10-mile, approximately $56 million [57,65] Prospect MAX in Kansas City, inaugurated in 2019, consistently handles over 100,000 riders per month [66] and therefore at least 1 million per year despite an estimated operating cost of only $6 million per annum [57]. Even when MAX was originally introduced as only a 6-mile BRT-lite system in 2009 with 3.75 miles of dedicated infrastructure [67], it doubled the ridership of its first corridor within two years [58] and prompted further BRT expansion in the area, and several BRT systems have increased the bus line ridership by over 50% [68]. It is also clear from the above ridership numbers in systems such as Cleveland and Alameda's that the potentially large capacity required in the future is no problem for BRT, Expansion into a network from the single BRT line VTA has now, as we see in Kansas City, is also feasible. From an operator's perspective, BRT exists as an effective medium between conventional bus lines, which discourage long-distance ridership due to long trip times, and the exorbitant expense and density requirements of rail transit.

BRT is also popular with passengers because it is time-competitive and convenient to utilize while providing similar service and speed to a rail line [69]. With bus lanes and transit signal priority on major arterials as well as an effective stop spacing of 1 – 2 stops per mile, similar to light rail, average bus speeds can reach rail-equivalent speeds of 15 – 30 mph [61] while offering level boarding and light-rail-like service levels. Past dedicated-ROW-only projects, such as Fordham Road in New York City, achieved a 15–20% reduction in travel time [70], and full BRT can reduce travel times by 25–50% [68]. If travel times could be reduced by a similar proportion on arterial roadways during congested hours, BRT lines may have the potential to be time-competitive with driving at such times.

Additionally, as seen in Kansas City [58], conventional bus lines can be upgraded to a BRT standard with only minor route changes, and it took Kansas City only three years to construct their first line. Significant construction is only needed at first for areas of high congestion that necessitate full bus dedicated right-of-way infrastructure, and preexisting station structures in some areas can be kept, upgraded, and utilized—less trafficked parts of the system may be upgraded later to full-corridor BRT when the funding is available. Given that some of VTA's current bus corridors, notably El Camino/Santa Clara and Stevens Creek Blvd. already receive high ridership, with multiple rapid and frequent routes operating on the same right-of-way [35], and do not parallel a major light rail line, it is only logical to upgrade congested portions of these corridors first with busway and specialized stops to benefit the maximum number of riders and vehicles. New changes to the residential and commercial landscape, such as shopping malls, mid- and high-rise apartments, and major workplaces, may alter the location of trip generators in the coming decades, and an expandable BRT is poised to be able to accommodate this through its relative routing flexibility and far lower cost in comparison with LRT.

Concerning connections, BRT is also capable of integration with both small-scale and large-scale modes of transportation. From pedestrian traffic to heavy rail and metro systems, we have seen in the United States with Los Angeles, Latin America's various systems, and India [69] the possibility of integrating BRT effectively with other modes. The stations, vehicles, and headways offer sufficient capacity and frequency for a bus line between large intermodal transit facilities—see Figure 1—while still having the bus-like flexibility to stop at local transit hubs along the way. Passengers may then smoothly connect onward to their final destination. With the short headways of BRT, connections using the system should be relatively simple, even without adhering to any type of schedule.

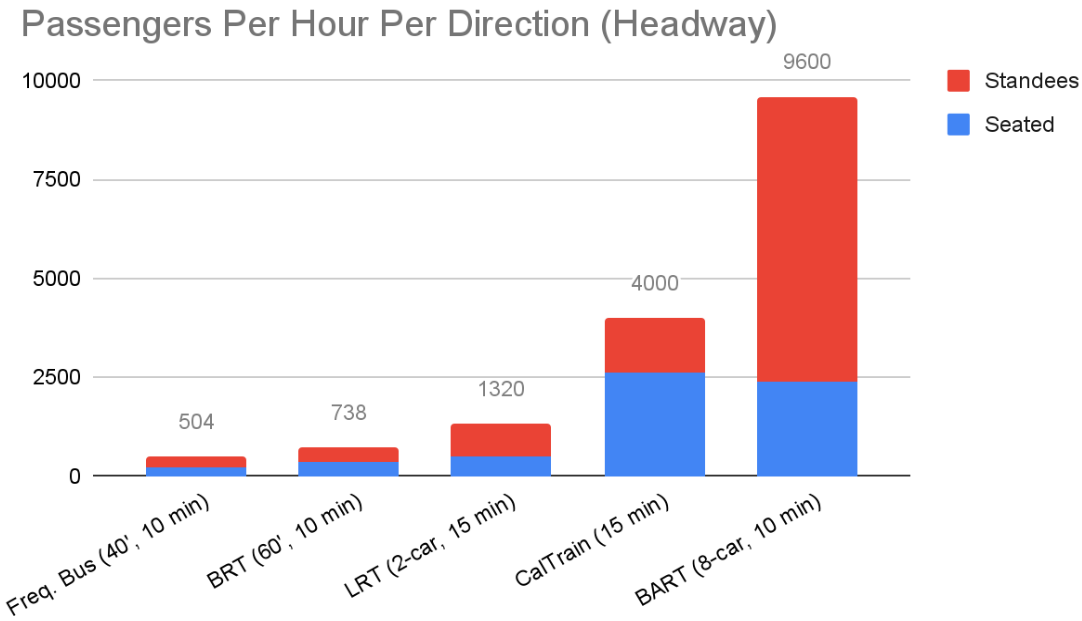

Figure 1. Comparison of line capacity per hour of differing transit modes, adjusting for typical peak-hour headways and vehicle configuration [71–75].

Despite all its positives, BRT is not perfect for VTA—and neither can any solution be. As with every rapid or semi-rapid transit mode, BRT requires significant construction in some parts of the network: specialized stations, procurement of road space for dedicated right-of-way in the form of bus lanes or shared carpool-bus lanes, and other dedicated support infrastructure [61]. This all comes at a cost—VTA's only true BRT project, the Santa Clara-Alum Rock BRT project was procured at an estimated $110–150 million for its 7.2 miles [8,60,76] BRT corridors are also often located on major thoroughfares, where the accommodation of excessive lane closures for construction may be difficult because of the congestion implications. Building around this restriction, or at night, increases costs and lengthens construction time.

BRT also utilizes significant road space: one lane per direction for a non-guided busway [77] with yet more required if specialized roadway-median stations are used or if the bus lane is to be physically blocked from the rest of the roadway, as in VTA's current setup on Alum Rock Avenue. This required right-of-way can either take away a travel or bicycle lane from each side or parking if the road incorporates parking, and in any case, will require deliberation with the local authorities and citizens. An alternative idea for greater road space utilization is to convert a lane to HOV and have buses operate through it, but this compromise may increase trip times for buses during times of heavy traffic, with turning traffic changing in and out of the lane and carpool traffic. Finally, conflicts with intersections' turning traffic are inevitable no matter where the bus guideway is placed within the road [61]. Finally, BRT plans will have to be approved by local businesses and citizens. With increasing density and the congestion that comes with it, it is hoped that local forces and authorities alike understand the need for improved public transportation—if instead work cooperatively to provide strategic locations for BRT stops and rectify other concerns together, from parking to pedestrian safety, their entire community will benefit from the increased mobility [61] that high-quality transit provides at any time of day.

Finally, VTA has already spent over $2 billion constructing and operating light rail for its semi-rapid transit plan [72], and is continuing to extend the system at great cost [9]. Constructing a bus rapid transit system may create a conflict of interest in some areas with regards to maximal utilization of this costly light rail. Even with BRT connections to light rail, the LRT system's fundamental speed and convenience issues make it a somewhat undesirable transfer mode in its current state.

3.4. Light Rail Transit

This solution aims to improve the speed, efficiency, and ridership of the presently-existing light rail system, as well as to expand the system to serve more destinations and corridors in an efficient manner, as necessary, to serve current and future requirements.

Light rail has a few major advantages over conventional buses and even BRT. Firstly, it can achieve the highest peak and average speeds if designed well: a dedicated line can reach 55 mph and 35 mph when operating in a separated median [23, 78]. Typical end-to-end average speeds are 10–30 mph depending on the operating environment [78], with dedicated right-of-way trending towards the upper ranges of that figure. This upper figure is at the optimistic end of BRT systems' capabilities on expressways and completely unreachable by conventional buses [72]; with VTA setting a goal of 25 mph back in 2007 and having plenty of dedicated infrastructure, it is clear VTA intended for the light rail to be a true rapid-service system [79] although this has not been achieved in reality. This is even despite many improvements projects such as signal priority and speed increase projects (VTA 2018c).

The light rail also has significant capacity for ridership growth. Even the current sections, despite the vehicles' slow average speed and inefficiency, have capacity far in excess of the demonstrated ridership. During peak hour with two-car trains, most LRVs still had seats to spare [72], with the average rush-hour, two-car train less than 25% of maximum capacity. Seating would still be available on most portions of the network even if rush-hour services were downgraded to one car [72]. If the system could be upgraded to run 8 to 10-min headways, as VTA aimed to do during peak hours in 2007 [79], passenger capacity would be even higher. Hence, if transit ridership on the system were to somehow increase by nearly an order of magnitude due to severe congestion, transit-oriented development, and greatly expanded transit service, the capacious light rail system would certainly be able to handle the increased demand [78].

As has been noted previously, VTA already has a sizable amount of light rail infrastructure in place, and therefore, any improvements to the light rail may be built off of the current system; additionally, VTA already has experience with maintaining and operating LRT vehicles. However, excessive construction costs in the past [9,72] point to possible inefficiencies, and light rail, even if no expansion is pursued at all, is very costly to keep operational; to meet VTA's own past goals for the light rail of a minimum 20–25% farebox recovery and some 40,000 daily riders on the system [79], ridership would have to nearly quadruple from current levels [31].

The most salient disadvantage of light rail is its cost in construction, extension, maintenance, and operation. The previously mentioned 2.4-mile, $653 million Eastridge LRT [37] extension represents over ten times the cost per mile of the 7.2 mile, $110–150 million Alum Rock BRT Project. Funds saved could then be used to build more bus rapid transit route-miles [8] to serve a greater catchment area. As the data shows, a light rail line will certainly convey nowhere near ten times the ridership of a BRT. VTA's financial statements also demonstrate a consistent operating cost of over $120 million, inflation-adjusted, in the past six fiscal years [31, 80] and an operating cost per rider of nearly $29 in FY2024. These construction and operations costs make the high capacity somewhat irrelevant if riders simply do not use the light rail to its capacity.

Additionally, the network contains sections of slow-speed and mixed-traffic operation on the main trunk that impede time-competitiveness and defeat many of the benefits associated with light rail [13] and require new construction to be mitigated. For example, the downtown San Jose transit mall, where Blue and Green line light rail vehicles are limited to 10 mph: the trains are essentially "running on the sidewalk" [13] and pedestrians may freely cross the tracks. Furthermore, the awkward layout of the mono-directional trackwork on 1st and 2nd streets in the transit mall compared to the rest of the bidirectional double-track network causes a noticeable lengthening of journey times [13]. Nevertheless, this major issue is finally in the planning stages of being rectified, although no construction has begun as of 2025 [81].

Finally, many stations have too little ridership to be considered viable stopping points: according to VTA's own 2007 Light Rail Service Guidelines, the goal for any given station should be about 1000 riders per weekday [79], with some smaller stations being kept open. Fewer than 100–200 boardings and alightings per weekday is less than many major VTA bus stops [35], and stopping at such stations for a few people to board or alight represents poor time efficiency for such a high-capacity transit mode [78]. Therefore, according to best practices and VTA's own guidelines [13, 79], many low-ridership stations on less densely-built parts of the network are best combined or bypassed entirely until some new development increases their utility (Figures 2 and 3).

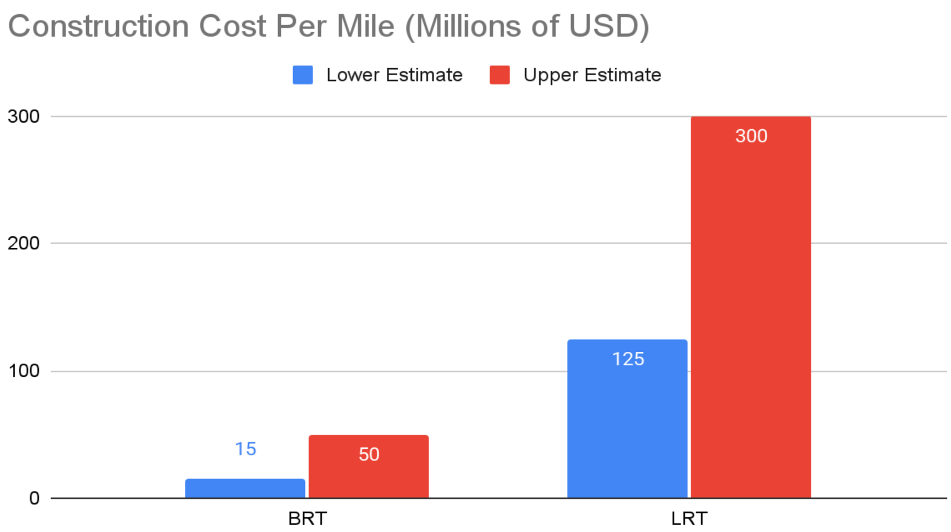

Figure 2. Comparison of bus rapid transit and light rail transit per-route-mile construction costs; both ranges are large due to varying road utilization, land value, and grade separation requirements [8,76,82,83].

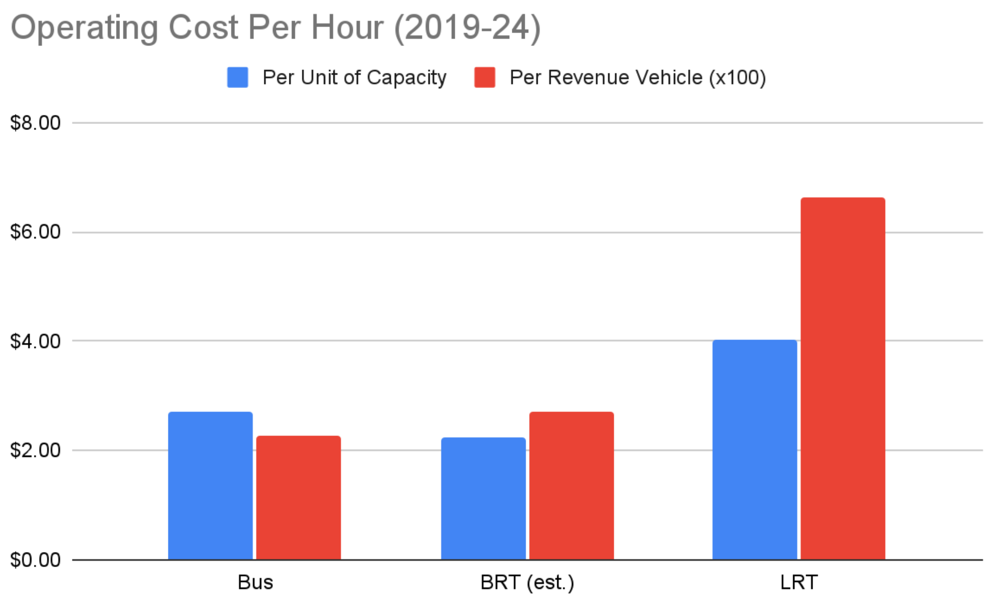

Figure 3. Comparison of operating costs per hour normalized per passenger capacity (blue) and vehicle (red, multiplied by 100) [31,56,80].

While cost may be the most obvious negating factor, zoning restrictions and overall land use struggles are perhaps the foremost impedance to the success of LRT in San Jose. Stations are often located in the middle of low-density developments [1,12] and high-speed roads where public transportation is far inferior in terms of trip time compared to driving. LRT is designed for urban and interurban use between relatively major and dense trip generators in a large area and for capacities beyond what a bus or BRT system would be able to comfortably accommodate [78]. VTA's full light rail system, as we have seen, hardly has enough daily riders along its three lines to crush-load a *single* BRT line a quarter its length such as Alameda's Tempo [84]. Hence, the light rail is an inefficient use of resources rather than a needed capacity and velocity increase—the capacity is not required and the velocity is little better than a well-designed BRT on similar routes.

3.5. Interpretation and Comparison of Solutions

It is clear from Figure 1 that VTA's potential ridership throughput on any system is well in excess of the current required capacity [85], yet a lack of quality public transit cannot be considered a viable option in the future. Even considering rush hour, the blue line only handled 491 passengers per hour in its peak direction in 2017, despite ridership before the pandemic being generally greater than on the system today [25,31,80]. Such ridership could be just about handled by a standard bus line operating 40-foot buses at 10-min headways, albeit with significant crowding (see Figure 1). If 60-foot buses, 7.5-min headways, or both are utilized, demand could be comfortably accommodated, even with BRT infrastructure. Other routes have even fewer riders—historical ridership figures demonstrate that the blue line has had the heaviest ridership of all routes and modes on the system for many years [25], and it likely remains in this position, although the public lacks post-2017 ridership by line data [25]. Another fact to note is that the 22/522 and 23/523 bus lines combined on the El Camino and Stevens Creek corridors respectively have had similar ridership to the blue line alone, and hence, these could represent the maximum demand per *corridor* on the system; however, they are served by two bus lines whose split individual loads are much lower, within the abilities of a standard frequent bus route. In any proposed revision, these two routes could simply be planned and operated as "local" and "express" buses similar to the local and rapid system in use today in order to jointly accommodate their routes' heavy loads effectively.

If capacity with standard buses is sufficient, is it an argument for a more cost-effective bus network to take over VTA? Little new infrastructure is required, and operating costs per vehicle are the lowest of any plan. Per capacity is a meaningless measure if such capacity cannot be utilized anyway. While such a proposal may seem attractive on the surface, a bus-only plan, even with the proposed improvements such as TSP, timed transfers, and stop reorganization is insufficient for the reasons of required future capacity to expand and insufficient operating speed, as mentioned previously.

As congestion continues to worsen and cities construct new housing, including transit-oriented developments, ridership may grow in the future, especially if VTA improves transit performance today. It may even double from today's low figures and rebound to the values encountered in the late 2000s or greater. Demand on busier routes such as El Camino and Stevens Creek, given the previously mentioned 50 – 100% ridership increase demonstrated by BRT systems' installation alone, could justify the use of BRT; an even greater increase is possible with the continuing densification of surrounding areas and construction of transit-oriented development [86]. Nevertheless, a peak ridership increase of more than 150% to about 1200 riders per hour per direction, even for these main lines, is regarded as unlikely in the short-term, given a lack of precedent for such ridership increases elsewhere [68]. The extreme extra capacity of LRT seems unnecessary given its high costs in construction, maintenance, and operation [31,82] compared to other modes; with that money, a more extensive, more frequent BRT network for greater capacity throughout the system could be operated at lower cost per seat, as we see in Figures 2 and 3.

Another reason to select some BRT and LRT to complement standard buses is average speed. Poor time-competitiveness on longer routes may be a reason for low present ridership. Arterial BRT and LRT speeds are comparable, at 10–30 mph, with LRT perhaps holding a travel speed advantage while BRT may have superior headways and last-mile performance due to the lower individual capacity of its vehicles and much lower operating cost per vehicle-revenue hour. Travel times with either mode are comparable [72] and much faster than conventional buses.

Finally, density—or lack thereof—and cost considerations point to bus and BRT. Census data show that many higher-density suburban areas surrounding major arterials contain 8,000 to 14,000 people per square mile, or perhaps 2500 and 5000 dwellings units in that square mile [87], assuming 2.67 persons per dwelling, the Santa Clara County average [88] Even relatively dense census tracts in the city of San Jose have perhaps 15,000–20,000 people per square mile [87], or about 5000 to 7500 dwellings per square mile given the dwelling per population size approximation. By Minneapolis' reckoning, these are hardly sufficient even for a frequent bus network, never mind BRT or especially LRT [89]. For more information on guidelines for density by mode of transit, see Figure 4. However, their considerations only lie within a quarter-mile of the BRT stop, for which overall population density data is not available —but we can extrapolate that such "pockets" of density and demand, as encouraged by transit-oriented development, multiunit housing, or commercial development in specific areas smaller than entire census tracts by VTA and other governments organizations in some areas [19] may bring the necessary levels of density for BRT along major transit lines, especially in the near future. The requirements for light rail are far higher, however, and the density guideline area is larger—a half-mile radius of such a station, or about the size of many census tracts. Very few census tracts in the entire county exceed 20,000 residents per square mile, which represents 8000 dwellings or so; even this is far fewer than the 12, 800 to 32, 000 dwellings per square mile required for effective LRT operation claimed by Minneapolis [89]. Densification in many neighborhoods and new developments are unlikely to consistently double or triple the overall density within large radii of LRT stations given past precedent—while densification is not everything, it remains important. Overall density along any major corridor is not conducive to LRT operation. Hence, a combination of BRT infrastructure on major arterial corridors, a reimagining of the bus network with TSP and route optimization, and continued LRT speed and efficiency improvements where possible may serve VTA's operations best while maintaining cost-effectiveness for the taxpayers.

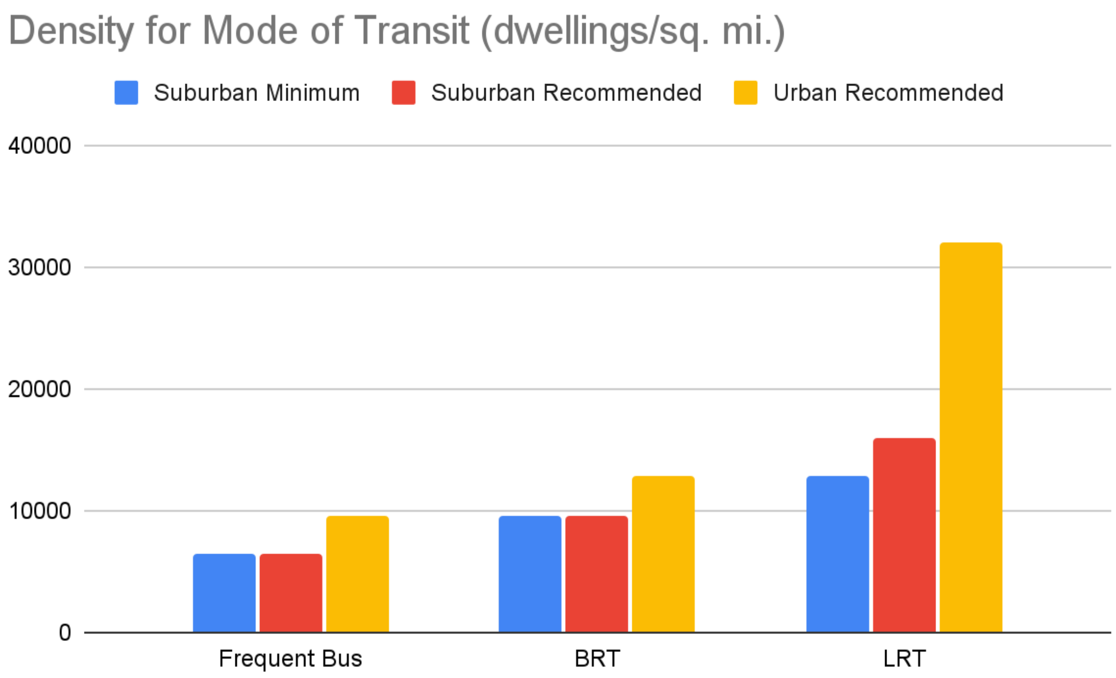

Figure 4. Recommended population densities several modes of transit in differing environments [89].

4. Conclusions

4.1. Summary

Santa Clara County and VTA need to improve the county's transit system and move away from its car-dependent past and present if it is to meet its targets for the future. San Jose would like to capture over 200,000 commuters who drive alone using other mobility methods by 2050 to reduce environmental impact and congestion [90] and benefit low-income or otherwise underprivileged residents [91]; due to the long commute distances, many of these trips may only be made by vehicle.

Lacking a dense downtown CBD, San Jose and that county surrounding it are far less centralized than its northern neighbor, San Francisco, which makes transit planning challenging. Nevertheless, there is hope for a revitalization of San Jose's downtown and therefore the major increases in transit ridership. However, traffic congestion in the county is heavy and still growing, necessitating better transit service and ridership in the near-term as well.

VTA is one of 27 different transit operators serving the Greater San Francisco Bay Area. It operates bus, light rail, and demand-response paratransit services and offers connections with four other operators. In its present state, ridership is poor for the size and expense of the network and city due to insufficient convenience and time-effectiveness on many destination pairs. Additionally, VTA's project management has been criticized for being inefficient and producing poor results.

Many solutions have been considered to address fundamental mobility issues in different cities, but several are unfeasible, whether for general reasons or ones specific to the area. Overall, it is demonstrated that improved public transportation, along with other methods to reduce congestion and increase overall efficiency, is required.

We explore three possible solutions for the future expansion and revision of VTA's transit network: standard bus, BRT, and LRT. With TSP, stop and route optimization, and timed transfers to other modes, a rework of some sections of the standard bus network may be enough for the time being, and such a network is by far the least costly and time-consuming to implement and may benefit the most routes. However, this solution cannot solve the fundamental problem of long travel times and traffic impediment, and may have to sacrifice last-mile convenience for faster speeds. Additionally, due to capacity and speed constraints, this solution lacks suitability for major future expansion, which would be necessary to meet San Jose's goals.

An alternate solution would be bus rapid transit, or BRT. A "full BRT", with level, all-door boarding, proof-of-payment ticketing, TSP, and dedicated bus right-of-way—as opposed to the "BRT-lite" or rapid bus system currently in place on segments of VTA's network, would be constructed along arterials such as Stevens Creek and El Camino to supplant the light rail as a second, more flexible mode of semi-rapid transit. This will significantly lower travel times along these lines, and with the short headways of BRT, greatly improve overall convenience. Past BRT projects in other, comparably-sized cities have yielded large ridership gains at operating costs not much higher than standard bus and construction costs much lower than light rail. Despite all its advantages, BRT is not without several downsides: it consumes road space, which must be discussed with local residents and governments, and costs several hundred million dollars to construct while also disrupting traffic on a major arterial, both during construction and operation. Finally, BRT may take away from LRT network patronage as a potential transfer mode.

VTA has invested significant resources into its light rail system. Over the three modes, light rail generally has the highest speeds although BRT is comparable, and the highest capacities, giving fantastic potential for ridership growth. Unfortunately for VTA, the velocity and capacity are poorly utilized—-San Jose and its surrounding areas, especially the areas which the light rail operates through, do not have the density and ridership demand to fill up seats on a dedicated right-of-way and operate quickly. Lastly, the light rail costs many times more than BRT to construct and operate while providing relatively few advantages over it.

4.2. Result

Due to the above considerations, a combination of speed and convenience improvements to the current bus and LRT networks along with several all-new BRT routes is our proposed solution. Bus networks would be improved by optimizing stop spacing, road use choice, and service frequency in areas which would benefit most from such changes, in addition to linearizing heavily-ridden routes where possible. Light rail would have no further construction beyond the in-progress Eastridge extension due to excessive cost and insufficient ridership. Rather, operations would focus on giving trains on the current network signal priority and continuing the present project of increasing speed through the transit mall and on North First Street to provide a more effective modality for medium-distance travel and transferring passengers. In addition, current light rail vehicles should be replaced or refurbished in the near future. New BRT corridors will be able to provide high service levels on several arterials and expressways at a fraction of the cost and density requirement of a comparable light rail line; particular corridors of note for priority BRT conversion include Stevens Creek/San Carlos as well as El Camino/Santa Clara. The current policy of transit-oriented developments for both residential and commercial developments should continue and be concentrated along major BRT and LRT stations in addition to multimodal interchange points. This overall combination of solutions was identified due to long commute distances, lack of centralization and density, the need to serve a diverse range of communities, and the requirement to handle significant ridership growth and increased density in the future.

4.3. Recommendations for Further Consideration

It is hoped that the processes and conclusions outlined above can be of some use to VTA and other agencies, as well as members of the transit community conducting further study. While this is by no means a complete assessment of VTA's challenges and possible solutions, we have provided a bystander's assessment of a possible set of steps the agency could take from its current state to better serve its customers and taxpayers. If deemed feasible, appropriate, and beneficial by transit professionals and officials, we hope that a few of the suggestions made in this paper will eventually make it onto the ground in some form. We aim to do our part in creating a more equitable, efficient, and sustainable transportation system for the county which will help it thrive decades into the future.

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Informed Consent Statement

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Conflicts of Interest

The author declares no conflict of interest.

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