



**City of Mountain View
Automated Guideway Transit Feasibility Study**
Evaluation of Alternatives and Feasibility Report

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Front Cover Image Sources:

- Monorail - Las Vegas (Bombardier.com)
- 3rd Generation GRT (2getthere.eu)
- M City, University of Michigan (Navya.tech)
- Roosevelt Island Tramway (Flickr: m01229)

1. EXECUTIVE SUMMARY

The City of Mountain View is considering a transit connection between the Downtown Transit Center, North Bayshore employment center, NASA Ames facility, and residential areas to support long-term growth and reduce roadway congestion. This is meant as a first- and last- mile transit solution as an extension to the existing major rapid transit services and would provide competitive travel times compared to automobiles and traditional transit solutions.

The feasibility study focuses on fully automated and driverless technology. The four categories of technologies considered were Aerial Cable, Automated People Mover, Automated Transit Network (personal rapid transit and group rapid transit), and Autonomous Transit. A number of criteria were considered to rate the technologies against one another on factors such as passenger experience, infrastructure, technology maturity, and cost.



Roosevelt Island Tramway -Poma

Las Vegas Monorail – Bombardier

GRT vehicle - 2getthere

University of Michigan - Navya

While all of the technologies considered in the study are technically feasible, Group Rapid Transit and Autonomous Transit technologies are the most appropriate technology options for this transit application and environment. Aerial Cable and APM technologies do not provide the flexibility needed to maneuver through the area with minimal private property impacts due to the alignment geometry required for turning radii. Smaller vehicles such as Personal Rapid Transit are not the most appropriate solution to serve the transportation demand due to the large fleet size required and significantly short headways, which are not proven and could pose safety concerns.

Group Rapid Transit and Autonomous Transit can provide a system that serves a higher passenger demand from Caltrain during peak commuting periods but also be cost effective and flexible in service during off-peak periods. These medium capacity vehicles can operate at a frequency of 30 seconds in a typical line haul operation during peak periods but can also provide passengers with personalized point-to-point service between their origin and destination during off peak hours.

Further technical and financial study is needed to inform decision-makers and advance the project. Some recommended next steps to successfully incorporate GRT and Autonomous Transit technology into Mountain View includes an in-depth review of GRT and Autonomous Transit technologies and a detailed evaluation of potential alignment alternatives, including development of horizontal and vertical alignments, station concepts, and maintenance and storage facility locations and sizing. The feasibility study and technology evaluation included a cost estimate of each technology but additional review of potential procurement strategies as well as an economic benefit analysis and potential funding strategy for implementing an AGT system will be needed.

2. PROJECT OVERVIEW

The City of Mountain View is working to improve overall transit connectivity between the Downtown Transit Center and the North Bayshore and NASA-Ames employment area areas to support long-term growth and minimize traffic impacts. The goal of this project is to assess if and how an Automated Guideway Transit (AGT) system could serve as this connection. The AGT solution will need to be successfully integrated into the other transportation improvement strategies and projects the City is undertaking to support the City's continued growth and the quality of life of its residents.

This feasibility study is solely focused on advanced transportation technology that is characterized as being both fully automated and driverless. Defined broadly, AGT includes technologies that require grade-separated exclusive rights-of-way, but also those that can operate at grade in dedicated lanes physically separated from vehicular and pedestrian traffic. This study takes an inclusive approach in defining AGT and considers a wide variety of technologies including Aerial Cable, Automated People Movers, Automated Transit Network technology, and Autonomous Transit.

This report summarizes the year-long planning process for the AGT connection, the methodology for the technology evaluation, and the results of the evaluation effort.

2.1 Study Purpose

The purpose of this AGT Feasibility Study is to review the available AGT technologies to identify which, if any, could provide a solution to improve transportation and last-mile connections for the North Bayshore and NASA-Ames area. The AGT system should enhance mobility and connectivity, particularly facilitating trips to/from current fixed rail transit services. For this study, the AGT system is characterized as elevated and fully grade separated to minimize traffic impacts to current roadways. All technologies were evaluated using this criteria for equal comparison of operating characteristics, but some technologies have the potential to operate at grade in the future.

This study broadly assessed AGT technology to understand the feasibility of introducing AGT to Mountain View; the study does not specifically assess or focus on any individual suppliers. Therefore, the available AGT technologies were grouped into the following four categories:

- Aerial Cable (e.g. gondola and aerial trams)
- Automated People Mover (e.g., rubber tire/steel wheel automated people movers, monorails, and maglev)
- Automated Transit Network (group rapid transit and personal rapid transit)
- Autonomous Transit (non-physically guided automated vehicles)

2.2 Study Area

The focus area of the study is the corridor linking the Downtown Transit Center to the City's North Bayshore area and the NASA-Ames area as shown in Figure 2-1.

Figure 2-1 Study Area



The identification of the study area is a critical first step to understanding the existing and planned future conditions that the AGT system may serve. In an effort to determine the study area, the project team reviewed recent and current planning and transportation studies conducted by the City and stakeholder agencies including Caltrain, the Santa Clara Valley Transportation Authority (VTA), and the Mountain View Transportation Management Agency (TMA) to establish candidate corridors, station locations, and passenger demand.

3. COMMUNITY OUTREACH AND MEETINGS

As part of this project, community outreach efforts in the form of public meetings, City Council study sessions, stakeholder meetings, and a project website were utilized to educate and inform the community about the different technologies under consideration, solicit feedback about community priorities, and update stakeholders on the project status.

Community Meetings

The goal of the first Community Meeting (held on April 3, 2017) was to educate the community on the technologies and receive feedback on their initial thoughts and concerns. Meeting participants were given an overview of the study including an introduction to the four technology groups identified for the study. By means of three interactive stations, participants provided input regarding the technology options, project goals and objectives, and key considerations. The feedback provided valuable information to the study team regarding community priorities for study goals and values, as well as the system features/characteristics important to them.

The second Community Meeting was held on September 25, 2017. The goal of this meeting was to provide an update regarding the status of the study including initial technology evaluation findings. The presentation highlighted the evaluation methodology and criteria, and provided high-level results summarized in four primary categories (passenger experience, infrastructure, technology application, and cost). The meeting also included a discussion with participants to further define priorities for system service characteristics. A moderated discussion allowed participants to give feedback about the overall results and voice their opinion regarding elements of the trade-offs they thought best served the needs of the community.

City Council Study Sessions

City Council study sessions in May and October 2017 were held to inform the City Council on the study efforts and solicit input with regard to the study's direction and initial findings. Direction was sought on technology options, corridor characteristics, and evaluation criteria for the study.

Stakeholder Meetings

Meeting with various stakeholders such as the Mountain View Transportation Management Agency, Santa Clara Valley Transportation Authority, and Google were conducted throughout the duration of the study. The intent of the meetings was to both inform stakeholders of the study and the team's initial findings and to understand any ongoing and future efforts planned by stakeholders that would impact the analysis.

Project Website

As part of the outreach effort, a project website (www.mountainviewagtfeasibility.com) provided information and updates regarding the AGT study. The website is regularly updated with information about upcoming community meetings and council sessions. Community members can also find the technical resources and presentations from both community meetings posted. More than 1,150 individuals have visited the website and 60 have signed up to receive news and event notifications. The City, through various social media outlets, has also disseminated additional information regarding the project and notifications regarding outreach and City Council discussions.

4. POTENTIAL PASSENGER DEMAND AND MARKET

Travel patterns in Silicon Valley are undergoing significant change as the area continues to experience rapid employment growth and increase in vehicle congestion. Ridership on the Caltrain system has significantly increased over the last few years as a result of Bay Area economic growth and as commuters continue to shift to alternative modes to escape recurrent peak period congestion on the freeway network. As the North Bayshore area continues to grow, that shift in travel patterns is expected to continue. The evolution in commuting patterns, advent of new transportation methods (e.g. Transportation Network Companies), and substantial planned growth in the North Bayshore Area contribute to expected growths in transit demand in the Mountain View Transit Center - North Bayshore area. The North Bayshore Precise Plan identifies a 45 percent single-occupancy vehicle mode split target, emphasizing the need for and reliance on enhanced transit and active transportation options. Uncertainties regarding the pace of buildout of the North Bayshore Precise Plan and the ultimate land use makeup of the area do not allow for detailed ridership projections. In addition, it is unknown how the current commute market will transform with the introduction of a new transit technology that does not currently exist in the area. Therefore, ridership projections are provided as ranges and represent only reasonable estimates of activity based on currently known factors.

Several assumptions were made to estimate the potential ridership on an AGT system. The assessment of ridership potential allows for identification of system requirements and potential system operations. Ridership projections will need to continue to be refined as the AGT system project definition is developed. The adaptability of the system to efficiently support ridership demands that are both below and above the indicated estimates are important given the challenge in accurately forecasting future ridership.

The study evaluated two separate market demand sources to estimate future AGT ridership. The first future demand market consists of Caltrain commuters to North Bayshore/NASA-Ames whose trips originate outside of Mountain View. A significant number of these commuters currently use public or private commuter shuttles to travel between Mountain View Transit Center and North Bayshore/NASA-Ames. The second future demand market consists of commuters who generally live in the Study Area and would use an AGT to access the Mountain View Transit Center or downtown Mountain View. This demand considers both existing residents and future North Bayshore and NASA-Ames residential and commuter trips.

Given the uncertainty in projecting future AGT ridership, the analysis identified a range of potential ridership. The lower bound of the forecast assumes that future ridership will primarily reflect a shift of current shuttle riders to an AGT system and a lower level of development in North Bayshore. The upper bound of the forecast assumes that a percentage of travelers currently commuting into or out of the Study Area via other modes will shift their travel preference to the AGT system and a higher level of development in North Bayshore.

Estimates of the future populations for North Bayshore are based on the expected number of residents in North Bayshore. The low range assumes 6,000 housing units and the high range assumes full build-out at 9,850 housing units. Estimates of the future residential population in the NASA-Ames area was based upon the proposed number of residential units in the 2002 NASA-Ames Development Plan and Final EIS. While many future residents of North Bayshore/NASA Ames are anticipated to also work in North Bayshore/NASA Ames, estimates were made for a subset of residents commuting outside of the area, either to downtown Mountain View or other locations in the Bay Area.

The potential passenger market assumption developed through this study estimated a range (lower and upper bound) for daily ridership categorized by four markets as can be seen in Table 4-1 below. It is important to note that the estimates do not account for potential demand spikes related to the Shoreline Amphitheater, which could include event demand for an AGT service on weekday evening or weekend peaks.

Table 4-1 Lower and Upper Bounds for Daily Ridership Estimate

Market	Lower Bound Daily Ridership Estimate	Upper Bound Daily Ridership Estimate
Caltrain Riders Employed in North Bayshore/NASA-Ames	2,280	4,610
Existing Residential Neighborhoods	400	650
North Bayshore/NASA-Ames Resident Commute	1,170	2,860
North Bayshore/NASA-Ames Non-Commute	220	540
Total	4,070	8,660

Additional ridership would likely come from persons accessing lunchtime retail and restaurant uses in downtown Mountain View or North Bayshore. However, this demand is not quantified in this analysis. Since it will occur outside the peak periods of ridership demand, it is not anticipated to affect system design.

While daily ridership estimates are helpful in assessing overall demand for the system by market segment, the system will need to be designed to handle peak surges in demand. The system will experience the surges in demand when each Caltrain train arrives at the Transit Center and passengers disembark. The peak surge will occur when there are multiple Caltrain trains arriving in close proximity during the peak period. Based on current Caltrain schedules and ridership patterns, it was determined that peak activity at the transit center occurs when three Caltrain trains arrive within a 10-minute window. A key evaluation criterion is whether the system will be able to handle the demand associated with those trains within the 10-minute period, allowing the system to clear prior to the arrival of the next set of trains to avoid persistent queues. System capacity objectives were established around the peak 10-minute demands and are shown in Table 4-2, which are reflective of demand associated with both North Bayshore and NASA-Ames and reflect current Caltrain ridership distribution amongst trains within the peak period. It is noted that peak surge activity from the transit center is expected to be higher than peak surge activity to the transit center during both the morning and evening periods as a result of the instantaneous surge generated with each Caltrain train arrival. Peak activity to the Transit Center, whether in the morning or evening, will be metered as passengers will not be arriving to the station at one time.

Table 4-2 Lower and Upper Bounds Peak 10-Minute Surge Demand Estimate

10-Minute Peak Period	To Transit Center		From Transit Center	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
AM	50	115	165	335
PM	60	130	145	330

5. TRANSIT TECHNOLOGY ALTERNATIVES

Four key technology groupings were evaluated. They represent currently available fully automated (driverless) guideway transit technologies and are grouped based on similarities in operation, guidance, network configuration, and technology maturity. Each technology group has the capability to pick-up passengers at designated stations and transport them on a specified route in a safe and efficient manner. Additionally, each technology can operate on an exclusive right-of-way separated from vehicle, pedestrian, and bicycle traffic. These exclusive rights-of-way may consist of cables, elevated guideways, or at-grade dedicated rights-of-way.

A group may contain several different technology types and vehicle sizes but have similar operating characteristics that allow them to be categorized together for the purpose of this study. Grouping the technologies in this manner assists in highlighting the differentiating characteristics, as well as how they best fit the design parameters of this study.

The four technology groups are:

- Aerial Cable,
- Automated People Movers (APM),
- Automated Transit Network (ATN) which includes Personal Rapid Transit (PRT) and Group Rapid Transit (GRT), and
- Autonomous Transit.

The technologies have varying degrees of implementation. Some are more established technologies with many suppliers (aerial cable and APM), while others are newer, emerging technologies with fewer examples in operation and limited suppliers (ATN and Autonomous Transit). Table 5-1 shows an approximate number of operating US and Worldwide systems for each technology group, as well as systems under development or in pilot programs. While the Mountain View AGT Feasibility Study is focused on commuter transit in an urban environment, the technology inventory provided is a total of systems in operation independent of function. For example, many aerial cable systems operate in ski resorts and many airports feature APM’s for passenger connections.

Table 5-1 Summary of AGT Service-Proven Technology

Technology	Operating Systems		Under Development & Pilot Projects
	U.S.	Worldwide	U.S./Worldwide
Aerial Cable	50+	500+	N/A
Automated People Mover	30+	70+	N/A
Automated Transit Network (PRT/GRT)	0 PRT/1 GRT	3 PRT/1 GRT	1 PRT/1 GRT
Autonomous Transit	0	0	50+

Table 5-2 includes examples of technologies considered in the AGT grouping in urban setting with their capacity (passengers per hour per direction, pphpd) and daily passenger numbers. Autonomous Transit is not included, as the relatively young maturity of the technology does not have a valid data sample.

Table 5-2 Examples of Urban AGT Systems

Technology Group	Name of System	Location	Capacity (pphpd)	Daily Passengers
Aerial Cable	Portland Aerial Tram	Portland, Oregon	780	10,000
Aerial Cable	Roosevelt Island Tramway	New York City, New York	500	5,500-6,500
Automated People Mover	Jacksonville Skyway	Jacksonville, Florida	3,600	5,000 (2015)
Automated People Mover	Metromover	Miami, Florida	7,200	33,000 (2016)
Automated People Mover	Las Vegas Monorail	Las Vegas, Nevada	8,000	13,510 (2011)
Automated Transit Network	Morgantown GRT	Morgantown, West Virginia	4,800	16,000
Automated Transit Network	Masdar PRT	Masdar City, Abu Dhabi	200	700-1,000
Automated Transit Network	Ultra Global PRT – Heathrow Airport	Heathrow, England	656	Not available-
Automated Transit Network	Rivium GRT	Capelle aan den IJssel, Netherlands	600	2,400

5.1 Aerial Cable

Aerial Cable technology uses one or more cables for propulsion and stability, carrying passengers in suspended cabins above the ground. There are different types of aerial cable transportation technologies such as gondolas, aerial trams and funitels considered in this group. These different aerial classifications also differ in obtainable cabin and system capacity, as the smaller sized gondolas can transport about 2,000 people per hour per direction and the larger aerial trams can transport up to 6,000 passengers per hour per direction. They typically achieve an average operational velocity between 10 to 20 mph. Due to the large towers that are needed to support the suspended moving cables, this system is extremely difficult to expand after the initial system is constructed compared to the other technology groups being considered in this study. Aerial Cable technologies have been in operation for years resulting in a mature technology that is service proven and reliable. Traditionally aerial cable technology is utilized to overcome significant elevation changes in mountainous areas but can be applied to urban environments as well. Examples of aerial technology include the Portland Aerial Tram, Singapore Cable Car (Sentosa, Singapore), Funitel Hoakone (Kanagawa Prefecture, Japan), and the Roosevelt Island Tramway.

Aerial tram systems feature two larger cabins attached to one or more cables that can shuttle back and forth between destinations in tandem or independently. Gondola style systems operate with a cable loop allowing for multiple cabins on the system. Aerial cable vehicles operate on a fixed route between stations, to provide line-haul type service rather than point-to-point service. Due to the desired operation of the system including multiple stops, lower frequencies and wait times, and minimizing neighborhood impacts, gondola style rather than aerial trams would be better suited to meet the high level of service required for this system. Within the gondola style category there are multiple cabin sizes and cable configurations, such as the medium and larger size cabins of the Bicable and Tricable Detachable Gondola technologies.

Key Characteristics:

- System Capacity: 2,000-6,000 people per hour per direction
- Noise: Lower
- Speed: Up to 22 MPH
- Expandability: Harder
- Where it Operates: Exclusive Right of Way
- How it is Guided: Suspended Moving Cables

Figure 5-1 Aerial Cable Examples



5.2 Automated People Movers

This technology is best described as an automated transit system with large capacity vehicles operating on a fixed guideway. Propulsion can be achieved through several methods, such as self-propelled with on-board electric motors, cable-propelled by a continuous cable along the guideway, or magnetic levitation. Considered in this technology grouping are rubber-tire and steel wheel Automated People Movers, Monorails and Maglevs. These technologies can reach greater speeds compared to the other technology groups and thus can achieve greater system capacities and lower travel times. Automated People Movers operate on a fixed guideway between stations, to provide line-haul service rather than point-to-point service. Due to the equipment and guideway structure, this technology could be difficult to expand after the initial construction if not planned for. APMs have been in operation for decades resulting in a mature technology that is service proven and shown to be highly reliable. Examples include the Oakland Airport Connector, SFO AirTrain, Phoenix Sky Harbor SkyTrain, Las Vegas Monorail, and Rotem Urban Maglev (Incheon, Korea).

Key Characteristics:

- System Capacity: 1,500-15,000 people per hour per direction
- Noise: Lower (Rubber Wheels and Magnetic Propulsion)/ Higher (Steel Wheels)
- Speed: Up to 50 MPH (Except Low Speed Maglevs: Up to 60 MPH)
- Expandability: Harder
- Where it Operates: Exclusive Right of Way
- How it is Guided: Steel Rail/ Cable/ Guiderail

Figure 5-2 Automated People Mover Examples



Doppelmayr Cable Car: Cable Liner (Oakland, CA)



Bombardier: Innovia Monorail (Las Vegas, NV)

5.3 Automated Transit Network (Personal and Group Rapid Transit)

Automated Transit Network (ATN) vehicles can be characterized as smaller automated vehicles operating on a network of guideways to provide point-to-point service with the ability to bypass intermediate stations. Personal Rapid Transit (PRT) and Group Rapid Transit (GRT) technologies were included in this group as they both have smaller capacities and similar operation. GRT cars are currently larger at ~10-25 passengers per car, compared to the typical PRT car capacity of 2-8 passengers but may have increased vehicle capacity in the future. Guidance methods are numerous and will vary by supplier and can be road-based, rail-guided, or inverted monorail. Multiple vehicles can be staged at stations and deployed when requested by passengers, potentially resulting in shorter wait times than APMs. Aside from GRTs having a slightly larger vehicle capacity than PRTs, both technologies operate at similar speeds and use similar guideway infrastructure and travel networks for transporting passengers to their destination. The guideway system for this technology is easier to expand than APMs or aerial systems since the vehicles are on a network and infrastructure requirements are modular and can be less expensive.

Although there are examples of GRT and PRT systems in operation, they are not as numerous as APM or Aerial Cable technology. Several distinctive technologies are still in development and there are only a handful of service-proven systems or suppliers. The following are the five Automated Transit Network systems in operation, as well as one GRT project where service agreements have been completed but the project is not yet deployed. The ATN type (PRT or GRT) and the supplier is provided in the list below.

- Heathrow Airport (PRT, Ultra)
- Business Park Rivium, Netherlands (GRT, 2getthere)
- West Virginia University (GRT, Boeing Vertol)
- Masdar City, Abu Dhabi (PRT, 2getthere)
- Suncheon, Korea (PRT, Vectus)
- In development: Bluewaters Island, Dubai, UAE (GRT, 2getthere)

Key Characteristics:

- System Capacity: 2,000-12,000 people per hour per direction
- Noise: Lower
- Speed: Up to 43 MPH

- Expandability: Easier
- Where it Operates: Exclusive Right of Way
- How it is Guided: Sensors/Rails/Curbs/Beam

Figure 5-3 Automated Transit Network Examples



Ultra Global PRT (Heathrow, England)



2getthere GRT (Business Park Rivium, Capelle aan den IJssel, the Netherlands)



3rd Generation 2getthere GRT

5.3.1 Emerging Technologies/Suppliers

In addition to the operating systems discussed above, there are at least 10 new technology concepts in various stages of conceptual design, development, and testing.

Woojin (PRT) has completed its initial trial operation on a commissioning test track with a full-scale test track planned. Modutram (PRT) has a testing facility consisting of 600 meters of track, 3 stations, and 10 switches in Guadalajara, Mexico. Skytran (PRT), which is located at the NASA-Ames Research Center in Mountain View, has plans for a demonstration project in Israel.

Other ATN concepts, including Cybertran, Transit X, SwiftATN, Tubenet Transit, ROAM, Suyzer, Skycab, Taxi2000, Jpods, and EcoPRT are also in various stages of development and testing/demonstration. However, these concepts primarily focus on the smaller PRT technologies. The findings presented in subsequent sections show that PRT is not the best fit for the Mountain View application. In addition, these emerging technologies do not yet have proven systems or any regulatory approval.

Figure 5-4 Emerging Technologies



Modutram PRT Test Track



Skytran PRT Concept Rendering



SwiftATN Rendering



Transit X Rendering

5.4 Autonomous Transit

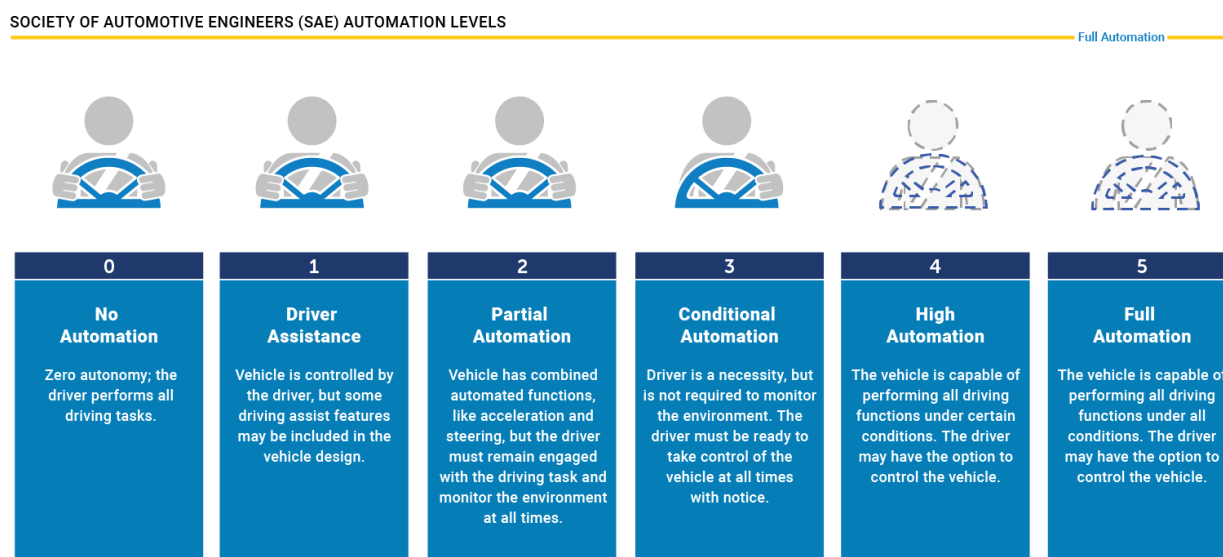
Autonomous Transit technology consists of automated vehicles that are capable of operating in a dedicated guideway or reserved lanes as well as on a mapped network in mixed flow traffic. For the evaluation of this technology in the near term, system throughput capacity would be considered to be equivalent to ATN GRT technologies.

This technology is considered as a stand-alone group because of its unique operating characteristics. The vehicle is equipped with sensors and high-resolution GPS technology to direct the vehicle to avoid obstacles and traffic control signals. Docking at stations can also make use of fixed guidance infrastructure, such as in-pavement magnets.

Autonomous Transit systems are primarily currently in the pilot or demonstration project stage. At this stage of project development, the typical speed is limited to a range of 6-25 mph depending on the complexity of the operating environment. When operating within an exclusive guideway, the speeds can be generally at the upper end of the range. As the project matures, it is expected that speeds will increase to 35-40 mph or even greater. Vehicle capacities currently being tested range from 4 to 16 passengers depending on the number of seats provided, but larger, next generation vehicles are under development. Autonomous Transit technologies are anticipated to mature over the next 5 to 10 years through continued testing and demonstration projects.

The primary challenge within this technology currently being addressed is in developing an autonomous system that can safely and reliably pilot itself in all conditions without human supervision. This challenge is not only being tackled within the transit environment, but also for personal automobiles by auto manufacturers, transportation network companies (TNCs, e.g. Uber, Lyft), and technology companies. The International Society of Automotive Engineers (SAE) has identified six distinct levels of automation (Level 0 to Level 5) as shown in Figure 5-5 SAE Levels of Automation. An Autonomous Transit system is considered a Level 4 operation, or full autonomy where a steering wheel and a supervising driver is optional. Level 4 operation has been reached in limited applications to date. A number of autonomous passenger vehicle programs are currently testing Level 3 technologies where a human has the ability to take control of the vehicle. These include Waymo/Google and Uber. Several suppliers, notably GM, have announced plans to reach Level 4 in the passenger vehicle environment within 4-5 years.

Figure 5-5 SAE Levels of Automation



Technological advancements in the driverless car/personal automobile spectrum are also anticipated to benefit the Autonomous Transit spectrum as well. As Level 4 technology is refined, it is expected to be applicable to a wide variety of transit applications, including a range of vehicle sizes. Therefore, it is not expected that vehicle size or configuration will be a limiting factor when the technology reaches maturity.

In several ways Autonomous Transit operates identically to PRT/GRT but without physical tracks and guideways in that the vehicle fleet can be managed through dispatch to meet fluctuating demands, can provide a mixture of point-to-point and trunk line service, and vehicles can be chained (or operated in close spacing) to meet larger demands. Autonomous Transit provides the additional benefit of being able to operate in mixed-flow or at-grade environments for segments of, or possibly the entirety of, the project alignment.

Examples of systems in limited passenger services are the EasyMile system currently operating with an attendant onboard at the Garden by the Bay in Singapore and a one-year pilot in Montreal, Canada, by Keolis Navya. Several different suppliers are currently pursuing Autonomous Transit pilot projects or actively preparing for project implementations. Currently there are many pilot programs around the

world that are using this technology on a demonstration basis at very low speeds, including: Contra Costa County Transportation Authority at Bishop Ranch Business Park; the City of Greenwich, UK; the City of Las Vegas, NV; Tampa, FL; among many others worldwide in Europe, Australia, the Middle East and the Far East. Recently, Navya tested a public Autonomous Transit vehicle on the streets of Las Vegas, Nevada. In January 2018, Toyota announced the e-Palette alliance which is the first major OEM to indicate their intentions to enter the Autonomous Transit market. Autonomous Transit systems based on the e-Palette platform are anticipated to be provided by Toyota for the 2020 Tokyo Olympics.

Key Characteristics:

- System Capacity: 2,000-12,000 people per hour per lane of traffic
- Noise: Lower
- Speed: Up to 25 MPH in pedestrian environment (40 MPH in exclusive right-of way)
- Expandability: Easier
- Where it Operates: Dedicated Lanes with Potential for Near Term Deployment in Mixed Flow Traffic
- How it is Guided: On-board Sensors and high-resolution GPS/localization

Figure 5-6 Autonomous Transit Examples



6. SYSTEM DESIGN AND CHARACTERISTICS

The following set of design and operational requirements characterize the system and service level and form the basis for the evaluation process. These characteristics influence the identification of potential technologies for the AGT system, as well as the identification of conceptual route alternatives used to evaluate the potential technologies. The following design characteristics were developed based on input from the City Council, stakeholders, the local community, and from previous planning studies.

6.1 System Design and Configuration

The following are three key design/configuration factors applicable for the project:

- Type/configuration of service provided: The type and configuration of the service provided is important and is typically influenced by the type and level of demand in the area being served. To meet the commuter passenger market demand levels and patterns for this system, the AGT technologies can operate in two main service types. The first is a traditional transit system that stops at all stops along a designated route (such as a line-haul system). The second is a point-to-point system providing passengers a direct connection between their origin and destination stations with no stops in between, which can be laid out in a network configuration. The study area and commuter passenger market may warrant the use of both service types.
- Alignment route: For this feasibility evaluation, the AGT system is assumed to operate in a fully-dedicated, elevated corridor that does not share lanes or at-grade crossings with vehicular traffic. The reasoning is that this would avoid disruption by and to local traffic. Impacts due to the physical requirements for exclusive right-of-way (grade separations, elevated structures, retaining walls, etc.) can be anticipated and will be identified along the alignment. However, any future extensions may have the option to operate at-grade in dedicated lanes or in mixed traffic depending on technological advances.
- Technology-specific restrictions: The ability for technologies to maneuver and fit within the physical constraints (street configurations, existing over/underpasses, turn radii, etc.) is a key part of the technology review. The maneuverability and bi-directional ability of the technologies being reviewed is a factor in determining potential alignment constraints.

6.2 Capacity

The AGT technology must have adequate capacity to meet the estimated market demand (including surge demand) of the study area. As outlined in Section 4 above, the AGT technology must provide a service that is well sized for the 10-minute peak demand of 330 passengers.

Commuters in the Bay Area frequently use a bicycle as part of their first- or last-mile connections. Therefore, the vehicle and system capacity must factor in the ability of commuters to bring bicycles on board.

6.3 Connections to Other Transportation Modes

Providing convenient, reliable, safe and accessible transfers while minimizing the number of overall mode transfers and meeting the needs of the customer, are integral in providing an attractive system with a high level of service for all passenger groups (visitors, commuters, and residents).

Although the goal is to minimize the mode transfers needed for passengers to travel between their origin and destination there are potentially two key mode connection points identified for the AGT system. The first is the Transit Center, which provides a connection to the AGT system for VTA light rail and Caltrain service, VTA bus, employer shuttles, local pedestrian traffic, and bicyclists. The second is located within North Bayshore where passengers might, upon exiting the AGT system, walk or bike to their final destination, or potentially transfer to another AGT technology. Although some AGT technologies may be able to transition from the corridor-based service envisioned between the Transit Center and the North Bayshore area and a network type system that could provide circulation and last-mile connections within North Bayshore, such as ATN and Autonomous Transit, there is a possibility that multiple technologies are utilized to optimize on their service characteristics. For example, Aerial Cable and APM could provide typical line haul service from the Transit Center to North Bayshore, while ATN and Autonomous Transit provide circulation within the North Bayshore area. To assess the potential for an additional AGT mode, one of the representative alignment alternatives includes the possibility for a separate system serving North Bayshore only (i.e. an Automated Transit Network /Autonomous Transit system). This will also allow for a better understanding of the benefits of corridor vs. network-capable technologies.

6.4 Travel Time

The goal for the AGT system is to be able to reduce the current bus shuttle time from the Transit Center to the North Bayshore area by half, with an average wait time of no more than 5 minutes during the peak periods.

The current shuttle system has an actual travel time of 15-25 minutes going to the West Bayshore area and a travel time of 25-30 minutes going to the East Bayshore area. Therefore, the selected technology system is looking to have a travel time of 7-13 minutes and 13-15 minutes respectively to each destination.

6.5 Accessibility

To ensure optimal service within the study area, the representative alignments and station nodes were developed to provide access to key development nodes (residential and commercial).

Another factor considered is general system accessibility (ADA) and ride comfort. Each of the technologies was evaluated with respect to their ability to provide accessible service, such as level boarding platforms for passengers to readily enter and exit vehicles.

6.6 Expandability and Adaptability

System expansion is a key criterion for the technologies to potentially connect to existing and/or future identified land use projects. The evaluation addressed the potential technologies' ability to add mid-line stations and/or to extend the system to serve existing and future developments.

As part of the expandability assessment, the adaptability of infrastructure for different technologies is critical in the ability for the system to adopt new technology, especially as the autonomous vehicle technology continues to grow and improve.

6.7 Environmental Limitations

It is essential to assess and identify environmental conditions and constraints of the area that may limit or restrict the alignment of the potential AGT system.

Environmentally sensitive areas within the project area have been identified and avoided when developing representative alignments for the candidate technologies. The technologies should protect local air and water quality as vehicles are electrically powered with no local emissions and minimal impacts to water runoff from guideway structures. While all the technologies considered are electrically powered, the power generation of this electricity is flexible and can be supplied from “greener” sources.

The development and review of representative alignments will be used to understand how the technologies impact land use and environmentally sensitive areas that they may pass through/by.

7. ALIGNMENT CORRIDOR ALTERNATIVES

The review of AGT technologies was performed at a corridor level, focusing on the connections between key nodes. The goal was to identify conceptual system routes that efficiently link the city of Mountain View's Transit Center to the North Bayshore and NASA-Ames areas of the city, while also ensuring that key developments, both current and future, are also connected. The route alternative(s) are considered "representative" and are used as a basis to compare the technology options. As the focus of this study is to identify the feasibility of AGT technology, a full development and analysis of alignment alternatives is not included.

Key factors for the conceptual corridor alternatives are:

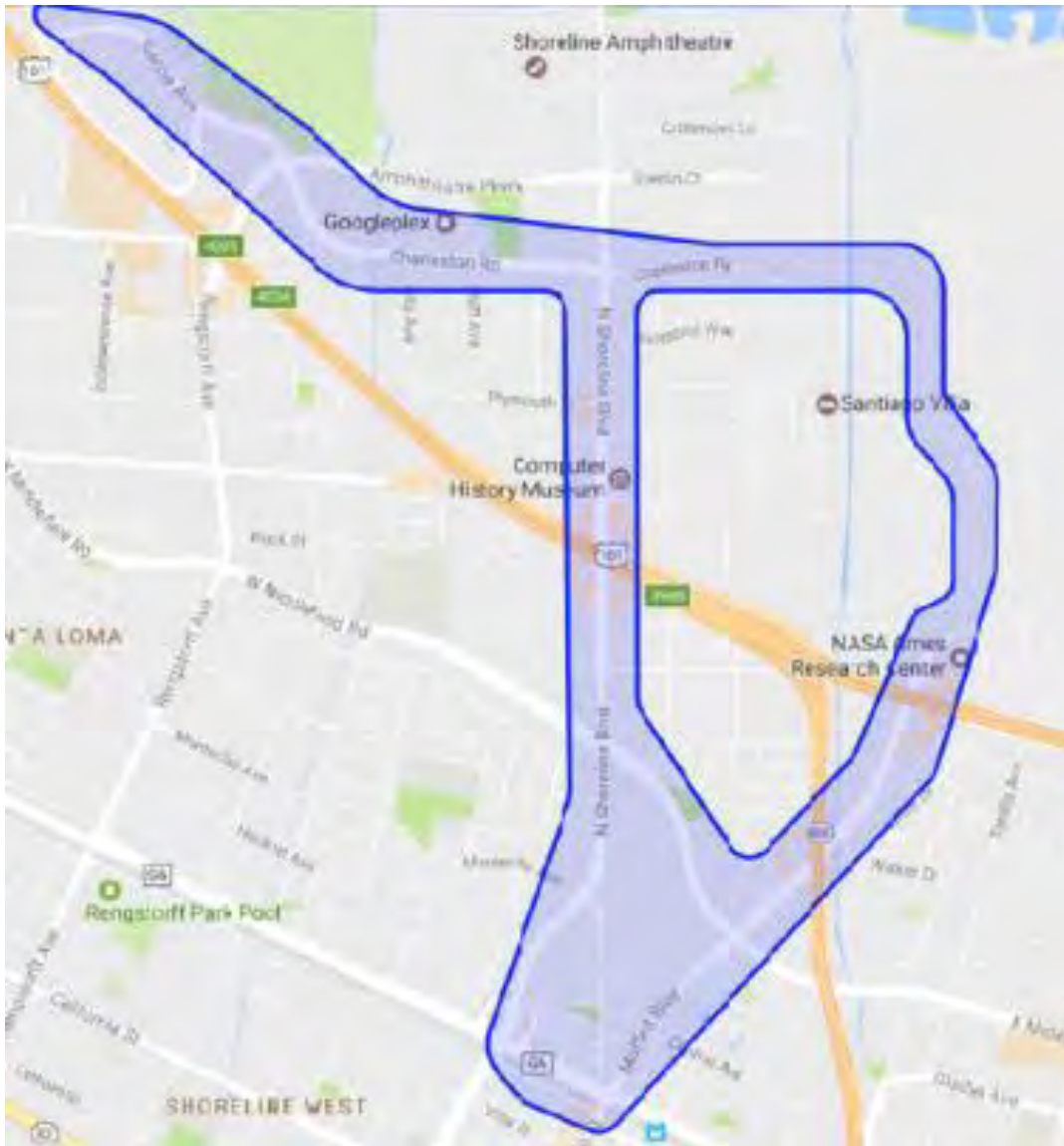
- To serve the Transit Center, North Bayshore, and NASA-Ames.
- To serve key development areas identified in the study area.
- The alignment must travel along city streets and public pathways as opposed to being over private properties (if possible).
- To use, where possible, key arterial corridors to minimize impacts to communities. Arterials include Moffett Blvd, North Shoreline Blvd, East Middlefield Rd, and Charleston Rd.
- The AGT system will operate in a fully-dedicated corridor that does not share lanes or at-grade crossings with vehicular traffic.

Habitat Overlay Zones were examined to identify areas such as HOZ baselines, Burrowing Owl habitats, Egret Rookery and residential boundaries, and open water, creeks, and storm drain facilities and residential boundaries.

Also identified were PG&E substations and electrical powerline locations that could present a potential hazard for an elevated guideway. Additionally, Heritage Trees (mature Oak, Redwood and Cedar trees designated by Mountain View's City Code Chapter 32, Article II) in the city lining Charleston Road, North Shoreline Blvd, West Middlefield Road and Moffett Blvd could impact the alignment. Stevens Creek Trail is a designated regional park also identified as an area to avoid disturbing. The Hetch Hetchy Easement is an accessible corridor that has been identified as a potentially acceptable throughput for the alignment to traverse between Moffett Boulevard and Shoreline Boulevard if needed.

The identification of the candidate corridors shown in Figure 7-1 for the future AGT system was based on the existing and future planned development in the areas between and within the Transit Center, North Bayshore, and NASA-Ames.

Figure 7-1 Candidate Corridors

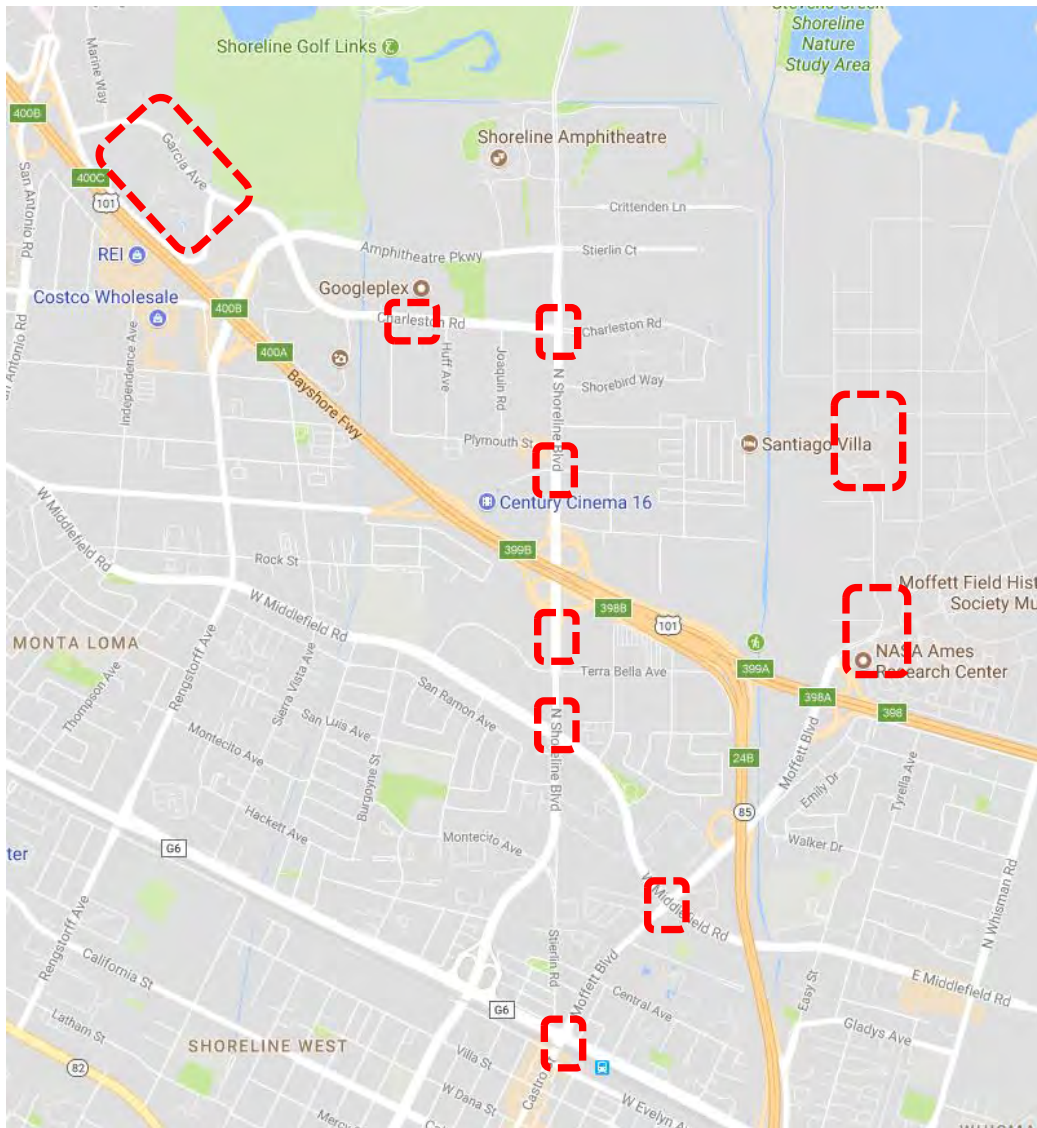


7.1 Station Locations

The identified station locations were based on the review of the existing land use in the City of Mountain View Zoning Map and a summary of the identified future developments from the City of Mountain View Planning Division. In addition, the stations within North Bayshore and the NASA-Ames areas were identified through discussions with the City and the TMA.

The possible station locations were then compared against each other to come to the final representative station locations shown in Figure 7-2 Representative Station Locations.

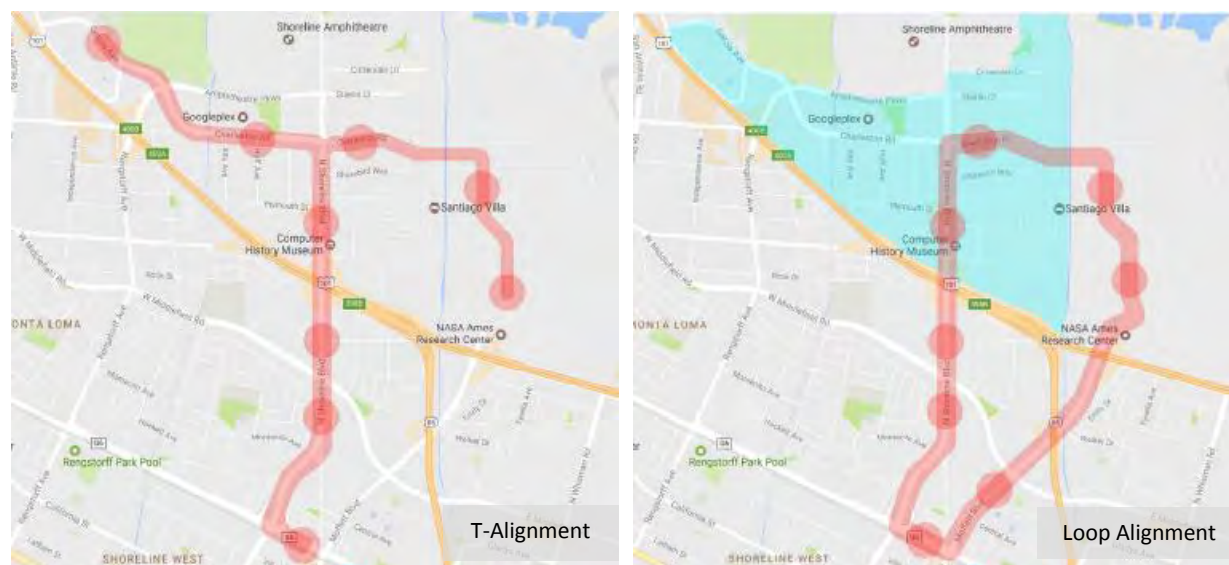
Figure 7-2 Representative Station Locations



7.2 Representative Alignment Alternatives

The study team reviewed multiple options within the candidate corridors for connecting the key nodes and identified two representative alignments for use in the evaluation, shown in Figure 7-3. The “T-alignment” features a line-haul type service with two routes: one to West Bayshore, and one to NASA-Ames. The “Loop” alignment features a dual lane bidirectional alignment for line-haul service with a supplemental network type system to provide further connection within North Bayshore. The route alternatives are considered “representative” and are used as a basis to compare the technology options. As the focus of this study is to identify the feasibility of AGT technology, a full development and analysis of alignment alternatives is not included.

Figure 7-3 Representative Corridor Alignments



In order to estimate the operational characteristics of a potential system, simulations (using Lea+Elliott’s proprietary ©Legends software) and spreadsheet-based calculations of the different technology groups’ service characteristics were performed using the representative “Loop” alignment. While both alignments are equally valid, simulations/calculations were only performed on the “Loop” alignment in order to streamline the evaluation process. Alignment geometry, station dwell times, operations at stations (particularly at the Transit Center), maximum travel speeds, passenger comfort parameters, vehicle turnback time, and type of service (line haul vs. point-to-point) were evaluated in the analysis. The simulated travel time was then used as part of the operational analysis to calculate fleet sizes needed to meet the demand, passenger trip times, passenger wait times, and vehicle frequency (refer to Section 8.2.1).

8. EVALUATION OF AGT TECHNOLOGIES

The four AGT technology groups were evaluated against a set list of Evaluation Criteria developed from the system characteristics discussed in Section 0 to determine those technologies that are a best fit for the needs of Mountain View and this AGT system.

8.1 Evaluation Criteria

The four technology groupings identified were evaluated against the set of Evaluation Criteria shown in Table 8-1. The evaluation included both qualitative and quantitative assessments to better understand the characteristics of each technology group and determine if they can or cannot meet the needs of the project. As indicated in the table, the 11 criteria were grouped into four key categories in order to highlight the most critical characteristics and the trade-offs associated with each technology, including passenger experience, infrastructure, technology application and cost. It should be noted that in addition to the qualitative review for the cost category, rough order magnitude systems capital and operation and maintenance (O&M) cost estimates were developed for each technology grouping.

Table 8-1 Evaluation Criteria

CATEGORY	CRITERIA	DESCRIPTION
Passenger Experience	1 Ability to serve market demand estimate	Evaluation Type: Quantitative A review of the capability of each technology to effectively meet the estimated daily and peak hour demand.
	2 Flexibility in service / responsiveness to demand	Evaluation Type: Quantitative A review of the fleet requirements for peak and off-peak operations will be performed to identify service flexibility and efficiency of use of fleet to accommodate demand patterns.
	3 Provides convenient and high-level service	Evaluation Type: Quantitative Simulation results will be used to identify the travel times and service frequency (i.e. resulting wait times for passengers). Providing convenient, accessible, safe, and comfortable mobility and transfers are integral in providing an attractive system with a high-level of service.
Infrastructure	4 Possible impact on neighborhoods	Evaluation Type: Quantitative Understanding the peripheral effects to the main corridor and side streets is integral to providing a comprehensive evaluation. This criterion addresses the potential impacts to the adjacent transportation system and modes (e.g. walking, biking) and potential impacts imposed on neighborhoods such as visual and noise.

CATEGORY	CRITERIA	DESCRIPTION
	5 Ability to fit within the local environment	<p>Evaluation Type: Qualitative</p> <p>The development and review of representative alignments and potential corridors will be used to understand whether a technology fits within a neighborhood or negatively impacts land use that the alignment may pass through/by. This includes a high-level review of the constructability of a system (typical alignment geometry requirements vs. physical constraints).</p>
	6 Adaptability of infrastructure	<p>Evaluation Type: Qualitative</p> <p>Because technology is changing and developing so quickly, this criterion is meant to review the ability for the infrastructure to be adapted for a different technology.</p>
Technology Application	7 Ability to add stations to serve existing or new developments	<p>Evaluation Type: Qualitative</p> <p>This criterion addresses the technology’s ability to add mid-line stations to serve existing and future developments along the initial alignment.</p>
	8 Ability to expand the system	<p>Evaluation Type: Qualitative</p> <p>The potential for each technology to be easily extended or expanded to serve areas beyond the initial alignment</p>
	9 Integration into Transit Center	<p>Evaluation Type: Qualitative</p> <p>A high-level review of the ability of each technology to integrate with the planned station at the Transit Center and is integral to identify potential issues and to overall success.</p>
	10 Level of technology maturity	<p>Evaluation Type: Qualitative</p> <p>It is important to understand how relative maturity, and therefore applicability, of technology relates to the project schedule. The service proven aspect of the technologies needs to be reviewed in conjunction with the project timing, ensuring that any selected technologies will be proven and therefore implemented as needed to meet the project schedule.</p>
Cost	11 Financial Feasibility	<p>Evaluation Type: Qualitative</p> <p>A high-level review of the potential or limitations for a system to utilize public/private partnerships/sponsorship and provide revenue opportunities such as through branding/wrapping of vehicles.</p>

8.2 Key Findings

The following is a summary of key findings, highlights, and considerations from the full evaluation provided in Attachment 1, Evaluation of AGT Technologies. Findings are presented based on the four key categories: Passenger Experience, Infrastructure, and Technology Application, and Cost.

8.2.1 Passenger Experience

Travel time, service frequency, vehicle size, and boarding features are major factors that shape passenger experience. These factors are interrelated and vary by AGT technology group.

To better understand these operating characteristics, an operational analysis was conducted for each technology grouping based on travel time simulation results and peak period passenger demand estimates. The resultant operating parameters for each technology group is summarized in Table 8-2.

The vehicle capacities indicated are based on the types of vehicles that have been typically used for each technology grouping, although GRT and Autonomous Transit is still evolving and could grow in capacity in the future.

Table 8-2 Operational Characteristics

Operational Characteristics	Aerial Cable	APM	ATN (PRT/GRT)	Autonomous Transit
Vehicle Capacity (passengers)	14 – 32	80	3 / 20	10 – 20
Travel Time to N. Bayshore (minutes)	11	7	6 / 7	6 – 7
Frequency to N. Bayshore During Peak Period	30 sec – 1 min	4 min	10 sec / 45 sec	30 sec - 1 min
Operating Fleet (vehicles)	22 – 48	8 x 2-car trains	135 – 140 / 25 – 30	35 – 80

The key takeaways regarding passenger experience are as follows:

- Vehicle Size and Service Frequency**—APMs feature high vehicle capacity with lower frequency of service and require smaller fleets to meet peak demands. Aerial Cable, ATN, and Autonomous Transit have much smaller vehicle capacities and, therefore, higher frequencies of service which equates to shorter passenger wait times. However, these smaller capacity vehicles require larger fleets to serve peak demand. As the system demand is commuter-driven, during off-peak periods, much of the ATN/Autonomous Transit fleet would be unused and need to be stored. This additional need for storage, as well as the efficiency of the fleet size and operations, needs to be considered in future planning efforts.
- Boarding Wait Time Experience**—APMs operate similarly to fixed-route transit, where passengers wait on a platform and board together onto larger trains at intermittent frequencies. Comparatively, Aerial Cable, ATN, and Autonomous Transit have vehicles constantly arriving and departing at stations, resulting in a continually moving queue as passengers wait to board vehicles. Overall, all technologies fare well in this area allowing for minimal wait times of <5 minutes during peak periods and throughout off-peak service periods.

- **Boarding Flexibility**—As a public transit system, an AGT system will need to be capable of serving all riders in the Mountain View community. This includes the ability to meet Americans with Disabilities Act (ADA) requirements. Aerial Cable and Autonomous Transit, and some ATN technologies, may present challenges.
 - The gondola-type systems where cabins typically do not come to a complete stop during boarding would require the entire aerial system to stop to allow for some ADA boarding. This would likely warrant the use of station attendants to assist passengers.
 - Another ADA consideration is level boarding. Compared to the other technology groups, most Autonomous Transit technologies have not demonstrated the capability for precision stopping and a minimized gap (1" to 2") between the vehicle floor and platform edge needed for level boarding without the use of in-pavement guidance
 - Some smaller in-development ATN and Autonomous Transit technologies have vehicles that require the passengers to sit in seats, similar to cars, which may cause concern to some in the ADA community and may result in boarding and travel time delays. Modification of the vehicle cabin would be needed to allow for flexibility and ease of use.
- **Bicycles on Vehicles**—While bicycle demand may not be high because of planned bike facilities in the study area and availability of bike share, some on-board bicycle capability will likely be needed and was taken into consideration in the analysis. This is not an issue with the medium to large vehicle/cabin sizes but may require modification of smaller ATN (e.g. PRT) and Autonomous Transit (e.g. 10 pax/vehicle capacity) vehicles to handle bikes.
- **On-Call/Point-to-Point Capability**—With the larger vehicle sizes and less frequent service, APMs operate with vehicles stopping at each station which can diminish the overall passenger experience. Aerial Cable systems also require all cabins to use all stations because the cabins are attached to the same cable. Additionally, with the lower operating speeds of Aerial Cable systems, the overall travel time between the Transit Center and North Bayshore is increased. Comparatively, the point-to-point and on-demand nature of ATN and Autonomous Transit systems allows for more personalized service with minimal wait and travel times for passengers during off peak periods. These technologies also allow for improved operating flexibility to adjust to service demand needs, providing either point-to-point service or traditional transit service during peak periods.

8.2.2 Infrastructure

The evaluation of the infrastructure for each AGT technology group focuses on the community impacts due to infrastructure needs and ongoing operations.

- **Visual Impacts**—The typical guideway design for an elevated APM, ATN, or Autonomous Transit system includes consistent column placement (every 80' to 120') along the alignment with a viaduct deck width similar to freeway ramps. Column placement locations might include landscape buffers adjacent to sidewalks street parking spaces, or medians depending on the alignment and available space. Tree removal or relocation will likely be necessary at some station and alignment locations. The viaduct structure is slightly smaller for ATN and Autonomous Transit than for some APM technologies; however, within the APM technology group, there are subcategories of technologies that have a smaller running surface compared to a typical rubber-tired APM, such as monorail.

Aerial Cable towers are located intermittently (approximately 500’ to 1,000’ apart) along the alignment with footprints that vary based on the system’s height and cabin size. The use of cables instead of a viaduct creates a very different visual impact along the system route.

Figure 8-1 provides renderings of potential infrastructure for Aerial Cable, APM, and ATN/Autonomous Transit systems.

Figure 8-1 Aerial, APM, and ATN/Autonomous Transit Infrastructure



Examples of different infrastructure styles are provided for reference for Aerial Cable, APM, and ATN technologies in Figure 8-2, Figure 8-3, and Figure 8-4, respectively. It should be noted that the style and overall dimensions of AGT infrastructure is dependent on the specific technology and local code/standards.

Figure 8-2 Example Aerial Cable Towers



Figure 8-3 Example APM Guideway Infrastructure

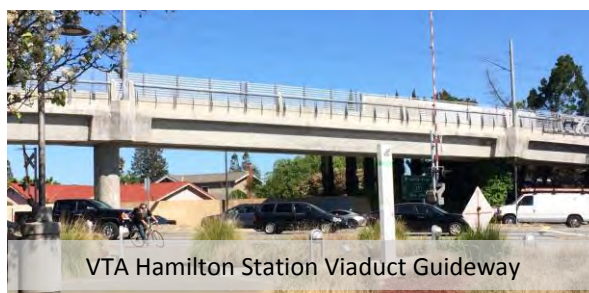


Figure 8-4 Example ATN Guideway Infrastructure



Preliminary guideway width estimates for some of the technology options, including emergency walkway, are provided in Table 8-3 for reference. These are general estimates based on existing structures and were not used to assess the viability of the potential alignments. Lane widths for Autonomous Transit were assumed to be in line with that of ATN/GRT. However, as this technology is not yet established it is unclear if additional requirements will be applied.

Table 8-3 Guideway Structure Width Estimates

Technology	Single Lane Width (Ft.)	Dual Lane Width (Ft.)
APM	18	30
APM- Monorail	11	18
ATN/GRT	12.5	22
Autonomous Transit	12.5	22

- Noise Impacts**—As this system will pass by residential neighborhoods, noise will also be a factor in selecting a technology. Other than Aerial Cable, the technologies are assumed to be electrically powered and operate on rubber tires to minimize noise impacts. APM, ATN, and Autonomous Transit will have intermittent sound as vehicles pass. Thus, the noise impact will depend on the frequency of the vehicles. Aerial Cable system noise impacts are minimal and limited to cable and cabin movement through sheaves at towers and in stations. However, the noise is constant as the cables are constantly moving.
- Privacy Impacts**—Privacy concerns may also pose an issue to residents. Due to the limitations regarding the turning radii and number/size of towers needed to make turns, it is likely that an Aerial Cable system cannot solely operate within and over public roadways and may need to operate over private property in some areas. The Aerial Cable vehicles will also operate at a higher elevation and, even if within the right-of-way, could provide riders more visibility into private property.
- Right-of-Way Impacts**— APM compared to ATN and Autonomous Transit requires larger turning radii to maintain speeds, which ultimately impacts ride comfort and travel times. These larger radii may result in limited options with regard to column placement where turns are needed along the system’s route. With the smaller allowable turning radii of ATN and Autonomous Transit, guideway infrastructure may be kept in medians or along sidewalks more effectively. The minimum operating radii required for APM’s may force the location of the structure outside of the public right of way and onto private and/or developed properties. While feasible, the infrastructure required to maintain ride comfort parameters and supplier design limitations for APM’s does not provide the flexibility of ATN and Autonomous Transit sized vehicles. There are a few intersections where geometry constraints pose a potential problem. Figure 8-5 shows the differences in required turning radii at one of these intersections, Charleston Boulevard and Shoreline Boulevard.

Figure 8-5 Turn Radii Required



8.2.3 Technology Application

Technology application considers status of technology maturity, system expansion flexibility, and technology adaptability.

- Technology Maturity**—There is a significant range between the mature, service-proven technologies of the Aerial Cable and APM technology groups and the ATN and Autonomous Transit technology groups, which are minimally established or still in development and testing. Thus, consideration should be given to the risk associated with technologies still in development and prior to Federal and State certification. The timing to implement ATN or Autonomous Transit will need to consider the time for development and/or certification.

As there is a significant difference in the degree of maturity across the chosen technologies, the funding for mature versus developing technologies is variable. Due to the maturity of the APM and Aerial Cable technology, there is likely little to no opportunity for private funding from a technology development or testing standpoint. However, suppliers for Autonomous Transit and ATN technologies that are in-development status may desire the opportunity to showcase their particular technology in an operational public setting with a public-private partnership. Also, as a main feature of this system is to provide a connection between the Transit Center and North Bayshore campuses, interest from private companies looking to provide an alternative mode for their employees to commute to campus may lend to the possibility of a public-private partnership.

- System Expansion Flexibility**—The ability to expand a system to serve new areas or to add midline stations is another technology consideration. ATN and Autonomous Transit technologies generally are easier to expand as stations would typically be off of the main line. Aerial cable and APMs are more difficult to expand or insert mid-line stations due to the technical complexity of those systems.
- Technology Adaptability**—Should an AGT guideway be developed in all or part of the corridor in the near future, it could be designed for conversion to a developing technology such as Autonomous Transit. Generally, a viaduct type structure used for non-monorail APM or ATN can be adapted for future similarly sized or smaller technologies. An example of existing AGT infrastructure being adapted for emerging technologies includes the Jacksonville Transit Agency

planning to convert their 27-year-old downtown APM system to Autonomous Transit by remodeling their existing guideway structure and allowing Autonomous Transit vehicles to operate at-grade in some corridors.

Alternatively, there are suppliers that are adapting their GRT technology to autonomous applications, such as Ultra Global PRT and 2getthere. These types of adaptations should be considered as the AGT system is developed further as they would allow for an effective transition from a more service proven technology to those currently in development, with little or no change to infrastructure.

Infrastructure for Aerial Cable systems, some APM technologies, such as monorail, and some ATN technologies, such as those that are suspended, are not adaptable for use by other technologies.

8.2.4 Cost Estimate

Rough order-of-magnitude cost estimates were developed for each technology group, including both capital cost (on a per-mile basis) and operations & maintenance (O&M) costs and are provided in Table 8-4. For purposes of this study, a fully elevated system and typical viaduct configuration for the APM, ATN, and Autonomous Transit technology groups were assumed. This assumption greatly affects the cost estimate, since about 80% of the cost is associated with system infrastructure. Costs could be lower if the guideway provided only a single (possibly reversible) lane or if (for Autonomous Transit) some of the guideway could be at street level.

As the project is in a very early feasibility study stage a range of ±20% was applied to all costs to address the fact that the project is still very undefined. Key elements that affect the cost estimates, including the alignment geometry, number and size of stations, and operations and fleet are still unknown. The ranges therefore reflect the rough order-of-magnitude aspect of these estimates.

Table 8-4 Preliminary Cost Estimate Summary

	Aerial Cable	APM	ATN (Assumes GRT)	Autonomous Transit
Capital Cost (per mile)	\$35M - \$50M	\$130M - \$195M	\$85M - \$130M	\$85M - \$135M
O&M Cost (per year)	\$9M - \$13M	\$15M - \$22M	\$6M - \$8M	\$5M - \$8M

Note: Depending on the technology and environment in which the system is being implemented, costs for facilities, or civil works, make up approximately 60-85% of the capital costs.

The per mile capital cost estimate includes systems equipment (e.g., vehicles, guidance, power, communications, train control, etc.), facilities (e.g., civil works for stations, guideway structure, and maintenance facility), soft costs (e.g., design, engineering, and project management), and includes a 20% contingency. This contingency is applied to address unknowns for the project that can be anticipated to increase costs based on previous experience, such as the extent of utility relocation, lengths of highway crossings, and possible land acquisition. Implementation of this type of system will also require interagency and property owner coordination, the extent of which is unknown at this stage.

The annual O&M cost estimate for each technology listed addresses labor, material (i.e., parts and consumables), and utility costs needed for the operations and maintenance of the estimated fleet size. O&M functions include items such as vehicle and guideway maintenance, central control operations, fare collection, janitorial services, and roving staff that can respond to mechanical problems and emergencies. As an automated system, AGT O&M labor costs can be relatively low compared to regular transit due to the absence of train operators and allow more frequent service to be operated.

Any transit system, whether automated or traditional, will have fixed and incremental operation costs that will vary based on service levels. The incremental costs associated with service level changes for traditional and automated systems may include similar functions such as preventive maintenance and cleaning services. For both types of systems in extended service, maintenance personnel and spare parts will be needed to maintain the vehicles and guideway components due to the additional vehicle mileage. The costs of these will vary based on the method of propulsion and specialized equipment needed. Additional fuel/electricity costs are also present in both automated and non-automated systems in situations of extended service. The advantage of automated transit relative to traditional transit is in the labor savings of operators, both in regular service and extended service. In the event that service is required to operate outside its normal planned schedule, no additional cost for operator labor is incurred with automation. Potential scheduling issues and overtime costs will be present in non-automated systems. Thus, if a special service is needed that is not part of the regular operating schedule, an automated system can provide improved cost and flexibility.

9. KEY CONCLUSIONS

9.1 Technology Evaluation Summary

The following is a summary of the evaluation findings based on four key categories - Passenger Experience, Infrastructure, Technology Application, and Cost. Within these categories, the evaluation showed significant differences between some of the technology groups. The full matrix and detailed evaluation of the each of the original 11 criteria is shown in Attachment 1, Evaluation of AGT Technologies.

The evaluation is a combination of qualitative and quantitative analyses that ties the design characteristics and the operational characteristics of the technologies with bigger picture impacts and benefits. Each technology was evaluated against each of the 11 criteria listed in Table 8-1 and given one of the following ratings. An explanation for each rating supported by either a quantifiable analysis or a qualitative assessment is provided in the evaluation matrix (Attachment 1).

- Fully Meets ●
- Moderately Meets With Reservations ◐
- Poorly Meets With Reservations ◑
- Fatally Flawed ○

Table 9-1 Ratings Summary

Technology	Passenger Experience	Infrastructure	Technology Application	Cost
Aerial Cable	◐	○	◐	◐
APM	◐	○	●	○
ATN/GRT	●	◐	◐	◐
Autonomous Transit	●	◐	◐	◐

While all of the technologies considered in the study are technically feasible for this project with regard to passenger experience and technology application, some technology characteristics, such as infrastructure design needs and cost, may not be best suited for the application and environment of the study area and therefore received fatally flawed scores. A summary of these key finding is as follows:

- Overall, aerial cable, APM, GRT, and medium-sized Autonomous Transit technology can comfortably accommodate the required demand with reasonable operations.
- Due to the PRT vehicle size and the resulting required high number of vehicles needed, as well as operational, safety, and regulatory uncertainties surrounding the under 10 second headways, this technology does not appear to be the best fit for the needs of this system.
- Due to limitations on turn radii, aerial cable technology may need to operate over private properties, leading to privacy concerns.
- Due to the congested urban environment that the system will run through, APM infrastructure and alignment design requirements may be too cumbersome to provide flexibility in column and guideway placement and may not best suited to fit within the environment.

- Medium-sized vehicles technologies including GRT and Autonomous Transit are more appropriate with respect to maneuvering through an urban environment and meeting demand with reasonable operational parameters.

The following is a summary for each technology group:

- **Aerial Cable**—While a well-established technology, Aerial Cable systems are generally deployed where there are topographic barriers, not usually in urban areas. Although less visually intrusive along the major roadways in Mountain View, the towers require larger footprints than the columns of the other systems and the vehicles are at a higher elevation creating a potential privacy concern for nearby residences. The potential need for station attendants to stop the system and assist passengers with disabilities adds to the operating costs and is contrary to providing an automated system which is desired for this connection. In addition, Aerial Cable technology operates at slower speeds than other technologies, is not easily expandable, and is not adaptable to other technologies.
- **Automated People Mover (APM)**—APM is also a well-established technology but is often developed in self-contained areas such as airports. There are a few urban systems such as the Seattle Monorail and people movers in Detroit, Miami, and Jacksonville. APM uses larger vehicles running somewhat less frequently. As a result, APM can be effective in serving peak demand but may provide more capacity than is needed in the off-peak. The APM infrastructure is heavier and higher in cost than other options and allows for less flexibility to maneuver through built-up environment like Mountain View. APM infrastructure requires turning radii that are too large for the current roadway designs and will limit options for column placement as shown in Figure 8-5. Some APM technologies can also be challenging to expand or extend if not properly planned for initially.
- **Automated Transit Network (ATN)**—Although not necessarily a new technology, ATN technology has only been fully deployed in a few locations. For the North Bayshore corridor, ATN with small (2 to 3 passenger) vehicles would require a fleet of approximately 135 to 140 vehicles traveling at a 10-second frequency to meet peak demand. At stations, multiple berths and a large staging area would be needed to achieve the throughput required to meet this peak demand, and because much of the PRT fleet would be used only during peak hours, a large storage area would be required for the remainder of the operating day. This type of operation would mean a high number of vehicles would be stored for the majority of the operating day and only be pulled into service during the relatively short peak periods. These vehicles would still need to be maintained despite only operating for a few hours thus incurring increased maintenance costs for vehicles that are not operating efficiently. While suppliers note headways below 15 seconds are possible, there are regulatory-related safety concerns regarding such low headways, as vehicles potentially cannot emergency stop without fully avoiding a stopped vehicle ahead. For these reasons, a Personal Rapid Transit (PRT) approach may not be appropriate for the study application. The Group Rapid Transit (GRT) variation, with larger vehicles, could be a better fit to serve the corridor demand, while retaining a reasonable midday service level. The medium sized vehicles of GRT can also accommodate ADA needs and bicycles more readily compared to some smaller PRT counterparts. Since the guidance system is generally integrated with the guideway, these systems do require exclusive right-of-way or full grade separation.

- **Autonomous Transit** —The newest technology, Autonomous Transit, would be operationally similar to ATN and could operate on a fully grade-separated guideway. The guidance systems are provided in the vehicles, simplifying the elevated guideway segments to be just structural elements. In addition, this technology offers the potential to reduce costs by operating partially at-grade in dedicated lanes with shared crossings of vehicular traffic, or even in mixed-flow conditions, with appropriate safety provisions (i.e. transit preemption or priority) and demonstration of crashworthiness. Autonomous Transit technology is still mostly in the development phase by the majority of system suppliers with only two known operating systems¹. The significant number of pilot and demonstration projects indicates the intensity of interest in this emerging solution, particularly the potential to reduce deployment cost by eliminating the need for the civil infrastructure of elevated guideways and tracks as well as the operational costs of drivers in each vehicle. As pilot and demonstration projects continue, the number of viable suppliers for Autonomous Transit systems ready for revenue service will continue to increase within the next five to ten years.

9.2 Final Assessment

Based on the evaluation, ATN/GRT and Autonomous Transit technologies are the most appropriate technology options for this transit application designed to be an extension of major transit services with relatively short distances. Although the other technologies can provide the service to meet the estimated demand, they are not the best fit for the environment. The alignment geometry required for turns by Aerial Cable and APM technologies do not provide the flexibility needed to maneuver through the area with minimal environmental and private property impacts. In addition, although PRT would provide a personalized point-to-point ride, it is not the most appropriate solution to serve transportation demand with significant peak activity due to a large required fleet size and significantly short headways, which are not proven and could pose safety concerns.

9.3 Proposed AGT Objectives and Characteristics

In addition to the recommended focus on the ATN/GRT and Autonomous Transit technologies, the study also helps to define the type of system and service needed for the study area. In general, the desired system should be one that can:

- Connect major transit stations with nearby employment and residential areas, providing the first/last-mile connection
- Maneuver through and fit within the existing built-up environment with limited impacts
- Provide highly competitive travel times compared to auto or traditional transit service
- Provide a non-auto mobility option for local trips of all types
- Serve moderately high passenger demand during peak conditions (e.g. transfers from Caltrain)
- Provide frequent cost-effective service throughout the day
- Provide operational flexibility to change operating modes (line haul vs. direct point-to-point) to meet the needs of different passenger demand levels during peak and off-peak periods

¹ The Masdar City PRT system, while developed to use in-pavement magnets for navigation, no longer relies upon the magnets for navigation. The current generation 2getthere vehicles are capable of navigating the route without in-pavement infrastructure. The Bluewaters GRT system being deployed in 2018 will not require in-pavement technology.

These objectives help to better define the key system characteristics that would be needed for passenger service. The desired characteristics for this system include:

- Vehicles
 - Capable of speeds up to 30+ miles per hour
 - Vehicle capacity of 20-30 persons, including standees
 - Vehicle size of 20 to 30 feet; capable of operating in platoons
 - Battery powered with battery charging capability at stations

- Facilities and control system that support advanced transit service, including:
 - Capability to operate vehicles with peak service frequency of 30-45 seconds (or 1-2 minutes if operated in multi-vehicle platoons) and off-peak frequency of 5 minutes or less
 - Capability to operate vehicles on dedicated guideway and/or in exclusive at-grade lanes with limited interaction with regular traffic and pedestrians (Level 4 autonomy, fully self-driving in a controlled environment)
 - Precision docking to allow for level boarding at stations that meets ADA requirements
 - Off-line stations at intermediate locations to allow for point-to-point service
 - Operating control system (vehicle dispatching, customer information, trip routing, door controls, fare collection, vehicle platooning)
 - Safety and security provisions, including provisions for emergency evacuation
 - Adaptable guideway design that allows for potential at-grade extensions
 - Operations and maintenance facility integrated into environment, including the possibility of integrating with another building/function (e.g., parking garage)

- O&M provisions for guideway, stations and vehicles – staffing and equipment

10. CONSIDERATIONS FOR FUTURE PLANNING

If a transit solution in the Mountain View community is anticipated in the near future, GRT and Autonomous Transit have the capability to provide sufficient capacity and service on a fully exclusive right of way. However, there are several additional topics to consider in the general development of an AGT system.

10.1 Technology Evolution and Development

As discussed previously, the technologies currently available can meet the capacity with the vehicle sizes available. However, if this system is not implemented in the near term, there may be more flexibility on operations and vehicle size options as the technologies develop to meet the growing interest in automated transit systems worldwide. These trends will evolve depending on both how suppliers choose to evolve the technologies and how agencies' requirements dictate for the technologies to be developed. For example, the fleet size for GRT/Autonomous Transit can be reduced if the vehicle sizes can be increased. Similar to the evolution of the standard bus coach, automated driverless shuttles will likely settle on a reasonably small number of vehicle size choices based on customer (agency) demand over the next ten years. Virtual entrainment, or platooning, of vehicles together to form a higher capacity train is also likely to evolve.

Not only may vehicle sizes evolve but the speeds of these technologies are also likely to improve as technology improves. For example, although current Autonomous Transit technology operates at speeds ranging from 6 to 25 mph, the typical maximum operating speed listed by the manufacturers for current operating installations ranges from 15 to 25 mph depending on the operating environment. Over the next 5 to 10 years, this technology will increase travel speeds to between 35 and 40 mph as it matures, particularly in roadway vehicle traffic flows on city streets where pedestrian crossing activity only occurs at specific, signal-controlled locations. In the longer term (15+ years), speeds may reach up to 55 mph in high-speed (guideway-controlled) environments.

There are a significant number of companies working toward developing Autonomous Transit. However, these developing technologies are all currently in the testing/pilot phase. While ATN/GRT have proven technologies and the suppliers are still active, few new systems are being developed. It appears that their focus is shifting to autonomous vehicles or a hybrid to transition ATN technologies to Autonomous Transit. For example, the company that developed the Heathrow PRT system (Ultra Global PRT) is now partnering with TRL, a transportation research agency in the UK, to develop an Autonomous Transit pilot for at-grade operation. The first phase is under way and work is planned to develop a larger capacity and higher speed vehicle. In addition, 2getthere has established GRT vehicles that operate by following magnets embedded in a roadway. As part of their ongoing technology development they have adapted their technology to operate autonomously as well. This next generation technology is capable of transitioning between autonomous operations and the use of the imbedded magnets, which would allow for precision berthing (level boarding) and continued service in adverse weather conditions.

10.2 Safety Certification and Regulations

Safety standards for APM and aerial systems have been in place for many years and operational safety has been proven in many deployed systems. Autonomous Transit systems have no equivalent safety certification procedures at the time of this writing, although such procedures and standards are anticipated to be developed over the next 5+ years as the interest in these systems is increasing worldwide. However, the timeline of these standards and certifications is relatively uncertain and can

accelerate based on advancements in technology or lengthen based on public safety concerns or unforeseen issues.

It is currently in flux whether or not the California Public Utilities Commission (CPUC), the California Department of Motor Vehicles (DMV), or other regulatory bodies will be the principal authority having jurisdiction over projects such as the Mountain View AGT project. The California DMV has been issuing permits for the pilot shuttle projects and is expected to allow limited tests in mixed traffic. Historically, the CPUC has been responsible for transit system safety certification but currently has no directive to develop guidance on Autonomous Transit vehicles.

Operating at-grade public transit service with automated vehicles, particularly in the United States, brings additional regulatory and policy considerations. An important consideration is compliance with the Americans with Disabilities Act, particularly if funding is expected from FTA for the development and operation of the service. Where there exist long-standing and sufficient standards developed for safety provisions of automated people movers, no such standards have yet been developed for at-grade automated vehicles without dedicated guideway. While not certain, it is likely that Autonomous Transit vehicles operating in a controlled, exclusive environment by a single agency will receive regulatory approval sooner than Autonomous Transit vehicles operating in a mixed traffic environment.

The regulations include special features of the transit system for audio and visual communications to aid hearing and sight disabled persons, as well as more challenging requirements for passengers in wheelchairs. The loading and unloading of people in wheelchairs when no human attendant is present will probably require precision docking of the vehicle at the station berth (as FTA requires for low speed people movers). Alternatively, wheelchair ramps that extend from the vehicle onto the platform may be allowed. These elevations and slopes will require extending relatively long ramps several feet in length, which may be very challenging to accommodate. When a fully automated vehicle must extend a ramp and ensure that this operation of loading passengers in wheelchairs is performed strictly in accord with the safety requirements, the sensing and interdiction of operations under conditions potentially injuring passengers require technology that has not yet been developed or safety certified.

Crashworthiness of the automated vehicles is also an important consideration especially if they are expected to cross intersections at-grade, even with transit preemption or priority provisions.

10.3 Shoreline Amphitheater Service

The system has the potential to also be available for events at the Shoreline Amphitheater. A station at the North Bayshore/Charleston intersection is a close walk from the Amphitheater and would also serve as a means to 'meter' the flow of passengers departing events to access the system.

In addition, although it is not reasonable to size the system for the Amphitheater surging, there is flexibility in modifying regular service during special Amphitheater events, with a corresponding effect on the number of passengers that the system can transport. In order to get large amounts of people out of the Amphitheater area, an express route can be operated between North Bayshore and the Transit Center station with no intermediate stops. All available fleet can be utilized, and headways shortened to temporarily increase capacity. For example, even though GRT/Autonomous Transit technology is expected to normally operate close to minimum headways, optimizing operations by creating an express line-haul service that operates non-stop between the Transit Center and North Bayshore can achieve approximately 2,800 passengers per hour per direction.

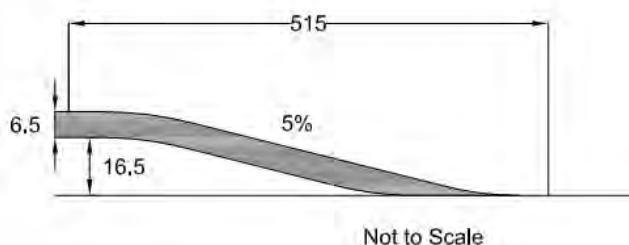
As an AGT system could potentially provide service to support Amphitheater events, coordination between the City and the Amphitheater is needed to both understand what Amphitheater service plans are and develop a strategic approach for utilizing the AGT system. For example, consideration is needed for station sizing at the Charleston and Transit Center stations as additional berthing and larger platforms for passengers queuing may be warranted if significant service for Amphitheater events is planned.

10.4 At Grade Sections

For this study, the system is assumed to run fully on elevated exclusive track. However, there may be opportunities to bring the guideway to grade in certain areas to reduce construction cost and guideway impacts. Further analysis will be needed to investigate site conditions to see where this may be possible along the alignment and to evaluate possible community and traffic impacts.

To help inform future assessments, a high-level review was done to determine the estimated horizontal distances needed to change elevation according to ATN technology design criteria. The transitions shown in Figure 10-1, will require, at minimum, approximately 515 feet of straight tangent track in flat topographical conditions to transition from an elevated right-of-way to grade for ATN technology. Site conditions and guideway design may increase the distances needed to make these transitions. At-grade, ATN technologies need dedicated lanes to maintain complete separation from vehicular traffic. However, Autonomous Transit technology may have the option of allowing shared at-grade crossings with vehicular traffic in the future.

Figure 10-1 Elevated to At-Grade Transition Distances for ATN/Autonomous Transit

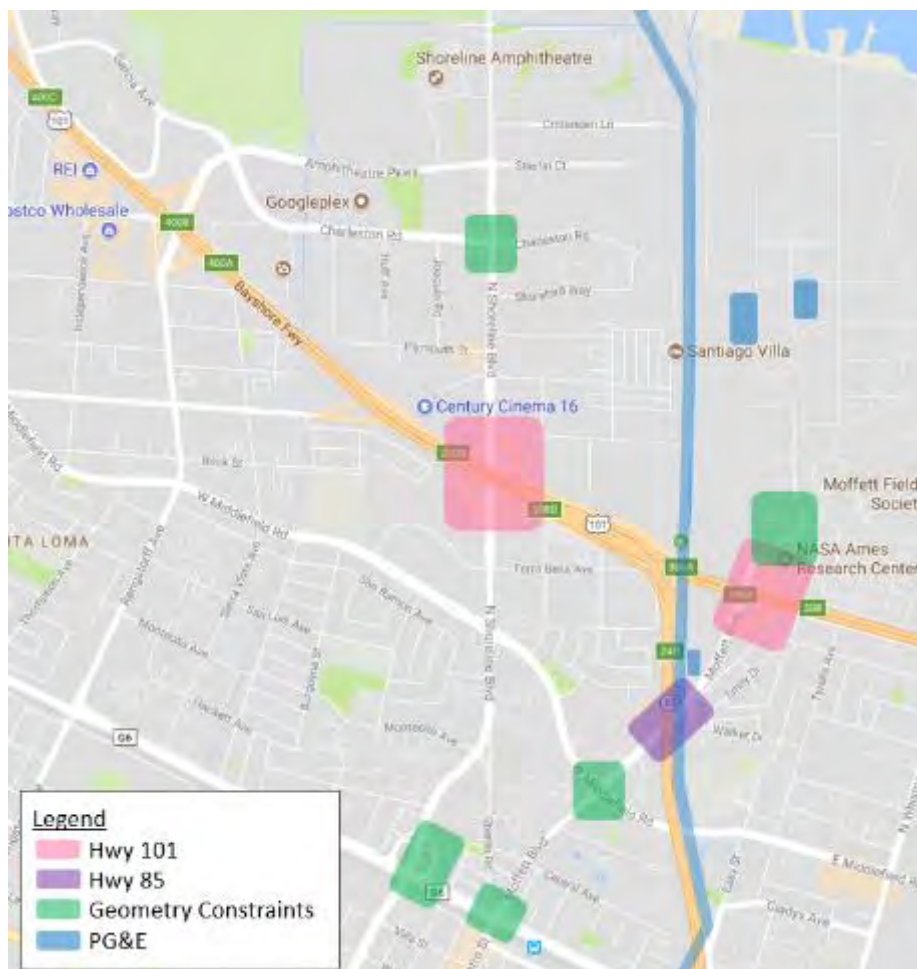


10.5 Corridor Challenges

The alignments and station locations shown in this report are representative only and are not intended to denote final locations. Possible alignments and station locations will need to be evaluated based on the alignment design parameters and geometric constraints for the chosen technology. This includes designing potential guideway concepts, with both horizontal and vertical layouts, as well as station layout concepts and footprints. Station sizing will also need to be considered when choosing locations as space must be accommodated for vehicle berthing for unloading/loading of passengers, vertical circulation, passenger queuing, and vehicle storage and staging. This is especially important at the transfer station at the Transit Center.

While the objective is to have the guideway structure run along public roads, sidewalks, and medians, there are challenges within the identified corridors that will affect the design and location of the guideway, such as locations where turns are needed, freeway crossings (e.g., 101 and 85, Shoreline/Central Expressway), PG&E lines and substations, Heritage trees, and crossing of Stevens Creek. Some of the challenges are identified in Figure 10-2 below.

Figure 10-2 Corridor Challenges



10.6 Transit Center Station

To better understand the general size and potential layout of a station and how it might integrate into the Transit Center area an AGT station concept was developed.

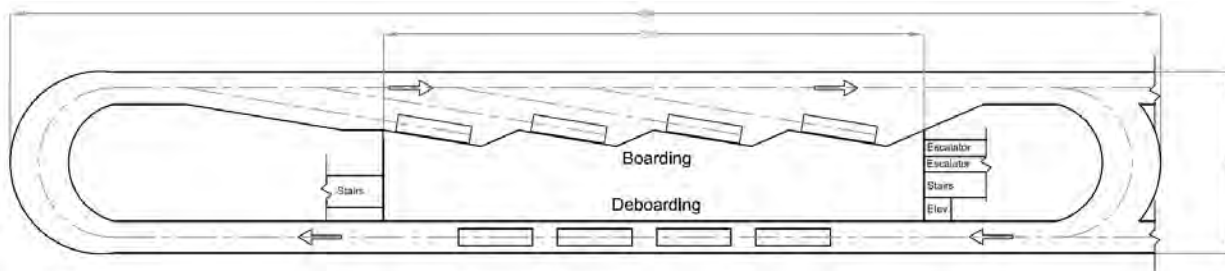
Due to the short headways and the high passenger volumes expected at the Transit Center, separate vehicle deboarding and boarding platforms were assumed. Although this results in berthing positions on both sides of the platform, it minimizes the impact and disruption to departing passengers, reduces passenger cross traffic on the platform, and can ease wayfinding in the station. To serve the high throughput estimated for the station (330 passengers in a 10-minute period) a sawtooth platform configuration is used for the boarding platform. It allows vehicles to pick-up and depart the station without being impacted by other vehicle delays. In contrast, the deboarding platform is an in-line platform which utilizes first in-first out operations and helps to minimize the overall station width.

required. The number of berths provided are based on the passenger demand and station throughput estimated for the Transit Center AGT station.

To allow for flexibility, the vehicle berth lengths are sized to accommodate 30-foot vehicles compared to the current ATN/GRT and Autonomous Transit vehicles available, which are approximately 20 feet long. This allows for the use of existing shuttle vehicles in the near term and safeguards for the possibility of longer ATN/GRT and Autonomous Transit vehicles with higher capacities in the future. In addition, the overall platform width considers both area for passenger queuing and cross traffic, as well as, the minimum vehicle turning radii for the turnarounds on either side of the station. Travel lane widths assume ATN/GRT or Autonomous Transit vehicles. Additional width for shoulders/barriers might be needed depending on regulatory requirements. Thus, the projected station size is approximately 73 feet wide and 464 feet long, including length for turnarounds, as shown in Figure 10-3.

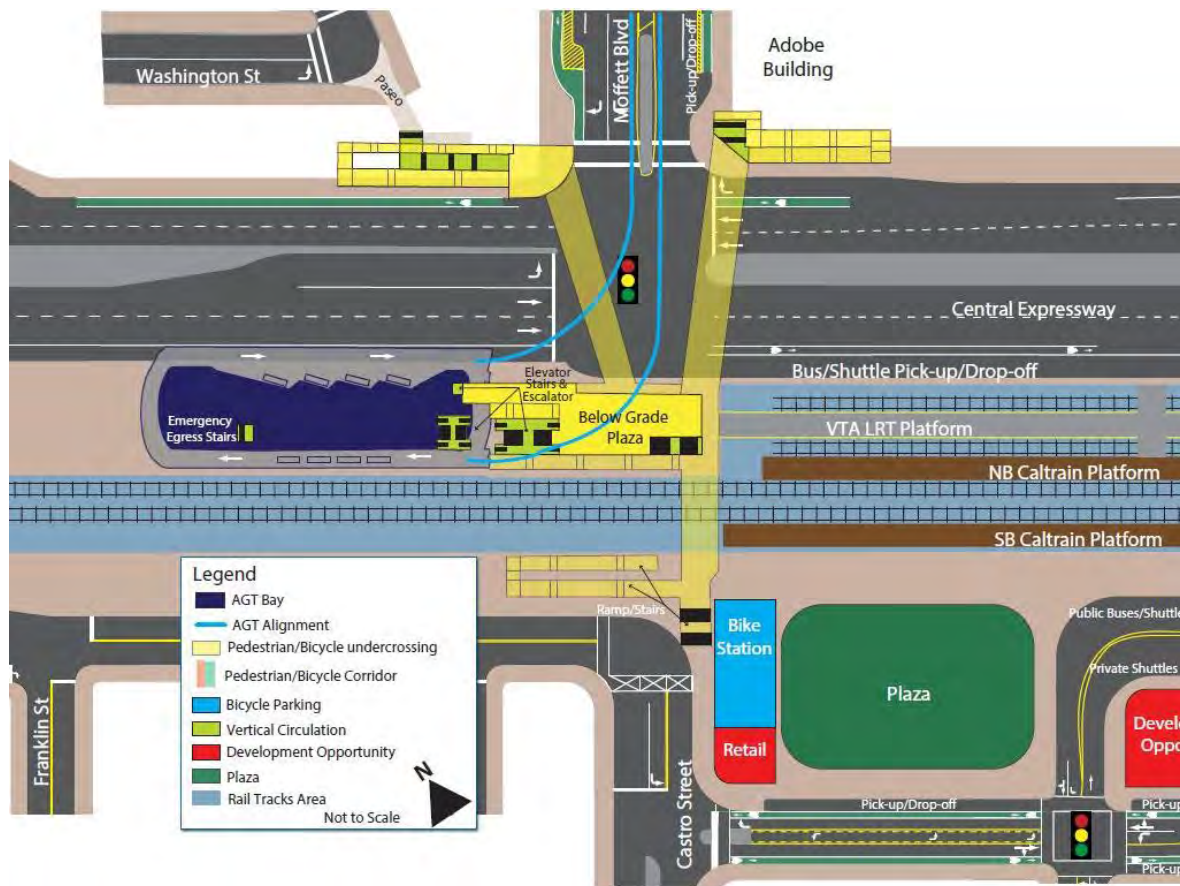
In addition, the Transit Center station concept is an end of the line station with the potential to be an intermediate station if the system is expanded in the future. As an end station, only one travel lane is needed on each side. An additional passing lane would likely be required on each side for an intermediate station to allow vehicles to pass the station without stopping. With the additional passing lanes, the station width would be approximately 100 feet.

Figure 10-3 Transit Center AGT Station Concept



The station location is assumed to be on the Southwest corner of the Castro Street-Central Expressway intersection, between the Caltrain tracks and Central Expressway. To accommodate the estimated station width, the station will need to extend over Eastbound lanes of Central Expressway. Figure 10-4 provides a concept for the potential integration of the AGT station into the Transit Center area.

Figure 10-4 Concept Transit Center AGT Station Integration



11. NEXT STEPS

The goal of this study was to identify what AGT technology, if any, could provide a solution to the increasing traffic and congestion for the last-mile connection, particularly between the downtown Transit Center and the North Bayshore and NASA-Ames areas. Evaluation results have identified GRT and Autonomous Transit as the technologies that best meet the service needs as well as fit within study area environment. However, more study is needed to inform decision-makers and further advance the project. The following are recommended next steps to not only get a more thorough understanding of the recommended technologies, GRT and Autonomous Transit, but also to better understand how these could be successfully incorporated into Mountain View.

- In depth review of GRT and Autonomous Transit technologies. This review should assess the state of the GRT and Autonomous Transit industries, including the available technologies' commercial technical development and the suppliers'/manufacturers' commercial viability and overall stability to support implementation and subsequent O&M. In addition, Federal and State regulatory requirements for use of these technologies for public transit operations, particularly Autonomous Transit, should be monitored and assessed as the project progresses. Having a better understanding of these elements will support the development of a more accurate timeline for implementation and system cost estimate and ultimately further inform decision makers.
- Detailed evaluation of potential alignment alternatives, including development of horizontal and vertical alignments, station concepts, and maintenance and storage facility locations and sizing. This would include assessing right-of-way requirements for the system infrastructure and associated roadway and traffic impacts and improvements needed. The results of this effort will help identify public and private party stakeholder coordination needed and support the development of a more accurate capital cost estimate related to system infrastructure.
- Review of potential procurement strategies for the AGT system (e.g., Design Build, Design Build Operate Maintain, P3, etc.). To identify the best approach a better understanding of the risks associated with the planning, design, manufacturing, implementation, testing, and O&M of an AGT system and the party that can best manage the risk will be needed.
- Conduct an economic benefit analysis and determine a potential funding strategy for implementing an AGT system in Mountain View. This analysis would include assessing potential partnerships with community stakeholders (public and private) and revenue sources, such as advertising and system fares. The economic analysis can go hand-in-hand with determining the best procurement approach for the project as there may be opportunities for some level of project financing or public private partnership.
- Continue outreach efforts with both the community and public and private stakeholders as the project progresses to ensure timely input and coordination. In addition, a coordinated study with major stakeholders may be beneficial to develop a concurrence as the project progresses. This effort can also help inform the partnerships needed and procurement approach, particularly as it pertains to O&M oversight and functions. Along with general outreach, City Master Planning efforts should also work in conjunction with the AGT project, as opportunities to integrate the AGT system and connections with future developments within the study area can be identified and supported.