DATE:	October 17, 2017
TO:	Honorable Mayor and City Council
FROM:	James Lightbody, Project Manager Dawn S. Cameron, Assistant Public Works Director Michael A. Fuller, Public Works Director
VIA:	Daniel H. Rich, City Manager
TITLE:	**Automated Guideway Transit Study Update**

STUDY SESSION MEMO

CITY OF MOUNTAIN VIEW

PURPOSE

The purpose of this Study Session is to inform the City Council about the initial evaluation of technology options for the Automated Guideway Transit (AGT) study and to solicit City Council input and direction for completing the study.

BACKGROUND

At its June 16, 2015 meeting, the City Council adopted three new major goals and accompanying projects for Fiscal Years 2015-16 and 2016-17. In support of the goal to improve transportation by enhancing mobility and connectivity, the Council directed staff to initiate a multi-year process in conjunction with other cities and agencies to improve last-mile connections, particularly fixed-rail options.

During an October 27, 2015 Study Session, the City Council provided the following additional direction to guide the development of a work plan that appropriately addresses the Council's desired result:

- The focus should be on the development of an off-street AGT system (e.g., automated people mover, group rapid transit, personal rapid transit, etc.).

- Priority focus should be given to the corridor linking the Downtown Transit Center to the City's North Bayshore Area.

The City Council also directed staff to monitor the North Bayshore Transportation Access Study that Google has contracted with the Valley Transportation Authority (VTA) to conduct.

On February 2, 2016, the City Council provided input regarding a proposed process to explore the development of an AGT system for the Downtown Transit Center to North Bayshore, and on December 6, 2016, the City Council authorized the City Manager or his designee to execute a professional services agreement with Lea+Elliott, Inc. (Lea+Elliott), to prepare the study.

The Lea+Elliott team is addressing the identification of candidate technologies, development of passenger market and demand estimates, identification of system requirements, and evaluation of technologies to meet system needs as well as conducting a multi-faceted outreach process.

On May 23, 2017, the City Council provided input on the proposed technology groups, the study corridor, and the recommended evaluation criteria. This input has been used to continue the evaluation of technology options.

Community and Agency Outreach

- **Project Website** (www.mountainviewagtfeasibility.com)—The project website provides information and updates regarding the AGT study. More than 750 individuals have visited the website and 41 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 City Council discussions.

- **Project Community Meeting**—A second community meeting was held on September 25, 2017. Meeting participants were given an overview of the study and provided input on the technology options, project goals and objectives, and key considerations. A summary of the community meeting is provided in Attachment 1.

- **Business Outreach**—Project team members are continuing to engage other companies and business groups throughout the study, including recent meetings with Google and NASA Ames.

- **Partner Agency Discussions**—Outreach is continuing with stakeholder agencies, including Caltrain, VTA, and the Mountain View Transportation Management Agency (TMA). In particular, there have been discussions with VTA to coordinate the Google-funded North Bayshore Transportation Study with the AGT Study.

DISCUSSION

The study team has conducted an initial evaluation of the following four AGT technology groups, which are summarized in Figure 1 and described further in Attachment 2:

1. Aerial Cable
2. Automated People Mover (APM)
3. Automated Transit Network (ATN)—both Personal Rapid Transit (PRT) and Group Rapid Transit (GRT)
4. Autonomous Transit

Figure 1—Technology Options

Aerial Cable Transportation This type of transit system 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 and aerial trams. The smaller-sized gondolas can transport about 2,000 people per hour per direction. The larger aerial trams can transport up to 6,000 passengers per hour. They generally operate in the 10 to 20 mph range.	 Roosevelt Island Tramway, Aerial Tram (NYC, NY)
Automated People Movers (APM) This technology is best described as an automated transit system with large capacity vehicles operating on a fixed guideway. Propulsion can be of several methods, such as cable, electrically power, or magnetic levitation. This grouping includes rubber-tire and steel-wheel APM, Monorails, and Maglevs. These technologies can reach greater speeds compared to the other technology groups and have larger vehicles and greater system capacity.	 Mitsubishi: Crystal Mover APM (Miami International Airport, FL)

Automated Transit Network (ATN) Smaller automated vehicles operating on a network of guide-ways and providing point-to-point service for passengers characterize this technology group. ATN guideways can use sensors and other technology to provide guidance, rather than tracks or cables. Personal Rapid Transit (PRT) and Group Rapid Transit (GRT) technologies were included in this group as they both have smaller capacities and similar operation. Multiple vehicles can be located at stations and are deployed when called on by passengers leading to shorter wait times.	 Ultra Global PRT (Heathrow, England)  2getthere GRT
Autonomous Transit This technology group consists of automated vehicles on a mapped network, preferably with dedicated lanes, but capable of operating in mixed-flow traffic. Equipped with sensors and GPS, guidance is provided by the vehicle rather than the guideway. Capacity is similar to ATN, although there is potential for higher-capacity vehicles to be developed. While current pilot operations involve lower speeds, average speed of the vehicles has the potential to increase in the future as the technology becomes more mature and service proven.	 EasyMile:  Navya: Arma

The methodology for the evaluation included updating the demand estimate for sizing the system, developing representative alignments, evaluating each technology group based on data gained from operational stimulations, and developing order-of-magnitude capital and operations and maintenance (O&M) cost estimates.

At the May 23, 2017 Study Session, Council reviewed and supported a set of 11 evaluation criteria. These have been used in the evaluation, and have been compressed into four categories for this summary: Passenger Experience, Infrastructure, Technology Application, and Costs. Attachment 3 shows the allocation of the criteria to these four categories.

Demand Estimate

Subsequent to the initial estimate of potential market demand for the AGT Study presented at the May 2017 Council Study Session, the project area was expanded to include the NASA Ames Research Center. The updated market demand shown in Table 1 takes into account both commute and non-commute travel and is based on approved long-term plans for the North Bayshore and NASA areas, plus the addition of potential North Bayshore Precise Plan housing.

Table 1—Daily Demand Estimate

Market	Lower Bound Daily Ridership Estimate	Upper Bound Daily Ridership Estimate
Caltrain Riders	2,300	4,600
Existing Residential Commuter Trips	400	650
Future Resident Commuter Trips	1,170	2,850
Non-commuter Trips	220	550
Total	**4,090**	**8,650**

Demand was estimated for a peak 10-minute period to ensure that the system would be able to handle overlapping demands from multiple peak-hour Caltrain arrivals. System capacity objectives were established around the upper bound peak 10-minute demands shown in Table 2 below.

Table 2—Peak 10-Minute Demand Estimate

10-Minute Peak Period	To Transit Center		From Transit Center	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
A.M.	51	115	166	333
P.M.	61	131	145	330

One demand issue that has been raised in previous meetings is potential service for Shoreline Amphitheatre events. Because the Shoreline events are infrequent with high trip volumes, the study team did not attempt to size the system for that demand.

However, depending on the technology, an AGT system could provide a useful access option for events.

Representative Alignments

The review of AGT technologies was performed at a corridor level, focusing conceptual system routes that link the Mountain View Transit Center to the North Bayshore and NASA Ames areas. Key factors in developing conceptual corridor alternatives were:

- The alignment should serve the Transit Center, North Bayshore, NASA Ames, and key development sites along the corridor.
- The alignment should travel, to the extent possible, along public right-of-way and key arterials as opposed to traveling through or over private property
- The AGT system will operate in a grade-separated, elevated guideway.

The study team reviewed multiple options within the candidate corridors for connecting the key nodes and identified two representative alignments as shown in Figures 2 and 3 for use in the evaluation. The "T Alignment" features a line-haul type service with two routes: one to Intuit and one to NASA Ames. The "Loop Alignment" features a dual-lane, bidirectional alignment for line-haul service and assumes a supplemental network type system will provide further connections within North Bayshore (which could be a combination of bicycle connections and an ATN or Autonomous Transit service). 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, further development and analysis of alignment alternatives would be part of a future phase.

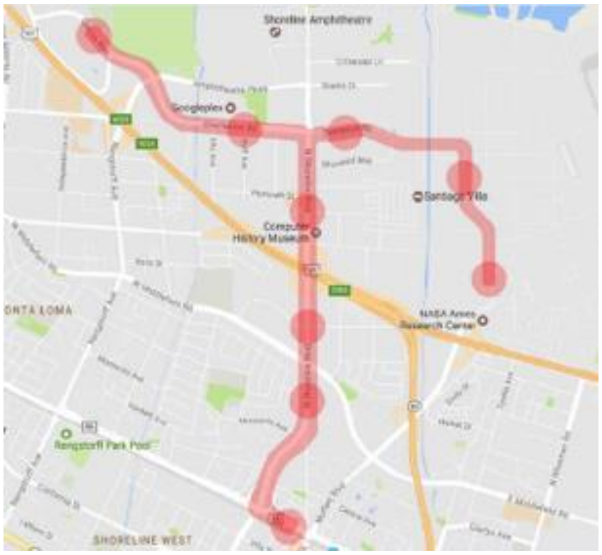

Figure 2—T Alignment

Figure 3—Loop Alignment

Operational Simulations and Characteristics

In order to estimate the operational characteristics of a potential system, simulations of the different technology groups were performed using the representative Loop alignment. It was determined that the T alignment would have similar travel time and fleet characteristics to the Loop alignment. Simulation inputs included factors such as alignment geometry, station locations, dwell times, vehicle/passenger comfort parameters, and car capacity (including bikes on vehicles). The simulated travel time was then used to calculate operating fleet sizes needed to meet the demand, passenger trip times, passenger wait times, and vehicle frequency.

Table 3 summarizes the resulting operational characteristics for each technological group based on the peak demand and travel time simulations. The vehicle capacities are based on the types of vehicles that have been typically used for each technology, although GRT and Autonomous Transit vehicles are still evolving and could grow in capacity in the future. The simulation also assumed minimal wait time during the peak, with a maximum wait of five minutes throughout the day.

Table 3—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

Initial Evaluation

The following is a summary of the initial evaluation findings, categorized into four key areas: Passenger Experience, Infrastructure, Technology Application, and Costs.

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 as follows:

- **Vehicle Size and Service Frequency**—APMs feature high vehicle capacity requiring lower frequency of service and smaller fleets to meet peak demand. Aerial Cable, ATN, and Autonomous Transit have much smaller vehicle capacities and, therefore, require higher frequencies of service and larger fleets during the peak period.

- **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. However, 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.

- **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 systems present challenges in meeting ADA requirements. The Aerial Cable system needed to serve the demand would likely be a gondola-type system where cabins typically do not come to a complete stop during boarding—they only slow down. Although it is possible for a cabin to come to a full stop to assist ADA boarding, this would require the entire aerial system to stop and 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 do not currently have the capability for precision stopping, which allows for the gap between the vehicle floor and platform edge to be minimized (1″ to 2″). Future development of this technology will likely need to provide level boarding capability.

Another issue is the ability to accommodate bicycles on board the 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. This is not an issue with Aerial Cable and APM, but for ATN and Autonomous Transit, vehicles may need modification 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. Aerial Cable systems also require all vehicles to use all stations because the vehicles follow the same cable. However, the point-to-point and on-demand nature of ATN and Autonomous Transit systems allows for minimal wait times for passengers during off peak periods, as well as potential point-to-point service during the peaks. This does assume a well-distributed fleet with vehicles staged at stations.

Infrastructure

The evaluation of the infrastructure for each AGT technology group focuses on the community impacts of the guideway design.

- **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 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 column locations. The viaduct structure is slightly smaller for ATN and Autonomous Transit than for APM; 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.

Below are renderings of the APM, ATN, and Aerial systems. Preliminary guideway width estimates for some of the technology options are shown in Table 4. Additional guideway photos are provided in Attachment 4.

Figure 4—APM

Figure 5—ATN

Figure 6—Aerial Cable

Table 4—Guideway 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 choosing between technologies. 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 the vehicles pass and the noise impact will depend on 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 and vehicles 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**—While the objective is to have the guideway structure run along public roads, sidewalks, and medians, there are corridor challenges 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. For instance, the APM compared to ATN and Autonomous Transit requires larger turning radii to maintain speeds, which ultimately impacts rider comfort and travel times. These larger radii may limit the ability to fully locate the columns and aerial structure in the public right-of-way.

Technology Application

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

- **Technological 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 still in development and testing. Thus, consideration should be given to the risk associated with the 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.

- **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. Aerial cable and APMs are more difficult 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 future technologies such as Autonomous Transit. Generally, a viaduct used for nonmonorail APM or ATN can be adapted for future similarly sized or smaller technologies, and this appears to be the direction that some agencies and suppliers are heading. Two examples are:

  - The Jacksonville Transit Agency is 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 off the guideway in some corridors.

— 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. The first phase is under way and work is planned to develop a larger and higher speed vehicle.

Aerial Cable systems are not adaptable to other technologies.

Costs

Cost estimates were developed for each technology, including both capital cost (on a per-mile basis) and operations & maintenance (O&M) costs. Rough order-of-magnitude costs for each technology group are provided in Table 5.

Table 5—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

The capital cost per mile estimate includes systems equipment (e.g., vehicles, guidance, power, communications, train control, etc.) and facilities (e.g., civil works for stations, guideway, and maintenance facility). For purposes of this study, a fully elevated system and typical viaduct configuration for the APM, ATN, and Autonomous Transit technology groups were assumed. Constructing a fully elevated system in conformance with California structural seismic requirements is a substantial element of the capital costs. The VTA North Bayshore Transportation Access Study currently under development has estimated similar costs for an autonomous vehicle aerial system. 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.

The annual O&M cost estimate addresses labor, power and material (i.e., parts and consumables) costs for the system operations, and estimated fleet size. O&M costs include vehicle and guideway maintenance, system controls, fare collection, and roving staff that can respond to mechanical problems and emergencies. As an automated system, AGT costs are relatively low compared to regular transit and allow more frequent service to be operated.

Preliminary Observations

Based on the above evaluation, as well as community input, following are preliminary observations regarding the potential AGT service characteristics and technology options:

- **Travel Time**—The operating simulation shows a potential travel time of less than 10 minutes from the Transit Center to the heart of North Bayshore. That time would be attractive for users and should substantially increase transit use in the corridor. It would be about half the current shuttle bus travel time.

- **Service Frequency**—All the technologies can provide frequent service with a maximum wait time of five minutes throughout the day. Differences in frequency occur in the peak depending on the size of the vehicle. Smaller capacity vehicles would need to operate more frequently (as low as every 10 seconds for 2 to 3 passenger vehicles). GRT and Autonomous Transit are estimated to have peak frequencies of about 30 to 45 seconds, which would minimize wait times in the peak.

- **Infrastructure**—The study, for now, has considered a fully grade-separated system, modeled as an elevated guideway (although other variations are possible). While the initial concept is a flexible viaduct that could support multiple technologies, there are trade-offs in the structure design depending on the technology. Some may have a narrower guideway (e.g., monorail) but may be restricted to a single technology or may be more difficult to expand.

  Established AGT technologies have been fully grade-separated, usually elevated. The cost of an elevated guideway is substantial given the corridor constraints and California structural requirements. However, the evolution of Autonomous Transit offers the promise of operating in dedicated at-grade lanes that could provide comparable travel times at a lower cost. No such system exists today, although pilot efforts are under way. Since autonomous vehicle technology is evolving quickly, this could be a viable option in the near term, although it is unlikely to fully replace the need for some elevated segments.

- **Assessment of Technology Options**—Preliminary observations about the individual technology groups are discussed below:

  — *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 corridor, 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. Overall, the cable system is a little slower than other technologies, is not easily expandable, and is not adaptable to new 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. Some APM technologies can also be challenging to expand or extend.

  — *Automated Transit Network (ATN)*—ATN is a relatively new technology that 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. For these reasons, a Personal Rapid Transit (PRT) approach may not be feasible. 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. Since the guidance system is generally integrated with the guideway, these systems need 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 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. The technology is not fully developed yet and there are no operating systems, only limited pilots. However, systems that could operate autonomously may be viable in the next 5 to 10 years.

Summary

The evaluation to date has shown that AGT technologies could meet ridership demands, would have different capabilities in terms of expandability, and would involve a substantial capital investment. Of the technologies explored, the ATN/GRT and the Autonomous Transit alternatives would appear to be most applicable to Mountain View's needs and environment. The AGT Study will fully evaluate all the technology options in the final report; however, with the City Council's concurrence, staff will investigate these two options in greater detail. For instance, staff would conduct additional research into the status of the GRT and Autonomous Transit technology in terms of readiness for full deployment. A preliminary assessment of the technologies is summarized in Table 6.

Table 6—Summary Evaluation

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

● High Rating: Higher Passenger Experience and Tech Application
Lower Infrastructure Impacts and Costs

◒ Mid Rating: Medium for all categories

○ Low Rating: Lower Passenger Experience and Tech Application
Higher Infrastructure Impacts and Costs

A hybrid Autonomous Transit alternative, combining at-grade fully dedicated lanes (or a single reversible lane) with some elevated or depressed segments crossing key traffic arterials could reduce the capital costs, visual impacts, and environmental impacts substantially while maintaining comparable travel times. It could also provide opportunities to make more effective use of existing and planned infrastructure. The

Shoreline Boulevard reversible bus lane and a potential similar lane in the median of Moffett Boulevard are examples of such opportunities. It is recommended that this concept be explored in a future phase when a preferred route is developed and studied.

RECOMMENDATION

Staff seeks input on the following:

1. Does the City Council agree with the suggested focus on ATN/GRT and Autonomous Transit technologies for the remaining study effort?

2. Does the City Council have any other input or direction regarding the preliminary study observations?

NEXT STEPS

Based on Council comments and direction, the project team will complete the current study involving the evaluation of technology options and bring the final study report to the Council in early 2018. The remaining technology evaluation will include additional refinement of costs and the status of evolving technologies. During this process, discussions with partner agencies (e.g., Mountain View TMA, VTA, Caltrain, Santa Clara County) will continue.

The AGT technology study report will recommend next steps for developing AGT service in the Downtown Transit Center to North Bayshore corridor. These steps will likely include evaluation of potential route alignments, options for combining at-grade and grade-separated segments, further development of cost estimates and analysis of cost-effectiveness, and opportunities for phasing in the preferred AGT technology.

PUBLIC NOTICING

In addition to the City's standard agenda posting requirements, notices regarding this Study Session discussion were distributed to the persons who have signed up on the project website for updates and information, previous business and/or community meeting participants, representatives of VTA, Caltrain, and Mountain View TMA, and other interested parties, as well as on social media.

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Attachments:
1. September 25, 2017 Community Meeting Summary
2. Technology Options
3. Proposed Evaluation Criteria
4. Guideway Examples