Item 5 - Correspondence

From: peter
To: MCP-Chair
Subject: Autonomous guideway alternative the BRT & light rail
Date: Friday, October 23, 2020 11:33:37 AM

[EXTERNAL EMAIL] Exercise caution when opening attachments, clicking links, or responding.

Dear Chairman and members:

As a long time resident of Montgomery County, I'd like to see a better transportation system for our county.

After crime, traffic congestion is the number one concern of Montgomery County citizen based on January 2020 poll.

To that end are asking the planning board to seriously consider autonomous guideways as a better public transit solution than BRT or light rail.

The County's recent MD355 BRT study project with BRT auto travel peak hour transit times between Gatihersburg and Bethesda will increase by seven minutes then with no BRT (47 vs 54 min). BRT transit time will be 61 to 77 minutes.

With our proposed point to point solution travel times will be 15 minutes during all hours of operation. This is a no brainer.

While the Purple line boat has sailed, the MD355, Veirs Mill and CCT BRT line have not.

With the rapid development of autonomous and connected vehicle technology.

Investing in BRT lines now is akin to building stage coach lines as the Continental railroad nears completion.

This is the presentation we made today to MCDOT on the autonomous guideway solution.

My brother, Robert James, is our autonomous & connected vehicle expert.

I develop the systems.

Please have your planners contact me to allow a full consideration of what I believe to the the best transit system for Montgomery County.

Peter James

Crystal Clear Automation, LLC

240 938-8439

From:	peter
To:	Reed, Patrick
Cc:	sean.emerson@montgomerycountymd.gov; Murillo, Julio; Kraut, Aaron; Kristin.Trible@montgomerycountymd.gov; ken.silverman@montgomerycountymd.gov; MCP-Chair; Anspacher, David
Subject:	Re: Will autonomous guideways be one of the transit modes in Corridor forward plan?
Date:	Friday, November 6, 2020 8:11:38 PM
Attachments:	7.2-20180828-GPATS-ATN-Feasibility-Study.pdf SanJoseRFIKHSummaryAssessm.pdf

Patrick,

May we have the name and contact information of your consultant? We would like to provide them with the same information.

23 CFR § 771.119 - Environmental assessments (b)

For actions that require an EA, the applicant, in consultation with the Administration, **must**, at the earliest appropriate time, begin consultation with interested agencies and others to advise them of the scope of the project and to achieve the following objectives: Determine which aspects of the proposed action have potential for social, economic, or environmental impact; **identify alternatives and measures that might mitigate adverse environmental impacts**;

Seems like EIS requirements compel Montgomery County to "at the earliest appropriate time" to identify alternatives. PRT is such an alternative. If the County expects seek FTA funding for any of these projects they must consider PRT because it has the least social, economic and environmental impact of all other transit modes.

I have attached a copy of a PRT study commissioned by Greenville, SC County. Here is a study being conducted by the City of MT. View California - https://mountainviewagtfeasibility.com/

Also, attached is the San Jose Airport's assessment of similar GRT & PRT systems.

I can get my head around plannings thought process. Prior to the continental railroad the prevalent mode of transit was stage coach. Did the transportation planners of that age throw out common sense because their did not exist a long range rail road line that exist to make comparison to? Or did they evaluate the clear advantages of the technologies such as speed, reliability, etc?

The Corridor Forward plan states your efforts to obtain citizen feedback. However, the poll had only 150 citizens. The county has an email list of over

100,000 citizens called the "Paper Airplane". I am on that list and did receive any poll on the Corridor Forward plan.

Your suggestion that your team may include, as a footnote, suggestion of future technologies, is wholly unacceptable. In any case autonomous guideways at not a "future" technology. The WVU PRT has been in continual operations since 1975 with no accidents(source for Vision Zero benefits). I am waiting a return call from WVU PRT staff to get formal confirmation of the PRT's safety record.

A newer autonomous PRT system was built in 2011 at Heathrow Airport at substantially less cost per mile than MoCo's proposed BRT. Here is another awarded project in the works in India.

The fact is that adequate public transit has failed to be achieved across America. Your insistence that MoCo planning will only consider failed approaches because they are prevalent or have been studied a lot, doesn't hold water, at least not to a rational mind.

I would always try to convince my mom to let me do something because all the other kids were doing it. Her response, "Just because everyone else jumps off a bridge doesn't mean you should too". Pursuing BRT is the transit equivalent of jumping off the bridge at the cost of taxpayer's wallet, future gridlock and the lives and safety of our citizens.

Just because planning hired a consultant that is not up to date on the current state of the art in transit modes, should be a reason to deny MoCo citizens that best transit available.

The City of Mountain View California is now studying a wide range of transit option many of them elevated and autonomous. San Jose Airport has recently reviewed 19 GRT and PRT proposals - see attached.

Corridor Forward Plan Timeline

- Phase One: Determine Six Key Options
  -**September:** Compare Characteristics of Transit Vehicle Modes
  -**November:** Develop Up to 15 Initial Transit Options (Route Alignments with Associated Modes)
  -**December 2020:** Develop Evaluation Methodology & Criteria
  -**January 2021:** Identify Six Key Options from Initial 15

It appears you consultant has not done his job for the September line item. They have failed to compare PRT/autonomous guideways. Many transit authorities are currently looking at autonmous GRT & PRTs as viable transit options as they offer many advantages over maganned transit vehicles. Since driver labor makes up 60% to 70% of conventional transit costs. BRT & light rail primary advantage of standard buses is the reduce of drivers per passenger. Autonomous vehicles multiple that primary advantage.

The result of the Corridor Froward Plan will effect area citizens for the next few decades. Cutting corners is not acceptable and all transit modes need to be consider regardless of how new and innovative they are.

BRTs were tried in London and removed from service because of the elevated accident incendences.

https://uktransport.fandom.com/wiki/Articulated_buses_in_London

In response to your comments regarding the challenge of submitting information to the board with "professional certainty", we know that articulating BRTs are involved in higher number of accidents than conventional buses, have higher rates of fare evasion. Even you own recent study shows MD355 will increase congestion. Your report states that Bethesda to Gaithersburg pm rush hour transit times for cars in 2040 will be 7 minutes longer with than without BRT. Since, auto traffic will be the bulk of persons transported. BRT mode will clearly have a net negative impact.

Good planning must be forward looking, anticipating emerging technology and trends going forward, not driving by looking in the rear view mirror.It would be "professional" to include autonomous guideways/PRT and other emerging transit modes in your study by adding a uncertainty weight factor to your evaluation methodology for newer technologies to adjust for that uncertainty. Not to completely ignore transit mode that offer much better outcomes. We offer an example of how to professionally account for the uncertainty of emerging technology. We are currently submitting a response with Dr. Cinzia Cirillo of UMD to SHA's Office of Research and Policy for "Smart Crosswalk/pedestrian safety technology evaluation" RFP. We since most of the technologies for smart crosswalks are new, we are proposing similar weight factors as suggested above to assess those technologies. The desire end-product of this study will be a tool for traffic engineers to assess smart crosswalk solutions for specific locations.

In regards to affordability, my points was, while the county can't afford all options considered, it can afford all alignments considered, if those are implemented using the low cost guideway approach.

The best cost data by which we take our assumptions is not publicly available. But based on a system that has roughly 33 pylons per kilometer(~every 100ft), two stations per kilometer, 2 levels of 2 tracks, associated ramps
Because detail cost information is protected under confidentiality agreements, we can't share those.

Based on general knowledge of vendor costs, this is a cost estimate per mile for a single level two deck guideway. $8.8 million per mile.

These costs include: Pile Caps/Foundations,pylons, pylon concrete fill, cantilevers,steel joists, running surface, skin, canopy(sans solar panels), railings, reinforced pour stops, side barriers, track surface lighting, system Comm, track marking, TMS, racking & boarding zones.
Other costs incurred are subject to alignment variables but should be within a $2M to $7M per mile window. Elimination of road widening, choke points, environmental impact and other considerations make any additional cost considerations inherently less than BRT.

The guideway advantages of no stop point-to-point service, headways of seconds instead of minutes, direct travel to destination, etc. are so compelling. As I mentioned this is the only transit mode that has transit times faster than auto travel. That was the number one preference state by citizens. Reliability was a close second. The guideway no wait feature eliminates late buses.

Another factor that should be consider should be road maintenance costs. BRT buses are typically $60K lbs. Heavy vehicles produce 90 times the road damage of standard passenger cars. Our pods are far lighter. Both the capital cost of much heavier road beds and ongoing road repairs is a major cost consideration. This analysis should also include the congestion caused by longer inital construction and ongoing road repairs.

MoCo planners and MCDOT are stuck in the driver paradigm. Autonomous vehicles are the future, don't get caught on the wrong side of history. As shown by WVU PRT, this is a proven technology whether or not it is now widely adopted is immaterial. Dick Fosbury, developed his "flop" method of high jump when no others were using it. He managed to jump higher than any other high jumper in Olympic history, today nearly every elite high-jumper uses the Fosbury flop.

A failure to include autonomous guideways/PRT in selected transit modes for evaluation is just not acceptable.

Pardon any perceived hoarseness of tone, I am passionate about MoCo giving all viable transit options a far vetting.

Peter

240 938-8439

On 11/5/20 9:31 PM, Reed, Patrick wrote:

> Mr. James:
>
> Thank you for the note. I am CCing my colleagues here who are also actively involved in managing this project.
>
> Currently, our consultant has not considered autonomous guideways as an option. As I mentioned when we met, the purpose of the plan is to look at existing ideas in the public sphere that have received some degree of study or that have had some degree of recommendation in a master plan or long-term planning document.
>
> We anticipate that the Plan could have some kind of reference to future technologies that may be interesting to consider. When we met, I mentioned that it would be great to learn more about the autonomous pods for inclusion in this section. If you can provide the documentation and sourcing for the Vision Zero benefits, costs, and environmental benefits, I think it would be great to learn about and potentially include. Unfortunately, the Plan scope that was presented and approved by the Board did not consider autonomous pods as an option for the Corridor. This technology is quite intriguing for many reasons, including the COVID-safe perspective, but because it is used in so limited a number of places, it would be challenging for us or our consultants to offer information to our board with professional certainty. As I mentioned when we met, providing more detailed information is the way to start moving an idea forward.
>
> When you reference a video, I believe you are referring to the community kick-off video in your email? There may be confusion, but the slides regarding the project purpose suggest that the County *cannot* afford all of the options, and that the County needs a strategy to sort our which existing ideas or plans in the public sphere merit further advancement. We have yet to work through the development of metrics, but are considering including items related to operating and capital costs.

Patrick

Patrick Reed, AICP | Transportation Planner Coordinator
Montgomery County Planning Department | Midcounty Planning
patrick.reed@montgomeryplanning.org

From: peter <peter@turfrobots.us>
Sent: Thursday, November 5, 2020 4:30 AM
To: Reed, Patrick <patrick.reed@montgomeryplanning.org>
Subject: Will autonomous guideways be one of the transit modes in Corridor forward plan?

Patrick,

Will autonomous guideways be one of the transit mode options in the Corridor Forward plan.

THe Corridor plan document has Phase One lists:

"-**November:** Develop Up to 15 Initial Transit Options (Route Alignments with Associated Modes)"

Autonomous guideways all the requirements all the requirements of "Strategic Mobility, Economic, Environmental, Equity and Health Benefits". If it exceeds all other modes for major corridors.

I found it interesting the omission of Vision Zero as one of the evaluation criteria listed in the Corridor Forward plan, since the County Council issued a resolution in 2016 to make Vision Zero a top priority.

Autonomous guideways by design meet the County's Vision Zero goal, where as studies show that articulating BRT buses cause more pedestrian deaths then standard buses.

Autonomous guideways are better, faster, cheaper, safer, sooner and more environmentally friendly than any other options listed in your Corridor Forward Virtual Community Kick-Off Meeting.

Our single passengers vehicles are the only transit option that provides a COVID safe ride.

This video states that the county can afford all the possible options guideways are so low cost they if fact can provide transit on all the transit alignments shown on your 270 corridor map.

Please conatact me in this regard as it is November.

Peter James

Crystal CLear Automation, LLC

240 938-8439

From:	Robert James
To:	MCP-Chair
Subject:	Planning Board Meeting Item 5 MD 355 BRT Corridor Comment
Date:	Tuesday, December 1, 2020 12:08:57 PM

Hello,

As an Emerging Mobility Subject Matter Expert, I would like to provide a response to the assumption of the MD355 Corridor to be a BRT corridor. Under state and federal guidelines the planning departments are supposed to include all viable alternatives in their evaluation of a new corridor projects. By their own admission the planners do not have expertise in the areas of emerging mobility and the technologies involved. If we want to Build Back Better we can't use the same old approaches that have failed drastically at meeting the future mobility demands. Fixed route BRTs are an old concept that do not move the needle in getting people out of their single passenger vehicles into shared rapid transit. That is why dozens of state and local agencies are looking at emerging technologies to meet the future demands. FHWA funded a $12.5B BUILD grant to convert the monorail to an automated vehicle guideway. In addition to Morgantown, WV operating a PRT for 45 years with no incidents there are many other locations in the US that are looking at AV Guideways. THese include:

- Jacksonville, FL U2C Program
- Project Connect Austin, TX
- Morgantown, WV PRT Replacement
- Dumbarton Rail Corridor San Francisco
- San Jose Connector
- MTC IDEAS Program
- CAVenue AV Corridor Michigan
- MD 355 BRT Corridor
- CT FastTrack Connecticut
- Greenville, SC
- Automated Bus Consortium
- Other rail, light rail, BRT, and toll road projects in planning

Automated Personal Rapid Transit (PRT)/Group Rapid Transit (GRT) are a very active field of development that must be explored as a more efficient, customer friendly, eco-friendly, cost effective alternative to BRTs. The smaller light weight vehicles allow much lower cost capital deployments as well as much lower operating costs. They offer:

- Significant Return on Investment allowing for public private partnerships
- Shared payment of operations savings from Demand-based fleet size,
- Eco-electric, maintenance, and staffing
- Limited Capital Investment Requirements with Capital Federal Innovation Grants
- Incremental Revenue Sources (i.e., Retail, Advertising, Value-Add Business Services)
- Reduced Operational Costs & Capital Investment for Maintenance
- Reduced construction time with light weight infrastructure

Reduced operating risk assumed by private operator

- Increased Passenger Safety
- Improved Customer Satisfaction

Elevated dedicated guideways can be built down the center of 355 removing the need for acquiring hundreds of millions of dollars of right of way needed to widen the existing roadway.

Some of the Customer Benefits include:

- Increased capacity over time
- One stop ride to a wider range of connections when complete
- Point to point rides instead of stopping at every bus stop
- Reduced freight vehicles on surface streets with joint use guideways
- Reduced wait time and travel time
- Reduced congestion

I would be happy to address the Planning Board on this matter as a subject matter expert.

Bob James
(c) 813-853-4472
robertdavidjames@gmail.com
Robert James CV
Website: www.rjamesinc.com
LinkedIn Profile: https://www.linkedin.com/in/robertjamesinc/

From: Jason Makstein
To: MCP-Chair
Subject: Dec 3 meeting item 5 Please include PRTs in the Corridor Forward
Date: Tuesday, December 1, 2020 11:01:47 AM

I wanted to resend this to specifically state this testimony is in regards to the Dec 3 meeting item number 5 and it is directed at the planning board as well as the planning chair.

Thank you,
Jason Makstein

---------- Forwarded message ---------
From: **Jason Makstein** <jasmak@gmail.com>
Date: Mon, Nov 30, 2020 at 10:00 PM
Subject: Please include PRTs in the Corridor Forward
To: MCP-Chair <mcp-chair@mncppc-mc.org>

Hello,

I am writing to request that the Planning board include PRT (personal rapid transit) and raised guideways in the Corridor Forward transit study.

I have seen a presentation that points to it being cheaper than currently planned BRTs, able to use significantly less land space (a major resource in that area). They also provide some privacy and safety as well that would be well received by many and would be a significant draw to be an early adopter with the way of the future with automation. It really deserves and should be in consideration for this long term study.

Thank you,
Jason Makstein

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Jason Makstein
jasmak@gmail.com
301-873-6289
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Jason Makstein
jasmak@gmail.com
301-873-6289

From:	peter
To:	MCP-Chair
Subject:	MoCo planning staff to recommend excluding PRT from Corridor Forward plan study - testomony item #5 Dec 3 meeting
Date:	Tuesday, December 1, 2020 11:26:33 AM
Attachments:	fcochfokenbpgbjb.png ag3.pdf mvagtreport_final_feb-2018_combined.pdf SanJoseRFIKHSummaryAssessm.pdf 7.2-20180828-GPATS-ATN-Feasibility-Study.pdf jacksonville.png

Dear Chairman Anderson and board members,

I desire to testify tomorrow on item #5, the Corridor Forward plan.

I run a robotics R&D company, Crystal Clear Automation, LLC in Gaithersburg, MD.

CCA is not a transportation civil engineering company. But despite that fact, we were selected as one of the top three finalist for the contract to develop MCDOT's new Advanced Traffic Management System.

The transportation industry is ill equipped, as the Corridor Planning staff emits, in evaluating the rapidly evolving transportation technologies.

PRT/autonomous guideways are the only transit system that meet all the criteria of the Corridor Forward Plan's stated goals. Here is a video of a PRT at Heathrow Airport that describe the technology well. https://www.youtube.com/watch?v=4Ujd4wutddE This PRT was installed in 2011, since then technology advances make PRT even more viable.

On 11.12 I received an email from Catherine Coello stating I would be able to testify on the planning staff's recommendation on the Corridor Forward study. Now listed as item #5 for tomorrow's meeting.

The email from Ms. Coello, said she would be in touch before the deadline to sign. She has not contacted me in this regards.

On December 3rd, Montgomery County Planning Board will review the Corridor Forward planning staff's recommendation to exclude PRTs in the study. This would be counter to the interest of the Citizens of the County.

The Corridor Forward study will select our transit options for the I-270 corridor for decades to come.

When listing evaluation criteria, the MoCo planning team failed to list safety as a criteria, nor cost.

Further, planning policy is to gain input from citizens. The kick-off video and report said only 150 residents were polled about transit needs. The planning staff went further to say that the poll did not reflect the actual diversity of the County citizens.

Vision Zero

The City of London removed articulating BRT buses, the kind MCDOT is using, from service after it was found they were 4 times more likely to be involved in accidents.

Miami Dade Transitway removed priority signals, which is a supposed benefit of BRT, because it resulted in higher accident rates.

BRT lines like MD355 will need to get rid of all left turns due to safety considerations.

PRTs have none of these disadvantages. Instead they have numerous advantageous as outlined in our presentation to MCDOT.

MoCo planning's own MD355 BRT report shows auto transit times during rush hour from Bethesda to Gaithersburg will take 7 minutes longer with BRT than without BRT.

Here is the planning staff's draft recommendation to the planning board regarding exclusion of PRTs:

"*MODES EXCLUDED FROM STUDY*
Staff has received comments and inquiries from individuals who believe the project's scope should be expanded to include less commonly used technologies including maglev and personal rapid transit (PRT) pods.

• Maglev – ...

• Personal Rapid Transit (PRT) – PRT is a general term for small individual transit vehicles, usually facilitating travel for three to six individuals, that run along a guideway network. Like many mass transit systems, PRT systems are automated. Unlike other options, they offer privacy, and when featured in a network, the ability to switch guideway paths to provide improved potential for point to point service. In practice, there is only one PRT-type system operating in the United States, which is located in Morgantown, West Virginia on the campus of West Virginia University. Other PRT systems operate at Heathrow Airport in the United Kingdom and in the United Arab Emirates. PRT systems require significantly greater number of vehicles to provide short enough headways to be viable solutions.

Due to project resource constraints, staff has not included the above modes in its study work to date as they are not reflective of options that have been master-planned, studied by a governmental or non-profit organization, or frequently requested by the community at large. Staff proposes to include information about these modes in the Plan as options to consider for future mobility; however, it is highly unlikely that Montgomery County, the State, or the

Federal Government would pioneer these modes in the Frederick-Northern Virginia Corridor in the near-term. Maglev and PRT options may be intriguing for numerous reasons; however, the limited sourcing of facilities and vehicles is consequential for lifespan system costs. Staff recommends that the Planning Board confirm that these options remain outside the scope of the Plan, particularly given that the study of such services would require additional project resources for support from third-party industry experts."

I'd like to respond to each of the planning teams reasons for excluding PRT from the Corridor Forward study.

- ***Like many masstransit systems, PRT systems are automated****.* - None of the other transit systems proposed are fully automated. PRTs are and therefore have 1/3 the operating costs of any other mode.
- ***PRTS .. usually facilitating travel for three to six individuals.*** *We propose, primarily, single passenger vehicles as the average transit group one person. This would achieve true point-to-point service.*
- ***There is only one PRT-type system operating in the United States*** *- Yes, and it has been operating with no accidents for 45 years. It solved a horrendous traffic congestion problem in Morgantown. Dick Fosbury was the only athlete to use the Fosbury Flop in the 1968 Olympics, he is the only one to come home with the gold medal too.*
- ***PRT systems require significantly greater number of vehicles to provide short enough headways to be viable solutions*** - The first part of this statement is true, the last part is just absurdly silly. Having more vehicles with short headways is the main advantage to PRT systems. Rather than wait 10 to 15 minutes or more for a bus or train, a vehicle is waiting for you at the stations. For the cost of one $800K to $1M articulating BRT bus, you can purchase 100 PRT vehicles. Currently, according to Google maps, it would take me 32 minutes to travel from my house in Gaithersburg to downtown Silver Spring by car in light traffic. It would take two hours by transit. With a guideway on 355, Viers Mill and Georgia, it would take 20 minutes. PRTs have no stops, no wait and no transfers. More vehicles makes PRTs the most viable mode of transit not the least. The assumption that large transit barns would be required is because transit planners are stuck in an old paradigm. The small footprint pods can be storied under the guideway all along the route for quick utilization as rush hour approaches.
- ***Due to project resource constraints*** *- Pennywise and pound foolish ! MCDOT has $18M over 6 years budegted for just the MD355 BRT engineering project. Seems like $50K to save $500M for just one project is a reasonable use of taxpayers dollars.*
- ***staff has not included the above modes in its study work to date as they are not reflective of options that have been master-planned -*** *It is my understanding the last draft of the master plan that in shrined BRT was 2013. Dick Fosbury was 14 years old 7 years prior to his Olympic win. The advance in autonomous and connected vehicle technology has been stellar. Just because planner in 2013 failed to take notice of the PRT system in Morgantown and it wonderful performance record, is no reason to ignore PRTs now. Did the Germans ignore the arrival of British tanks in the fall of 1916 because their war plans only considered horse drawn artillery?*
- ***are not ... studied by a governmental or non-profit organization -*** *This is a*

blatanly false statement, as I personally sent several PRT government studies (see attached) to the authors of the study recommendation draft document. A simple Google search will reveal many more PRT studies.

- ***are not ... frequently requested by the community at large -** Montgomery County planning and MCDOT have spent lots of taxpayers dollars promoting BRT transit. They have not spent a dime providing the public with any information on PRT systems. Traffic congestion is the one of, if not the primary pre-COVID concerns of Montgomery County residents. The community loadly and frequently has requested a viable transit solution. They have also, as can be found in the Corridor Forward public opinion poll, said that conventional transit does not meet there needs. see - reasons attached What would the public's reaction be if they later found out that the government with held the knowledge of COVID-19 vaccines.*
- ***Staff proposes to include information about these modes in the Plan as options to consider for future mobility -** The problem of not study aiong PRT for the I-270 corridor is that an alternative mode, probably BRT will be built instead and Montgomery County and other travelers will lose the ability to travel point to point through the I-270 corridor to other destinations like DC, Tysons, Silver Spring or Prince Georges County.*
- ***however, the limited sourcing of facilities and vehicles is consequential for lifespan system costs -** There are literally hundreds of EV manufacturers making small footprint vehciles for the expected huge PRT and CAV market. see - https://electrek.co/2020/08/20/gm-mini-electric-car-price-orders/ ; [https://ree.technology/;](https://ree.technology/) <$1,000 https://insideevs.com/news/427175/cheapest-electric-car-china-930-us/*
- ***highly unlikely that Montgomery County, the State, or the Federal Government would pioneer these modes in the Frederick-Northern Virginia Corridor in the near-term -** This conjecture has no basis in fact. County and State transportation and elected official overseeing transportation spending are only just now being informed about PRT transit mode. MTA, and the Maryland legilative committees are just now reviewing information on PRTs. Since PRTs are the only affordable transit mode that will have significant impact of traffic congestion is seems it is highly unlikely that the County, State and Federal Government wouldn't pioneer these models. In fact the FTA has provide Jacksonville a $12.5 million grant for their autonomous guideway project.*

Please review the email I just recieved from the mayor elect's office in Baltimore. It is evidence of some level of interest from the chair of the Senate subcommittee to at least look further into PRTS.

> *If MoCo planning and MCDOT staff are not qualified to study the latest transit modes then MoCo planning needs to acquire those expretise as knowledge of transportation technologies is key to any master plan.*

For the cost of one 116 mile Purple Line, Maryland can funded 350 miles of autonomous guideways.
Please feel free to contact me to discuss this further.
You can also reach out to my brother, [Robert James](), who is a connected and autonomous vehicle expert currently involved in many autonomous bus guideway projects.

Peter James
240 938-8439
##

My Transportation technology references:

- Dr. Cinzia Cirrillo, UMD
- Dr. Young-Jae Lee, Morgan State
- Dr. Celeste Chavis, Morgan State

Email from Baltiomore Mayor elect office - evidence of other juristicion's at least interest in PRT solutions.

Peter,

Good afternoon. My name is Michael Huber, and I am Chief of Staff to Mayor Elect Brandon Scott.

Senator Cory McCray let me know that you and he spoke recently, and that he was really impressed with what you had to say. Can you and I find some time to meet in the next couple weeks?
If you're available, can you propose some times? Happy to do so if that works better.

Thanks,

Michael Huber

MICHAEL HUBER

Chief of Staff
Office of City Council President Brandon M. Scott

100 Holliday Street, Room 404, Baltimore, MD 21202

Cell: 443-474-3093 Office: 410-496-4804 Fax: 410-539-0647

Email: michael.huber@baltimorecity.gov

Website: baltimorecitycouncil.com

Other interest in PRTs:

https://floridapolitics.com/archives/318926-clearwater-one-step-closer-to-aerial-transit-system-in-tampa-bay

You can reach Clement Soloman transportation director at WVU to ask more about their PRT system.
clement soloman

304 293-9095
Which has been running since 1975.

Autonomous Guideway

MoCo BRT alternative

WVU PRT since 1975

MD355 Purpose

- Enhance transit connectivity and multimodal integration along the corridor as part of a coordinated regional transit network;
- Improve the ability for buses to move along the corridor (bus mobility) with increased operational efficiency, on-time performance/reliability, and travel times;
- Address current and future bus ridership demands;
- Attract new riders and provide improved service options for existing riders as an alternative to congested automobile travel through the corridor;
- Support approved Master Planned residential and commercial growth along the corridor;
- Improve transit access to major employment and activity centers;
- Achieve Master Planned non-auto driver modal share;
- Provide a sustainable and cost-effective transit service; and
- Improve the safety of travel for all modes along the corridor.

Enhance transit connectivity and multimodal integration along the corridor as part of a coordinated regional transit network;

- Ultra light guideway provides low cost connectors to all nearby transit centers – no impact on transit times
- Smaller vehicles provide smaller passenger boarding stations
- More possible boarding stations with no impact on transit times
- No traffic delays guarantee no missed connections

Improve the ability for vehicles to move along the corridor (vehicle mobility) with increased operational efficiency, on-time performance/reliability, & travel times

- Dedicated guideway - MD355 Alignment
- 5 second headways – eventually ½ second headways – automated on ramp merge
- No impacts or delays from other traffic
- BRT 61 minute Gaithersburg to Bethesda BRT transit time vs 36 min @ 25 mph, 15 min @ 60mph
- Entire infrastructure control can go down and autonomous vehicle can still operate safely

Improve the ability for vehicles to move along the corridor (vehicle mobility) with increased operational efficiency, on-time performance/reliability, & travel times

- Dedicated guideway - MD355 Alignment
- 5 second headways – eventually ½ second headways – automated on ramp merge
- No impacts or delays from other traffic
- 61 to 77 minute Gaithersburg to Bethesda BRT projected 2040 transit time vs 15 minute
- Entire infrastructure control can go down and autonomous vehicles can still operate safely

Address current and future bus ridership demands

- 5 second headways can handle current demand with two lanes. One per direction
- Decreasing headways, increased speeds and added lateral and stacked decks will accommodate ridership growth
- Guideway can later be opened to shared road CAVs as the technology is perfected

Attract new riders and provide improved service options for existing riders as an alternative to congested automobile travel through the corridor

- Point-to-point & no wait service will drive increased demand
- Fastest transit times of any mode of travel
- All 355 alignment shortest path
- Connector guideways to neighborhoods, shopping, employment & entertainment centers
- Arrival times software integration to ride hailing and rail and bus schedules

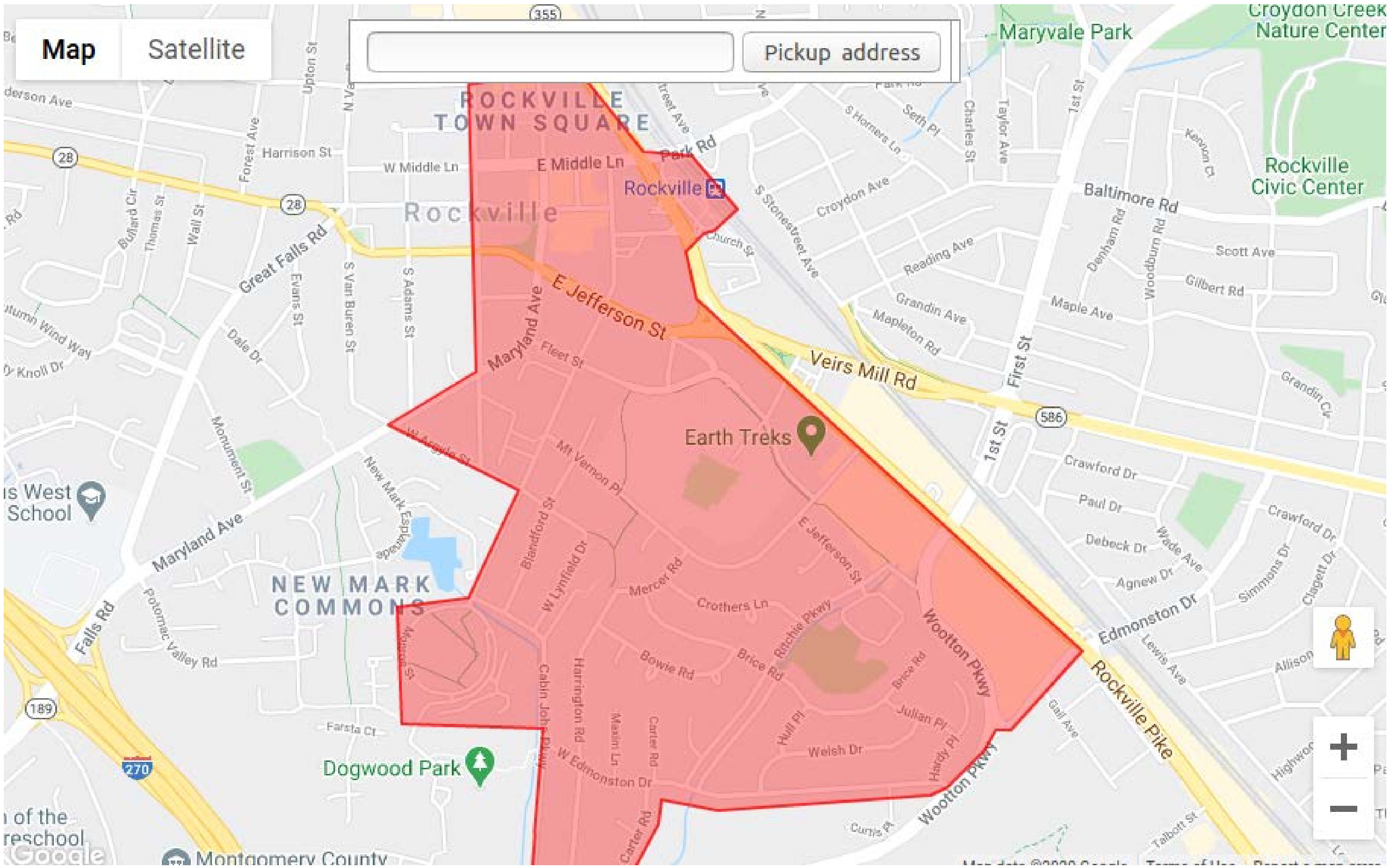
Support approved Master Planned residential and commercial growth along the corridor

- Will provide low cost developer funded connectors to adjacent developments
- Autonomous ride hailing scooters
- Vehicles can run on conventional building concrete floors with no additional load re-enforcement for indoor passenger loading platforms

Improve transit access to major employment and activity centers

- Low cost, light weight guideways provide connectors to these centers
- No transit time impact as single passenger pods travel point to point with no extra stops nor deviation from shortest path
- Small foot print bi-directional vehicles don’t require turning areas
- Integrates with Flex Bus app turfrobots.us/scripts/geo.html
-

Syncs with on-demand transit



Achieve Master Planned non-auto driver modal share

- With transit times significantly faster than private auto times, will drive up ridership share
- No traffic delays provide just in time connection to rail and bus services will encourage multi-modal public transit ridership
- MD355, Veirs Mills. CCT and other transit Corridors one integrated guideway system
-

Provide a sustainable and cost-effective transit service

- 60% to 70% BRT operating cost is driver
- Lowest capital and O&M cost of all alternatives
- Minimal pylon foot print eliminates most right-of way costs and environmental impact of street widening
- BRT will increase auto congestion & emissions
- Overall energy consumption reduced to “just enough” for ridership demand. BRT buses with a few riders waste energy and capital

3 MW Community Solar Farm

Robot Hydroponic Roof

Improve the safety of travel for all modes along the corridor

- Achieve Zero Vision – Dedicate guideway
- No interaction with street traffic
- Multiple redundant collision avoidance sensors
- Smart guideway connected vehicle technology aware of all vehicles position, speed and health
- Smart vehicles can safely operate if smart guideway goes down
- Low cost guideway connectors deliver passengers to directly destination. No exposure to traffic/cross walks

Pedestrian Detection

Capital Costs per Segment $millions

Segment	No Build	Transportation System Management	Alternative A: Mixed Traffic	Alternative B: Median Transitway	Alternative C: Curb Lane Transitway
1. Bethesda	$0.7	$18.0	$19.0	$19.0	$37.0
2. White Flint & Twinbrook	$0.9	$50.0	$346.0	$346.0	$190.0
3. Rockville Town Center	$0.2	$11.0	$92.0	$92.0	$65.0
4. Shady Grove	$0.3	$26.0	$170.0	$141.0	$123.0
5. Gaithersburg Core	$0.5	$9.0	$86.0	$80.0	$10.0
6. Gaithersburg & Germantown	$1.0	$9.0	$121.0	$91.0	$59.0
7. Clarksburg	$2.0	$19.0	$15.0	$15.0	$13.0
Vehicles	$10.0	$43.0	$37.0	$37.0	$37.0
Total	**$15.6**	**$185.0**	**$886.0**	**$821.0**	**$534.0**

Travel Times

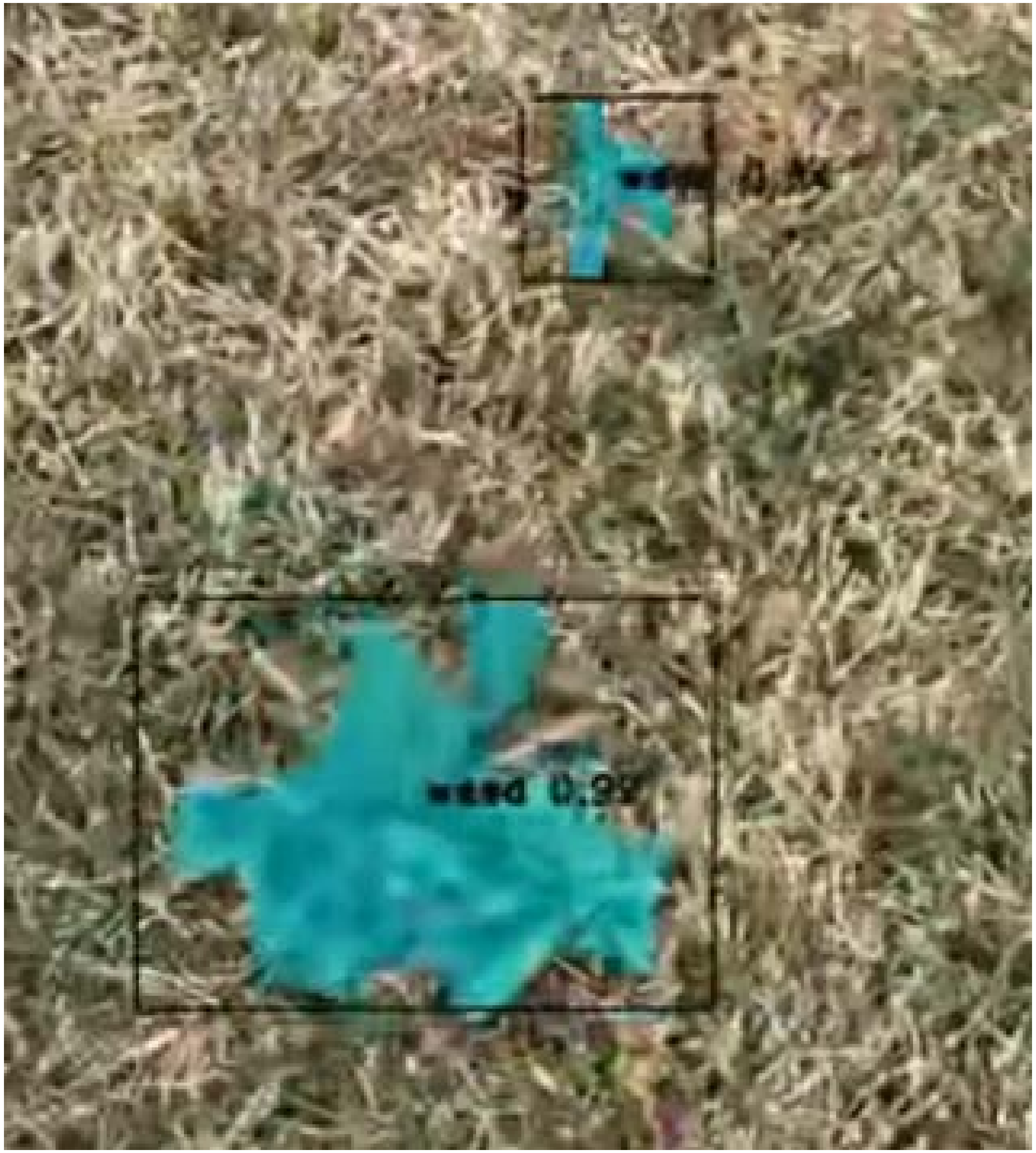
Table 5: BRT Travel Times Compared to Auto Travel Times in 2040 (Minutes)

Origin/ Destination	No Build	TSM Alternative		Alternative A (Mixed Traffic)		Alternative B (Median)		Alternative C (Curb Lanes)	
	Auto	Auto	Ride On extRa	Auto	BRT	Auto	BRT	Auto	BRT
AM Peak Southbound									
Gaithersburg to Bethesda	47	51	73	46	71	54	61	46	58
AM Peak Northbound									
Bethesda to Gaithersburg	45	41	69	40	63	41	65	43	67
PM Peak Southbound									
Gaithersburg to Bethesda	46	45	67	46	70	49	62	51	61
PM Peak Northbound									
Bethesda to Gaithersburg	67	65	86	60	82	73	77	70	79

1 cm Precision Platform

Autonomous Mower at Wheaton Regional Park

AI detects road debris and defects



Safety engineering

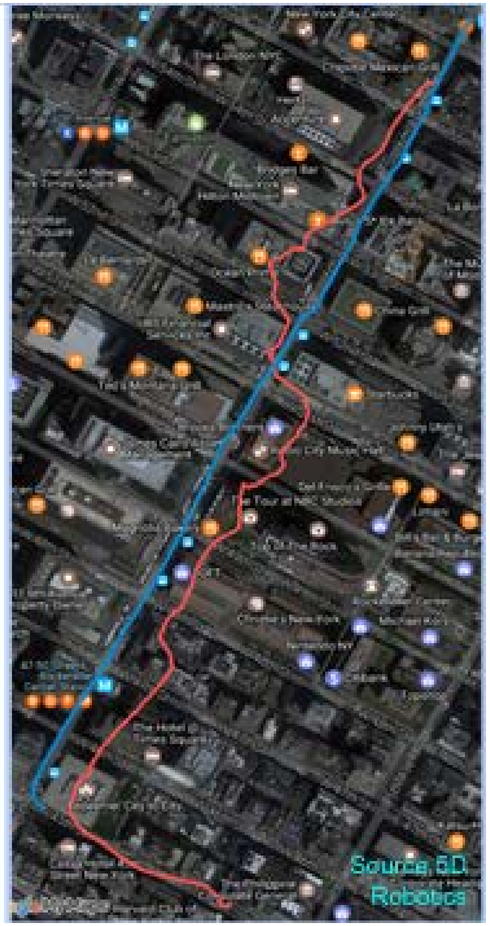
- Wide array of redundant collision avoidance sensors
- Fault resistant smart guideway can fail and vehicles can operate safely in peer to peer mode
- Can operate vehicles from remote operations center with end-to-end encrypted FPV (first person video)

Smart City
5G Micro-positioning

Robert James

Executive Consultant & Innovation Advisor

Executive Innovator. Connected Automated Shared Electric (CASE) Mobility thought leader.



White House Executive Order

- On February 12, 2020, President Trump signed Executive Order (EO) 13905, “Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services,” with the goal of ensuring that the Nation’s critical infrastructure can withstand disruption or manipulation of PNT services. EO 13905 directs the development of a national plan for the R&D and pilot testing of additional, robust, and secure PNT services that are not dependent on GNSS. These additional services may consist of multiple systems with varying functional specifications to satisfy one or more applications with differing requirements. To further enhance infrastructure resilience, the plan will also consider approaches to integrate and use multiple PNT services including GNSS services.

- **Problem**
- GPS/GNSS suffers from weaknesses in jamming/spoofing and poor quality in cities, tunnels, and mountainous areas.

- **Solution**
- 5G Ultra Wideband (UWB) micro-positioning will change the world
- (It will do so much more than unlock doors and share files)

Connected Vehicle Battle

- The FCC and USDOT are battling each other on what technology to use for connected vehicles (DSRC vs C-V2X)
- DOT dragged its feet for 20 years because of the “chicken or egg” problem.
- Both of these technologies are being surpassed with UWB due to superior capabilities and defacto market adoption.
    - UWB Adopted by Apple and Samsung on new cell phones
    - Several UWB chip vendors have become available
    - 5G deployments can easily incorporate and provide seamless long and short range applications
    - Provides <10 cm accuracy and low latency V2X
    - Demonstrated use of UWB for several CV deployments (NYC NYC CV Pilot, MTA Genius Challenge, Sprint Greenville, SC Smart City, etc.)

Connected Vehicle (CV) Applications Need Lane Level or Better Accuracy GPS Can't Provide

V2I Safety

Red Light Violation Warning
Curve Speed Warning
Stop Sign Gap Assist
Spot Weather Impact Warning
Reduced Speed/Work Zone Warning
Pedestrian in Signalized Crosswalk Warning (Transit)

V2V Safety

Emergency Electronic Brake Lights (EEBL)
Forward Collision Warning (FCW)
Intersection Movement Assist (IMA)
Left Turn Assist (LTA)
Blind Spot/Lane Change Warning (BSW/LCW)
Do Not Pass Warning (DNPW)
Vehicle Turning Right in Front of Bus Warning (Transit)

Agency Data

Probe-based Pavement Maintenance
Probe-enabled Traffic Monitoring
Vehicle Classification-based Traffic Studies
CV-enabled Turning Movement & Intersection Analysis
CV-enabled Origin-Destination Studies
Work Zone Traveler Information

Environment

Eco-Approach and Departure at Signalized Intersections
Eco-Traffic Signal Timing
Eco-Traffic Signal Priority
Connected Eco-Driving
Wireless Inductive/Resonance Charging
Eco-Lanes Management
Eco-Speed Harmonization
Eco-Cooperative Adaptive Cruise Control
Eco-Traveler Information
Eco-Ramp Metering
Low Emissions Zone Management
AFV Charging / Fueling Information
Eco-Smart Parking
Dynamic Eco-Routing (light vehicle, transit, freight)
Eco-ICM Decision Support System

Road Weather

Motorist Advisories and Warnings (MAW)
Enhanced MDSS
Vehicle Data Translator (VDT)
Weather Response Traffic Information (WxTINFO)

Mobility

Advanced Traveler Information System
Intelligent Traffic Signal System (I-SIG)
Signal Priority (transit, freight)
Mobile Accessible Pedestrian Signal System (PED-SIG)
Emergency Vehicle Preemption (PREEMPT)
Dynamic Speed Harmonization (SPD-HARM)
Queue Warning (Q-WARN)
Cooperative Adaptive Cruise Control (CACC)
Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)
Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)
Emergency Communications and Evacuation (EVAC)
Connection Protection (T-CONNECT)
Dynamic Transit Operations (T-DISP)
Dynamic Ridesharing (D-RIDE)
Freight-Specific Dynamic Travel Planning and Performance
Drayage Optimization

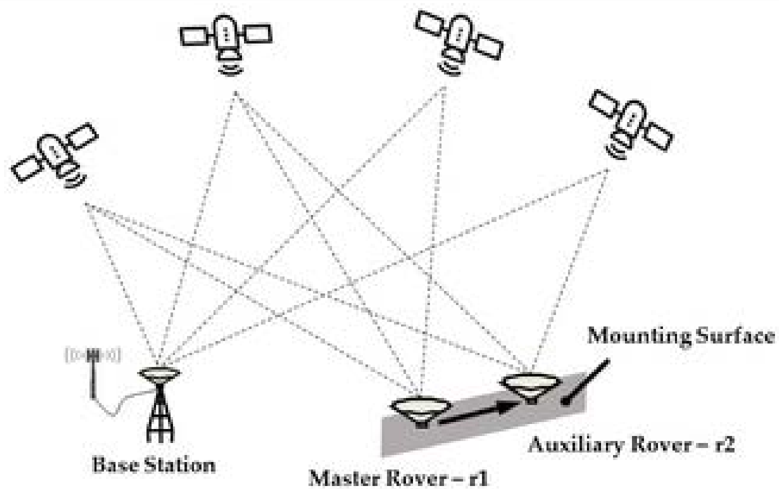
Smart Roadside

Wireless Inspection
Smart Truck Parking

RTK GPS 1 cm

CV Relies on GPS for Positioning

- Most CV Applications require lane level accuracy that GPS alone can't provide



Assuming CV goes to GNSS-RTK

- Correction with nearby base stations
- High cm accuracy positioning in open air environments
- Proposed by Qualcomm for C-V2X

Construction advantages

- BRT choke points like 370 bridge and Rockville metro footbridge eliminated by running guideway over sidewalks
- Faster construction, environmental impact study/mediation
- Less traffic disruption during construction

Revenue Enhancers

- Autonomous Freight carriers
- Community Solar
- Fresh Vegetables sales eliminates trips to the store
- Fees from developers for private connector spurs
-

City of Mountain View
Automated Guideway Transit Feasibility Study

Evaluation of Alternatives and Feasibility Report

FINAL – February 2018

Submitted by:

LEA ELLIOTT

In association with:

Kimley–Horn

Nelson\Nygaard

Apex Strategies

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Attachments

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 intial 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


Portland Aerial Tram (Portland, Oregon)


Funitel Hakone (Kanagawa Prefecture, Japan)

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

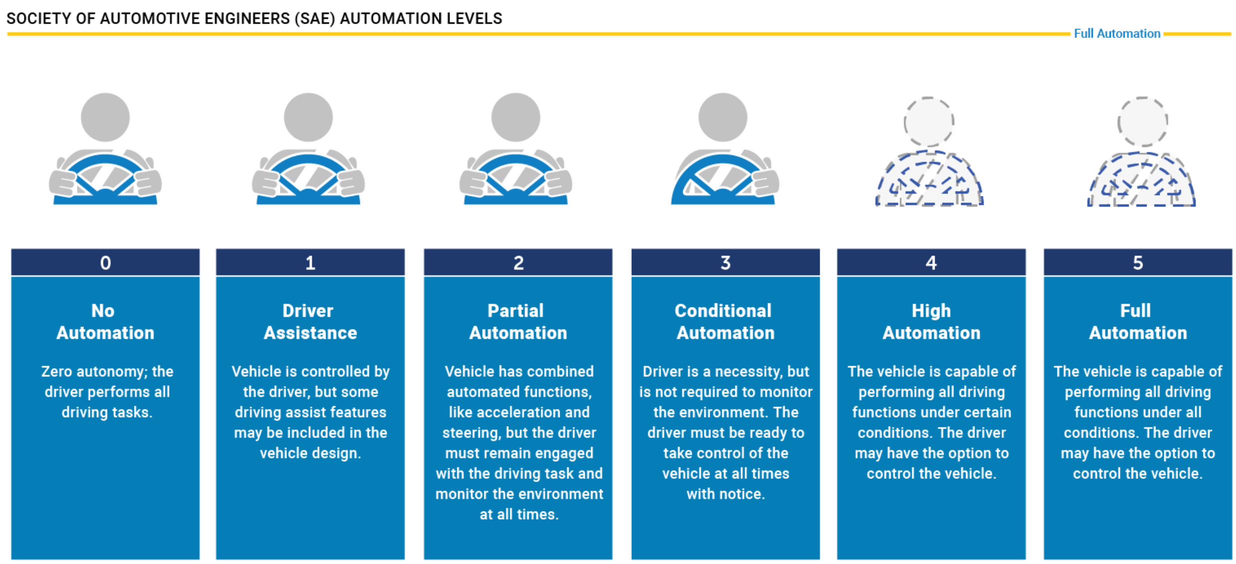
Autonomous Transit technology consists of automated vehicles that are capable of operating in a dedicated guideway or reserved lanes as well as on a mapped network in mixed flow traffic. For the evaluation of this technology in the near term, system throughput capacity would be considered to be equivalent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

Navya: Arma (Source: Navya, 12/9/16 press release)

EasyMile: EZ10 (Parc des Expositions – Paris, France)

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.

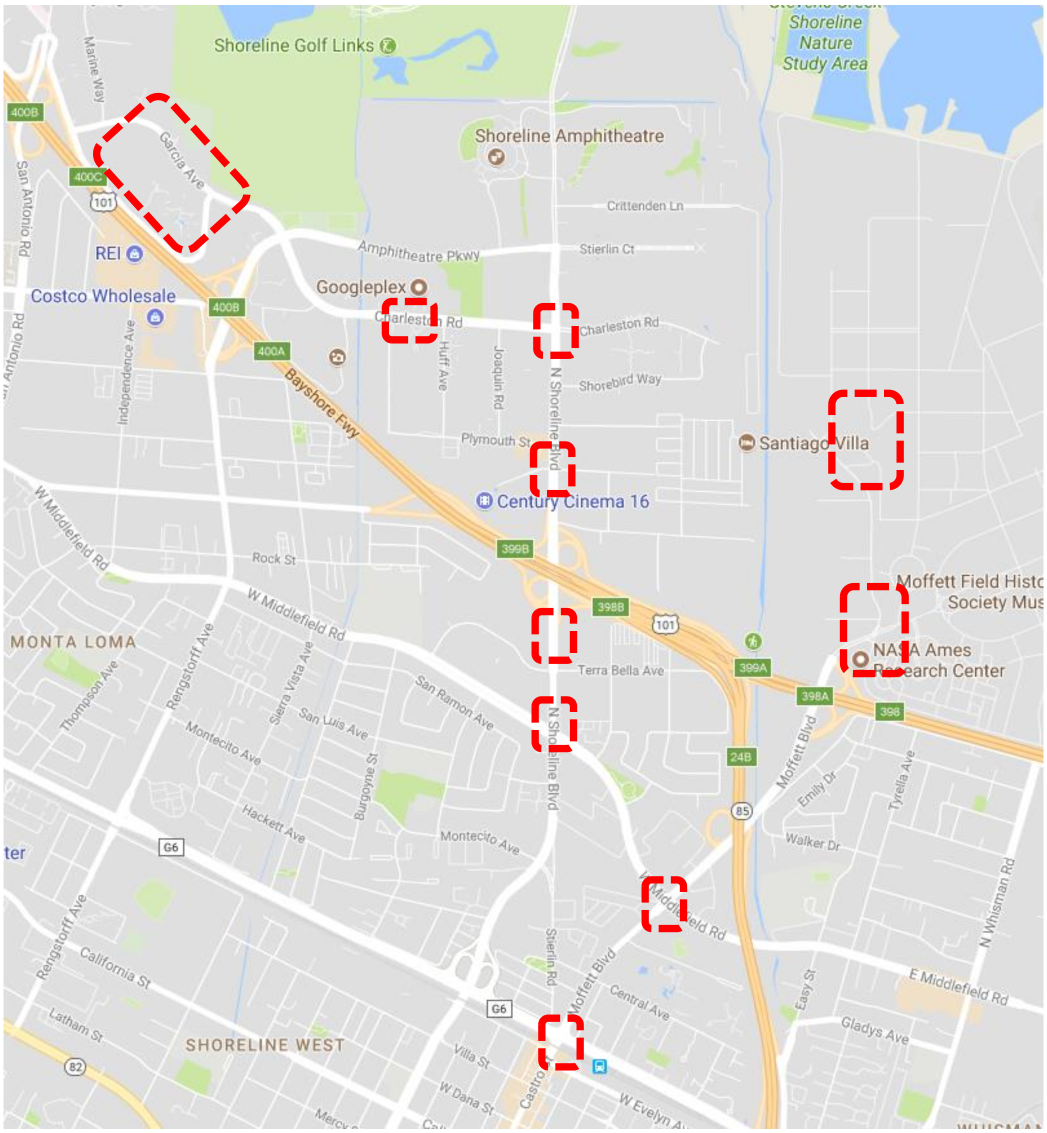
Figure 7-1 Candidate Corridors

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.

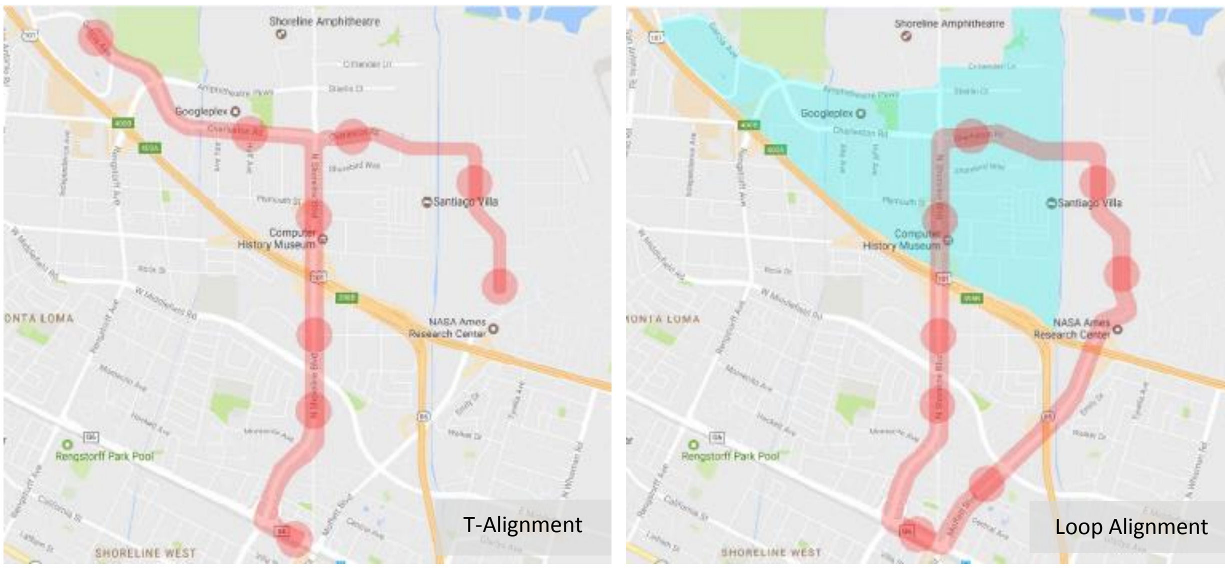
Figure 7-2 Representative Station Locations



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	Evaluation Type: Qualitative 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).
	6	Adaptability of infrastructure	Evaluation Type: Qualitative 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.
Technology Application	7	Ability to add stations to serve existing or new developments	Evaluation Type: Qualitative This criterion addresses the technology's ability to add mid-line stations to serve existing and future developments along the initial alignment.
	8	Ability to expand the system	Evaluation Type: Qualitative The potential for each technology to be easily extended or expanded to serve areas beyond the initial alignment
	9	Integration into Transit Center	Evaluation Type: Qualitative 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.
	10	Level of technology maturity	Evaluation Type: Qualitative 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.
Cost	11	Financial Feasibility	Evaluation Type: Qualitative 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.

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 diminishing 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


Portland Aerial Tram Cable Guideway Tower


Telecabine Lisboa Cable Guideway Tower, Lisbon, Portugal

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 are 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 and preventive maintenance and cleaning services. For both types of systems in extended service, maintenance personal 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 systems[1]. 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 additional 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 characterises 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.

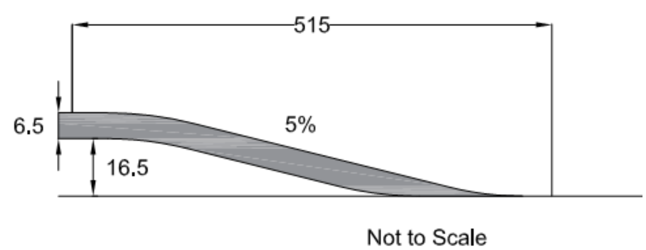
As an AGT system could potentially provide service to support Amphitheater events, coordination between the City and the Amphitheater is needed to both understand what Amphitheater service plans are and develop a strategic approach for utilizing the AGT system. For example, consideration is needed for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

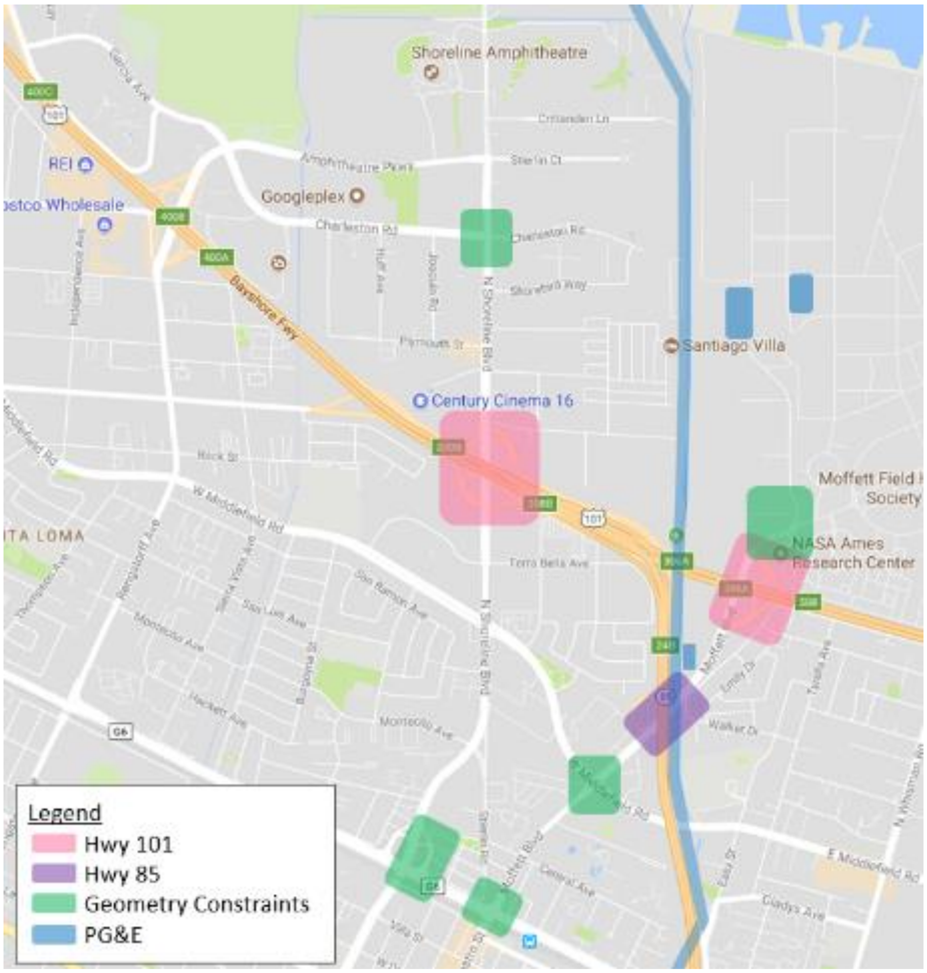


10.5 Corridor Challenges

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

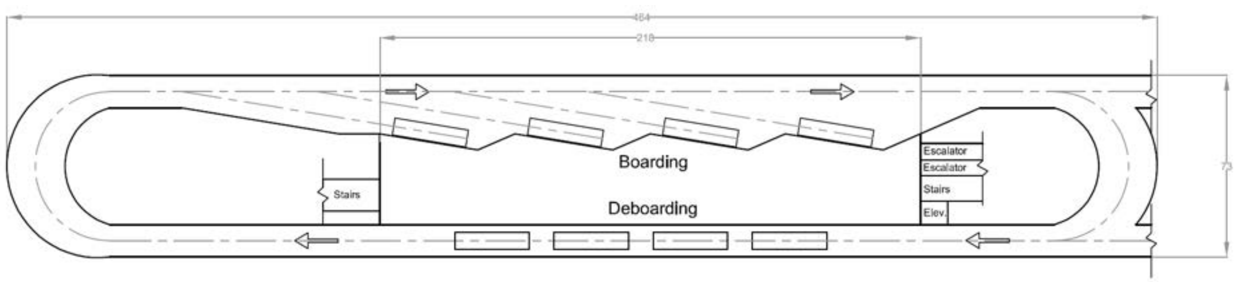
To better understand the general size and potential layout of a station and how it might integrate into the Transit Center area an AGT station concept was developed.

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.

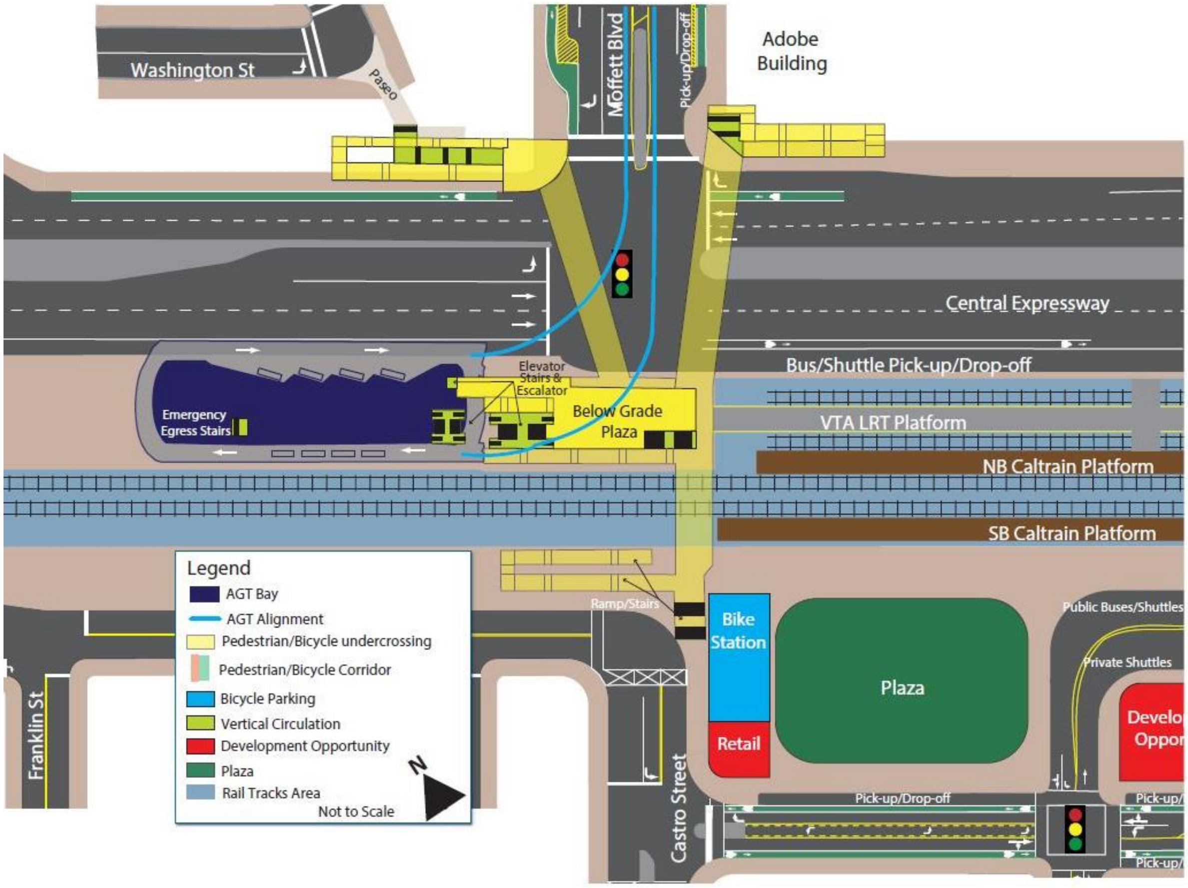
In addition, the Transit Center station concept is an end of the line station with the potential to be an intermediate station if the system is expanded in the future. As an end station, only one travel lane is needed on each side. An additional passing lane would likely be required on each side for 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 steps could be pursued over the next several years to monitor development and refine the recommended system technologies, but also to better understand how the guideway alignment 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 help develop 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 help determine 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.

ATTACHMENT 1

Evaluation of Automated Guideway Transit Technologies

The following is a summary of the evaluation of each technology grouping for the project area. 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.

The following ratings are used to identify how well each technology group meets the criteria.

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

CATEGORY: PASSENGER EXPERIENCE

CRITERIA 1: ABILITY TO SERVE MARKET DEMAND ESTIMATE

AERIAL CABLE TRANSPORTATION

Score: ◐

To meet the required demand, a Bicable or Tricable Detachable Gondola technology will be required. Bicable cabins have a capacity of approximately 15-20 passengers, whereas cabins for Tricable systems hold approximately 35 passengers. While Bicable Detachable Gondola technology can meet the demand, the Tricable technology would better meet the system's needs, including the requirement to allow bicycles on board, as well as the waves of passengers arriving from Caltrain.

The estimated travel times to the key stations provided below are based on a typical Bicable and Tricable system. These times assume a single V-configuration system.

- TC to:
  - NASA/Ames: 9 to 13 min
  - N. Bayshore: 9 to 13 min

AUTOMATED PEOPLE MOVER

Score: ●

The estimated travel times to key stations provided below are based on typical rubber-tire APM technology.

- TC to:
  - NASA/Ames: 4.0 to 11.5 min
  - N. Bayshore: 7.0 to 14 min

The following are the approximate operating fleets and headway results that meet the demand requirements. These results assume bikes are allowed onto vehicles.

To N. Bayshore or to NASA/Ames:

Approx. Headway (min)	Approx. Operating Fleet	Approx. Capacity (pphpd)
4	8 x 2-car train	2300

AUTOMATED TRANSIT NETWORK

Score: ●

The estimated travel times to key stations provided below are based on typical ATN technology.

- TC to:
  - NASA/Ames: 4.0 to 11.5 min
  - N. Bayshore: 6.0 to 14.0 min

As there are varying vehicle capacities for different ATN technologies, the operational summary is provided for PRTs and GRTs.

The following are the approximate operating fleets and headway results that meet the demand requirements for typical PRT and GRT technologies. These results assume bikes are allowed onto vehicles.

To NASA/Ames:

Type of Vehicle	Approx. Headway (min)	Approx. Operating Fleet	Approx. Capacity (pphpd)
PRT	0.8	11	220
GRT	5.5	3	230

To N. Bayshore:

Type of Vehicle	Approx. Headway (min)	Approx. Operating Fleet	Approx. Capacity (pphpd)
PRT	0.1	126	1800
GRT	0.7	24	1850

AUTONOMOUS TRANSIT

Score: ●

The estimated travel times to key stations provided below are based on typical Autonomous Transit technology.

- TC to
  - NASA/Ames: 6.0 to 10.0 min
  - N. Bayshore: 6.0 to 10.0 min

The following are approximate operating fleets and headways results based off of generic vehicle sizes that meet the demand requirements. These results assume bikes are allowed onto vehicles.

To NASA/Ames:

Veh. Capacity	Approx. Headway (min)	Approx. Operating Fleet	Approx. Capacity (pphpd)
10	2.1	7	230
20	4.9	3	210

To N. Bayshore:

Veh. Capacity	Approx. Headway (min)	Approx. Operating Fleet	Approx. Capacity (pphpd)
10	0.3	60	1,900
20	0.6	27	1,990

If dwell times in the transit center average 1 minute (including maneuvering in and out of berths), then 2 berths will be required as a

<table>
<tr><th colspan="4">CATEGORY: PASSENGER EXPERIENCE</th></tr>
<tr>
<td>The following are the approximate operating fleets and headway results that meet the demand requirements based on Bicable and Tricable systems. These results assume bikes are allowed onto cabins.

To N. Bayshore or to NASA/Ames:
<table>
<tr><th>Approx. Headway (min)</th><th>Approx. Operating Fleet</th><th>Approx. Capacity (pphpd)</th></tr>
<tr><td>0.5 - 1</td><td>22 - 48</td><td>1830 - 1920</td></tr>
</table>
</td>
<td></td>
<td>At stations, multiple berths and a large staging area are needed to achieve the throughput required to meet the demand. This system would require a theoretical minimum of 8 berths for PRT-sized vehicles. As much of the PRT fleet would be used only during peak hours, a large storage area would also be required for the majority of the operating day.

GRT vehicles are better sized for the demand needs but would still require multiple berths and a staging area to meet demand. This system would require a theoretical minimum of 3 berths per platform edge.</td>
<td>theoretical minimum for 20 passenger vehicles. For 10 passenger vehicles this same assumption yields a theoretical minimum of 4 berths.

If direct point-to-point trips are to be provided to multiple stations in the North Bayshore and the NASA Ames districts, and if allowance is made for some berths being out of service-of-service or tied up by a delayed vehicle, then more berths will probably be required to simultaneously board passengers bound for multiple destinations.</td>
</tr>
<tr><th colspan="4">CRITERIA 2: FLEXIBILITY IN SERVICE / RESPONSIVENESS IN DAILY DEMAND</th></tr>
<tr><th>AERIAL CABLE TRANSPORTATION</th><th>AUTOMATED PEOPLE MOVER</th><th>AUTOMATED TRANSIT NETWORK</th><th>AUTONOMOUS TRANSIT</th></tr>
<tr>
<td>Score: ⦸

Fixed link transit like aerial cable transportation systems have poor operational flexibility. When an aerial cable transportation system malfunctions, operations along the entire line are affected.

With regards to responsiveness to demand, since vehicles are detachable (except for Aerial Trams), it is possible to add more vehicles at an end station to serve a peak demand period. However, due to the size of the cabins (8 ft. height</td>
<td>Score: ◐

APM systems have moderate flexibility in service. If a vehicle malfunctions, operations can continue with built in crossovers along the alignment for vehicles still in service to maneuver around trouble areas. Additionally, backup vehicles stored at the Maintenance Storage Facility (MSF) can be brought into service.

With regards to responsiveness to demand, trains can be added or removed from the system as</td>
<td>Score: ●

ATN systems have high flexibility in service. If a vehicle malfunctions, operations can continue with built in crossovers along the alignment for vehicles still in service to maneuver around the trouble areas. Additionally, backup vehicles stored at the Maintenance Storage Facility (MSF) can be brought into service.

Headways are normally small during regular operation, so response time is quick when service is needed. Each station has a berthing area with vehicles staged nearby to handle a spike in passenger demand if needed. Vehicles can also be dispatched from nearby stations to</td>
<td>Score: ●

The nature of Autonomous Transit technology allows high flexibility in service. A small vehicle size and the lack of need for any type of physical, electrical or mechanical guidance as the vehicles travel along a transit service path (defined on the map in their control system's memory), Autonomous Transit provides full flexibility in responding to changes in the ridership demands. Additionally, backup vehicles stored at the Maintenance Storage Facility (MSF) can be brought into service.

Headways are normally small during regular operation, so response time is quick when</td>
</tr>
</table>

CATEGORY: PASSENGER EXPERIENCE			
x 12 ft. length and width), storing these cabins at an end station is unreasonable.	appropriate. Also, more cars can be added to a train to increase capacity, from 1 car up to 6-car train systems, to better accommodate demand as it continues to grow through the years. Stations need to be planned and constructed for the anticipated maximum train length.	help with surge demand. In addition, ATNs allow for operating vehicles on an as-needed basis only. Riders can call a vehicle to a station when needed, thus eliminating the operations of near empty trains, which is a common occurrence during off-peak periods on typical transit systems.	service is needed. Each station has a berthing area with vehicles staged nearby to handle a spike in passenger demand if needed. Vehicles can also be dispatched from nearby stations to help with surge demand. With regards to responsiveness to demand, individual vehicles can be dispatched to any station by the supervisory control system to serve any dynamic changes to demand that occurs, including dispatching to travel empty to another part of the network to service demand surges, bypassing all intermediate stations along the way.
CRITERIA 3: PROVIDES CONVENEIENT AND HIGH-LEVEL OF SERVICE			
AERIAL CABLE TRANSPORTATION	**AUTOMATED PEOPLE MOVER**	**AUTOMATED TRANSIT NETWORK**	**AUTONOMOUS TRANSIT**
Score: ◐ <u>Service and Reliability</u> Aerial Cable Transportation systems have been proven worldwide to provide a high level-of-service for all users. The systems in urban applications are highly reliable and consistently perform in the 99.3 to 99.9% range. Poor weather conditions (mainly high wind speeds, ice and thunderstorms to a lesser degrees) are generally the reasons behind service interruptions. As the systems are fully automated and operate in exclusive rights-of-	Score: ● <u>Service and Reliability</u> APMs have been proven worldwide to provide a high level-of-service for all users. APM systems are highly reliable and consistently perform above the 99.5% availability required by many O&M contracts. As the systems are fully automated and operate in exclusive rights-of-way, the system is not impacted by traffic, vehicles, or pedestrians. As these systems are guided, they have the ability for accurate berthing at stations, allowing for	Score: ● <u>Service and Reliability</u> There are five ATN systems in operation worldwide, and each of these systems has shown high reliability. As the systems are fully automated and operate in exclusive rights-of-way, the system is not impacted by traffic, vehicles, or pedestrians. As these systems are guided, they have the ability for accurate berthing at stations, allowing for level boarding onto the vehicles with a minimal gap between platform and vehicle. The point-to-point, or on-demand, nature of ATN systems allows for minimal to no wait	Score: ◐ <u>Service and Reliability</u> Although still in the testing phase, the objective of Autonomous Transit is to provide point-to-point service that can naturally be provided in a network configuration (or along a defined service corridor) with intermediate off-line stations bypassed without stopping. Autonomous Transit also has the potential capability of providing aspects of line-haul service where warranted between combinations of high-demand station pairs. Autonomous Transit technology has the ability to transition from grade separated to at-grade and circulate in the campus-like operating environment -- providing a higher level of

CATEGORY: PASSENGER EXPERIENCE			
way, the system is not impacted by traffic, vehicles, or pedestrians. However, as the system speed is slower, the overall time for riders is increased, which is a negative for a system primarily serving commuters who are time-sensitive. <u>ADA Considerations</u> 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. <u>Emergency Evacuation Considerations</u> A disadvantage of aerial cables is that in the unlikely event of a hazard, emergency, or power outage it is not possible to exit the cabins at the passengers' own volition.	level boarding onto the vehicles with a minimal gap between platform and vehicle. Typical APM systems operate at a high frequency with minimal wait times for passengers during peak periods. <u>ADA Considerations</u> APMs provide level boarding and are fully-ADA compliant without the need for any assistance by attendants. <u>Emergency Evacuation Considerations</u> APMs typically have emergency walkways adjacent to the guideway, allowing for passenger evacuation.	times for passengers during off peak periods. This does assume a well distributed fleet with vehicles staged at stations. <u>ADA Considerations</u> ATN systems currently in operation provide full ADA-compliance, with level boarding and space for wheelchairs. However, some smaller, in-development technologies with smaller vehicle sizes may have some ADA concerns due to lack in level boarding or, due to size and space constraints, may need to separate an assistant from the passenger in the wheelchair. <u>Emergency Evacuation Considerations</u> While there are no standards or regulations specific to ATN, it can be assumed that since transit systems all have emergency walkways, emergency walkways will be required for ATN systems. However, emergency evacuation may be more difficult for suspended ATN technologies.	service due to point-to-point rides for most passengers and providing a no-transfer ride to all passengers. This convenience benefits passengers with disabilities, the elderly, and those traveling with small children. <u>ADA Considerations</u> 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. In addition, some technologies in development are currently testing vehicles that are similar to existing cars, which require passengers to bend down and sit in the vehicle. These technologies should not be considered for Mountain View. <u>Emergency Evacuation Considerations</u> While there are no standards or regulations specific to AVs, it can be assumed that since transit systems all have emergency walkways, emergency walkways will be required for AV systems.

CATEGORY: INFRASTRUCTURE			
CRITERIA 4: POSSIBLE IMPACT ON NEIGHBORHOODS			
AERIAL CABLE TRANSPORTATION	**AUTOMATED PEOPLE MOVER**	**AUTOMATED TRANSIT NETWORK**	**AUTONOMOUS TRANSIT**
Score: ⦸ Emissions Vehicles are propelled by cables with no on-board motor and no local emissions. Most systems are electrically powered. Noise Impacts Noise impacts for this technology 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. Visual Impacts Visual impacts for this technology differs from a traditional transit system. Because the system operates overhead, the main visual impact are the towers, which are typically located every 500' to 1,000'. There may also be privacy concerns from residents as cabins are suspected above buildings and it is likely, due to technology constraints, that the system will operate over private properties.	Score: ◐ Emissions Vehicles are electrically powered with no local emissions. There is greater flexibility in selecting the power source for electrically powered vehicles. Noise Impacts Noise impacts for APMs are minimized, particularly for rubber-tire systems compared to steel wheel systems. Noise occurs only when vehicles pass. Visual Impacts Visual impacts for APMs are due mainly to the guideway structure and stations. APMs will have the largest guideway compared to ATN and Autonomous Transit, at approximately 30' for a dual lane system. Typically, parapet walls are included on concrete guideway structures that cover vehicle undercarriage and other guideway and power equipment that might be visible. Other structures include single beams for monorails.	Score: ◐ Emissions Vehicles are electrically powered with no local emissions. There is greater flexibility in selecting the power source for electrically powered vehicles. Noise Impacts Noise impacts for ATNs are minimized as vehicles are rubber-tired and occur only when vehicles pass. Visual Impacts Visual impacts for ATNs are lessened compared to APM technologies due to the slightly smaller guideway structure. Elevated structures will be concrete guideway structures with parapet walls, with a width of approximately 22' for a dual lane structure.	Score: ◐ Emissions Vehicles can be electrically powered with no local emissions. There is a greater flexibility in selecting the power source for electrically powered vehicles. Noise Impacts Noise impacts for Autonomous Transit are minimized as vehicles are rubber-tired and can be located either in an exclusive transitway structure or in mixed traffic. Noise occurs only when vehicles pass. Visual Impacts Visual impacts for Autonomous Transit vary by the system used. For exclusive facilities, the visual impacts of dedicated transitway structures and/or protected transitways are the same as other AGT technologies being considered. Elevated structures will be concrete guideway structures with parapet walls, with a width of approximately 22' for a dual lane structure. However, as the technology matures over the next 10 to 15 years and as the capability to operating in mixed traffic – including in the same operating space as pedestrians – are fully vetted and

CATEGORY: INFRASTRUCTURE			
			acceptable to the PUC, flexibility to operate on existing roadways may allow highly sensitive neighborhoods to be served without elevated structures or other such features.
CRITERIA 5: ABILITY TO FIT WITHIN THE LOCAL ENVIRONMENT			
AERIAL CABLE TRANSPORTATION	**AUTOMATED PEOPLE MOVER**	**AUTOMATED TRANSIT NETWORK**	**AUTONOMOUS TRANSIT**
Score: ⃠ As the system is elevated at a height above existing buildings, the impact to trees would be limited to tower locations and at the end stations where the stations should be as low as possible to minimize the vertical change for passengers and facilities costs. However, Aerial Cable technology requires large turning radii with large or multiple turning towers which would likely require placement in private and/or developed properties. This technology is better suited to an alignment requiring minimal turns to mitigate impacts. Due to the elevated nature of this technology, and depending on the capability of bringing cabins to grade at stations, it is likely that some stations will need to be elevated, which may result in additional impacts to private and/or developed properties.	Score: ◐ For elevated systems, physical impacts at grade include column placement along the alignment, station infrastructure, and power distribution facilities. Columns are placed every 80' to 120' and placement locations might include sidewalks, street parking spaces and medians depending on the alignment and available space. Trees removal or relocation might be necessary at station and column locations. APM technology requires larger turning radii compared to ATN and Autonomous Transit 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 and may force the location of the structure outside of the public right of way and onto private and/or developed properties. In addition,	Score: ◐ For elevated systems, physical impacts at grade include column placement along the alignment and station infrastructure. Columns are placed every 80' to 120' and placement locations might include sidewalks, street parking spaces and medians depending on the alignment and available space. Trees removal or relocation might be necessary at station and column locations. With the smaller allowable turning radii of ATN, guideway infrastructure may be maintained in medians or along sidewalks more effectively. Thus, there is more flexibility in the system routing and column placement while still maintaining ride comfort parameters and supplier design limitations. However, as this technology requires exclusive ROW for operations, elevated structures for the guideway as well as stations would likely be required. Depending on finalized	Score***:*** ● For elevated systems, physical impacts at grade include column placement along the alignment and station infrastructure. Columns are placed every 80' to 120' and placement locations might include sidewalks, street parking spaces and medians depending on the alignment and available space. In tightly constrained areas, Autonomous Transit has the option of traveling at-grade and/or in mixed traffic. With the smaller allowable turning radii of Autonomous Transit, guideway infrastructure may be maintained in medians or along sidewalks more effectively. Thus, there is more flexibility in the system routing and column placement while still maintaining ride comfort parameters and supplier design limitations. In addition, as this technology matures there is the potential to operate at grade mitigating the need for fully

CATEGORY: INFRASTRUCTURE			
	the elevated stations required for this technology may result in additional impacts to private and/or developed properties.	station locations there may be impacts to private and/or developed properties at station locations.	elevated guideway and stations structures.
CRITERIA 6: ADAPTABILITY OF INFRASTRUCTURE			
AERIAL CABLE TRANSPORTATION	**AUTOMATED PEOPLE MOVER**	**AUTOMATED TRANSIT NETWORK**	**AUTONOMOUS TRANSIT**
Score: ○ Very rigid technology usage and impossible to transition to a different technology.	Score: ⃠ Transition to a different technology and vehicle supplier, though possible, would require coordination and phasing to minimize impact on the operations of the system. The guideway structures should also be adequate for re-use for technologies of similar or smaller size than APMs. However, guidance equipment and running surfaces may not be able to be re-used and would need to be fully removed or replaced to accommodate other AGT technologies and in some cases APM technologies.	Score: ◐ Depending on supplier, the transition to/from a different ATN technology can be difficult or simple depending on the type of guidance equipment installed on the structure. Those with roadway-like running surfaces can more readily transition to another ATN or to autonomous transit technology with minimal rework. In any case, coordination and phasing is needed in order to minimize impact on the operations of the system. Guidance and running surfaces may not be able to be re-used (depending on supplier). The guideway structures should be adequate for re-use for technologies of similar or smaller size than an ATN.	Score***:*** ● Aerial structures can more easily adapt to different technologies for Autonomous Transit as the vehicle/guideway interface is a simple interface much like rubber-tired buses on roadways, with no mechanical guiding elements or switches required. For at-grade transitways and associated infrastructure, the adaptability will be the most flexible of all the alternative AGT technologies as the vehicles will operate on adjacent facilities to the existing network.

CATEGORY: TECHNOLOGY APPLICATION			
CRITERIA 7: ABILITY TO ADD STATIONS TO SERVE EXISTING OR NEW DEVELOPMENTS			
AERIAL CABLE TRANSPORTATION	**AUTOMATED PEOPLE MOVER**	**AUTOMATED TRANSIT NETWORK**	**AUTONOMOUS TRANSIT**
Score: ⦸ Adding stations along the route, while feasible, is extremely difficult. Locations for infill stations need to be predetermined and identified during planning to allow for the required station geometry and provisions needed (turning towers, elevations, land, etc.). The system will need to be shut down for most of the duration of the station construction.	Score: ◐ Locations for infill stations need to be pre-determined and identified during planning to allow for the required station and guideway geometry and provisions (tangent guide way, land, etc.) as well as incorporating the station and associated berthing location into the train control system for future activation. If planned appropriately, station implementation could primarily be done during off hours with limited disruption to operations. In addition to the physical station, the train control and communications would need to be updated for the new station. The level of update required depends on whether the station location was identified and planned for during the implementation of the initial system.	Score: ● As a network transportation system, stations can be added more easily when compared to other technologies. Stations are typically located on side tracks from the main operating line (to allow for trains by bypass a station) so a large amount of station construction can take place while the system is operating. Depending on the supplier, the identification of the infill station during planning would reduce the disruption to operations during construction. In addition to the physical station, the train control and communications would need to be updated for the new station. The level of update required depends on whether the station location was identified and planned for during the implementation of the initial system.	Score*:* ● As a network transportation system, stations can be added more easily when compared to other technologies. Stations are typically located on side tracks from the main operating line (to allow for trains by bypass a station) so a large amount of station construction can take place while the system is operating. Depending on the supplier, the identification of the infill station during planning would reduce the disruption to operations during construction. An important aspect of the flexibility of Autonomous Transit is that new stations can be easily created in the virtual map, which the control system uses in each vehicle's memory to track its precise location. For station docking precession, additional systems/equipment may be necessary and associated new equipment/control system changes must be addressed.

CATEGORY: TECHNOLOGY APPLICATION			
CRITERIA 8: ABILITY TO EXTEND THE SYSTEM			
AERIAL CABLE TRANSPORTATION	**AUTOMATED PEOPLE MOVER**	**AUTOMATED TRANSIT NETWORK**	**AUTONOMOUS TRANSIT**
Score: ⦸ If needed, an Aerial Cable Transportation system can be extended. However, extending a system that is not initially designed for future system lengthening is very difficult due to the infrastructure that needs to be added with regards towers and cable system and rework of an end of line station. Thus, initial planning should take into consideration future extensions to mitigate impacts and system downtime.	Score: ◐ Systems can be extended beyond end of line stations with minimal to no impact to the operations of the existing system during implementation. For system expansions that occur midline (i.e. not extending beyond an end station), constructing a spur track initially for the future expansion minimizes impacts to the system operations. All expansions would require an exclusive right of way; further coordination and planning is required to identify the right of way and to coordinate the overall transportation need, both within Mountain View and with neighboring cities. Incremental operating costs to expand service include fleet procurement and maintenance. Additional infrastructure includes guideway and station infrastructure, and potentially additional traction power substations and/or a new or expanded maintenance facility.	Score: ◐ System can be extended beyond end of line stations with minimal to no impact to the operations of the existing system during implementation. For midline system expansions, constructing a spur initially for the future expansion minimizes impacts to the system operations for some suppliers. Expansions likely require an exclusive right of way; further coordination and planning is required to identify the right of way and to coordinate the overall transportation need, both within Mountain View and with neighboring cities. However, some suppliers are also moving into the Autonomous Transit market so there may be opportunities for a shared right of way for expansions, depending on the supplier. Incremental operating costs to expand service include fleet procurement and maintenance. Additional infrastructure includes guideway and station infrastructure, and potentially a new or expanded maintenance facility.	Score*:* ● System can be extended beyond end of line stations with minimal to no impact to the operations of the existing system during implementation. Extending the network will have minimal to no impact to the operations of the existing system during construction and implementation. Expansion of Autonomous Transit that are in an exclusive ROW would require coordination and planning to identify the right of way and to coordinate the overall transportation need, both within Mountain View and with neighboring cities. Expansion of an Autonomous Transit network operating along existing at-grade roadway facilities without complete separation from other roadway vehicles, or complete separation from pedestrians and bicycles, will have minimal impacts to the system operations. Although operating speeds will possibly need to be limited to safe travel within the mixed-traffic operating environment, the flexibility to extend the operating route without construction of dedicated and protected transitways is a major advantage for the Autonomous Transit

CATEGORY: TECHNOLOGY APPLICATION			
			alternative. Incremental operating costs to expand service include fleet procurement and maintenance. Additional infrastructure includes guideway and station infrastructure, and potentially a new or expanded maintenance facility.
CRITERIA 9: INTEGRATION INTO TRANSIT CENTER			
AERIAL CABLE TRANSPORTATION	**AUTOMATED PEOPLE MOVER**	**AUTOMATED TRANSIT NETWORK**	**AUTONOMOUS TRANSIT**
Score: ⃠ The approximate station width for the tricable detachable gondola technology is 65-70ft. The station will therefore need to straddle at least part of Central Expy. To serve both N. Bayshore and NASA Ames the Transit Center station may need to be an inline station to allow travel in either direction and minimize the space needed for the station. Otherwise separate cable systems would be required which would require more space. In addition, due to visibility concerns for the properties in the area, it is anticipated that the system would need to transition quickly in height to clear buildings. Therefore, the resulting height of the station may be high, resulting in a longer time for passengers to access the station.	Score: ◐ The approximate width for a center platform station to accommodate the demand, two tracks, and vertical circulation is 55 to 65 ft. It is likely that the station will need to straddle at least part of Central Expy. For systems that turn north onto Moffett, the station will need to be a further west increasing the distance from the Transit Center and Caltrain as additional distance is required for the turn.	Score: ◐ The approximate width for a side platform and berths to accommodate the demand, two tracks, and vertical circulation is 65 to 75 ft. The station will therefore need to straddle at least part of Central Expy. Some technologies may need additional area for turnaround when leaving the station. For systems that turn north onto Moffett, the station will need to be a further west increasing the distance from the Transit Center and Caltrain as additional distance is required for the turn.	Score***:*** ● The approximate width for a side platform and berths to accommodate the demand, two tracks, and vertical circulation is 65 to 75 ft. The station will therefore need to straddle at least part of Central Expy. Some technologies may need additional area for turnaround when leaving the station, while others may allow for bi-directional operation and may not need a turnaround.

CATEGORY: TECHNOLOGY APPLICATION			
CRITERIA 10: LEVEL OF TECHNOLOGY MATURITY			
AERIAL CABLE TRANSPORTATION	**AUTOMATED PEOPLE MOVER**	**AUTOMATED TRANSIT NETWORK**	**AUTONOMOUS TRANSIT**
Score: ● Aerial cable technology is very mature, with numerous systems around the world, including urban areas. There are numerous suppliers worldwide who produce this type of technology system. It is not anticipated that there would be a regulatory or safety certification concern for the implementation of an aerial cable system.	Score: ● Vehicle and train control technology is very mature and have been widely adopted worldwide. Self-propelled APMs are at over 40 airports worldwide and the technology is also being used for urban systems (examples: Singapore; Guangzhou, China; Toulouse, France; Miami, Florida; and Busan, Korea). There are multiple established suppliers worldwide who produce APM systems. It is not anticipated that there would be a regulatory or safety certification concern for the implementation of an aerial cable system.	Score: ◐ Vehicle and train control technology has been in usage since 1975 and there are five systems currently operating worldwide, with one in development. While some ATN suppliers have completed a full certification process, the technology is overall still in development. There are only one or two suppliers currently active in the transit market with systems already in operation.	Score***:*** ◐ AV transit technologies are now entering the marketplace that have evolved from initial designs as ATN system applications using robotic vehicles that steer themselves along exclusive transitways. The inherent design features of these “cross-over” designs are based on their control systems’ ability to track within each vehicle’s computer memory the vehicle trajectories along a virtual map of the operating alignment. Both these ATN cross-over vehicle suppliers as well as other new-start Autonomous Transit technology developers are actively designing the necessary sensory systems and enhanced vehicle geo-location systems that will allow the vehicles to operate with deployments in mixed traffic environments (if necessary), although operating speeds may be reduced until full maturity of the Autonomous Transit technology occurs over the next 5 to 10 years.

CATEGORY: COST

CRITERIA 11: FINANCIAL FEASIBILITY

AERIAL CABLE TRANSPORTATION	AUTOMATED PEOPLE MOVER	AUTOMATED TRANSIT NETWORK	AUTONOMOUS TRANSIT
Score: ⦸ Due to the nature of the North Bayshore and NASA Ames service area, with tech company campuses and ongoing development plans (residential and commercial growth), a public-private partnership approach may be feasible as there may be private interest from companies and developers in providing the connection to the Transit Center (or downtown in general) to their employees and/or future tenants particularly if parking is limited for new developments. Due to the maturity of the technology, there is likely little to no opportunity for private funding from a technology development standpoint. However, the a-typical application of the aerial cable technology may garner support for implementation from a private party or technology supplier. Although the current MVgo shuttle is free to the public, providing improved service via the AGT system provides the opportunity to apply a fare, much like for bus or LRT system, to the AGT system for	Score: ◐ Due to the nature of the North Bayshore and NASA Ames service area, with tech company campuses and ongoing development plans (residential and commercial growth), a public-private partnership approach may be feasible. There may be private interest from companies and developers in providing the connection to the Transit Center (or downtown in general) to their employees and/or future tenants particularly if parking is limited for new developments. Due to the maturity of the technology, there is likely little to no opportunity for private funding from a technology development/marketing standpoint. Although the current MVgo shuttle is free to the public, providing improved service via the AGT system provides the opportunity to apply a fare, much like for bus or LRT system, to the AGT system for commuters and residents alike. Future planning should include review of a regional fare structure that allows transfers from Caltrain, VTA, and TMA	Score: ◐ Due to the nature of the North Bayshore and NASA Ames service area, with tech company campuses and ongoing development plans (residential and commercial growth), a public-private partnership approach may be feasible. There may be private interest from companies and developers in providing the connection to the Transit Center (or downtown in general) to their employees and/or future tenants particularly if parking is limited for new developments. The in-development status of the technology may also increase the possibility for a public-private partnership approach as the newer technology provides a draw and technology companies may have increased interest in showcasing their particular technology. Although the current MVgo shuttle is free to the public, providing improved service via the AGT system provides the opportunity to apply a fare, much like for bus or LRT system, to the AGT system for commuters and residents alike. Future	Score: ◐ Due to the nature of the North Bayshore and NASA Ames service area, with tech company campuses and ongoing development plans (residential and commercial growth), a public-private partnership approach may be feasible. There may be private interest from companies and developers in providing the connection to the Transit Center (or downtown in general) to their employees and/or future tenants particularly if parking is limited for new developments. With the capability to dispatch vehicles to service specific stations, it may be a consideration to obtain dedicated funding from private "sponsors" or "partners" to serve their chosen stations with the vehicles identified with this entity by its branding/advertising wrap. The in-development status of the technology may also increase the possibility for a public-private partnership approach as the newer technology provides a draw and technology companies may have increased interest in showcasing their particular technology.

CATEGORY: COST			
commuters and residents alike. Future planning should include review of a regional fare structure that allows transfers from Caltrain, VTA, and TMA collaboration for potential employee fare subsidies.	collaboration for potential employee fare subsidies.	planning should include review of a regional fare structure that allows transfers from Caltrain, VTA, and TMA collaboration for potential employee fare subsidies.	Although the current MVgo shuttle is free to the public, providing improved service via the AGT system provides the opportunity to apply a fare, much like for bus or LRT system, to the AGT system for commuters and residents alike. Future planning should include review of a regional fare structure that allows transfers from Caltrain, VTA, and TMA collaboration for potential employee fare subsidies.

Kimley»Horn

MEMORANDUM - DRAFT

To:	Ramses Madou City of San José
From:	Adam Dankberg, P.E. Kimley-Horn and Associates, Inc.
Date:	June 19, 2020
Subject:	San José New Transit Options RFI – Summary Assessment Technical Memo

Overview

The City of San José, in partnership with the Santa Clara County Valley Transportation Authority (VTA), City of Santa Clara, City of Cupertino, and County of Santa Clara issued a Request for Information (RFI) to develop new transit options connecting San José Diridon Station to Mineta San José International Airport (San José Airport) and to multiple destinations along the Stevens Creek Boulevard corridor.

Accommodating future growth in the region will require major changes in transportation infrastructure to allow more residents of San José and Santa Clara County to thrive without daily reliance on driving alone and the associated environmental impacts and personal costs. However, recent delivery of high-capacity mass transit has been characterized by projects costing hundreds of millions of dollars per mile and spending decades in planning and construction. These drawbacks have engendered an understandable skepticism that transit projects can be implemented quickly and can cost-efficiently achieve mode shift goals.

The City of San José and its partners issued the RFI to receive information from innovators in the field of transportation on how transformative transit projects might be completed more quickly and at lower costs. Submissions were requested that addressed new technologies, operational practices, and project delivery methods. The focus for this request was to solicit information on the opportunities for grade-separated transit solutions that could be constructed and operated at a significantly lower cost than existing and planned transit projects.

The RFI process generated a significant amount of interest and the proposals received by the City varied widely in level of detail and feasibility. Most of the proposals focused on technological solutions (with limited proposals for operational practices or project delivery methods), and the technologies ranged from products currently in operation to those that are still speculative. The RFI process succeeded in generating a cross-sectional assessment of emerging automated separated guideway solutions, ascertaining technological readiness, and promoting industry awareness of the specific opportunities and needs in Santa Clara County. The RFI process revealed that many technologies are still in their infancy and are a few years away from implementation readiness. It also highlighted that there are some technologies in operation and that the rapid pace of innovation and high level of international investment will likely lead to even more new transit solutions that will address the identified need being ready for deployment in the coming years.

Guide to this Document

As the goal of the RFI process was to learn about the state of the industry and the applicability of emerging technologies to two specific corridors in Santa Clara County, the summary assessment is not intended to select one or multiple technologies for deployment. This document rather summarizes the information received and identifies commonalities, trends, and areas for further consideration. The document is organized around categories that describe the proposed solutions, pivoting off of the questions asked of respondents in the RFI. This summary does not rank or score the responses received. A few notable proposals are highlighted near the end of the document to identify submissions that most closely aligned with the RFI's objectives and to give a snapshot of technologies generally closer to implementation. The main takeaways of the summary assessment are included in the Evaluation Summary section at the end of this document.

A summary of the characteristics of the reviewed proposals is included as **Attachment A**.

Proposals Received

The City of San José received a total of 23 proposals. Two of the proposals were from universities as part of student projects and were not intended to be developed into a working system. One proposal (4Dialog) suggested using the annual Podcar City Conference or other student competition to source a technology. Another proposal was from a signaling company (CRSC) not proposing a transit solution. The remaining 19 proposals recommended a specific transit solution for the Airport Connector and/or Stevens Creek Line. These proposals contained a variety of mass transit technologies, some already in operation and others still in development. While there is some overlap between technological categories, they may be roughly sorted into the following groups, described below with industry-accepted definitions.

Personal Rapid Transit (PRT)

Also known as "podcars," PRT vehicles typically seat a maximum of between three and six people and travel on an exclusive, automated guideway. Stations or stops are located on sidings allowing point-to-point travel.

Group Rapid Transit (GRT)

GRT systems function similar to PRT, traveling without an operator in an exclusive right-of-way, but with higher passenger capacity (up to 20, the size of a small bus).

Monorail

Monorail vehicles travel on an elevated guideway consisting of a single rail or beam. They typically operate without operators and most are powered by electric motors fed by contact wires in the guidance beam, rather than an overhead catenary cable (such as with Light Rail Transit).

Hyperloop

A relatively new technology, hyperloop is characterized by vehicles that travel within an enclosed and vacuum-sealed guideway, allowing them to travel at high speeds due to reduction in air resistance. The technology is still being developed and no hyperloop system is yet open for passenger service.

Automated People Mover (APM)

Typically found at airports or tourist attractions, APMs are essentially driverless trains traveling on exclusive guideways, composed of several cars and capable of transporting several dozen people. They may be powered by electric motor or traction.

Evaluation Methodology

Each of the 19 proposals was given an initial high-level review and assigned to a subject matter expert based on the general type of technology (e.g. tunnel boring, APM, PRT, etc.) for a more thorough review. At that point each project was evaluated with respect to several categories and sub-categories. The evaluation categories included:

- Technological Readiness
  - Infrastructure Readiness
  - Vehicle Capacity
  - System Capacity and Throughput
  - Scalability
  - Maintenance and Storage
- Cost
  - Capital Costs
  - Operating Costs
- Financing and Delivery
  - Funding Sources
  - Delivery and Risk Management
  - Regulatory Awareness
  - Timeline to Implementation

The proposal reviewers assigned to this effort were subject matter experts employed by Kimley-Horn and McMillen Jacobs. The reviewers summarized the information included in the proposals and documented themes and comparative attributes. No independent evaluation, verification, or assessment of the technology, costs, operational parameters, design feasibility, or any other aspect of the proposal was completed. Reviewers were limited to the information contained within the proposals and did not independently research or validate elements of the proposals. The opinions and judgments summarized below are not intended to be a warranty on any particular proposal, nor should they be considered to select any individual proposal for consideration or elimination.

The sections below describe the evaluation categories in greater detail and provide examples from the proposals received to illustrate the reviewers' findings.

Technological Readiness

INFRASTRUCTURE READINESS LEVEL

The proposals received varied widely with respect to their readiness for implementation, ranging from those currently in operation elsewhere internationally to those that are purely conceptual at this stage. As part of the subject matter expert evaluation, a level of 1-5 was assigned to each technology, with 5 being the highest infrastructure readiness level. This section describes each of the levels of technological readiness, the number of proposals that were determined to fall into that category, and a representative proposal from that group. Note that the proposals described were selected as typical representations of each category but are not intended to imply preference or exclusivity within that category.

Description of Infrastructure Readiness Levels

- Level 5: Widespread technology with multiple implementations (2 proposals)
- Level 4: Proprietary technology with at least one implementation (1)
- Level 3: Full test track (6)
- Level 2: Scale model and ongoing testing (4)
- Level 0/1: Concept only or pre-concept (6)

Level 5	Level 4	Level 3	Level 2	Level 0/1
-Bombardier -BYD	-2getthere	-Chamara -Hyperloop -Miller Hudson/GA -moduTram -Primerail -The Boring Co.	-CyberTran -Plenary Glydways -Supraways -Virgin Hyperloop	-Citytram -Hotspur Design -JPods -SwiftAPM -The Gen. Tr. Fund -TriTrack Motors

Level 5 (2 proposals)

As one example within this category, Bombardier is a widely known manufacturer of both planes and trains. The proposal included information about its Monorail, APM, and LRT technologies, all of which are currently in operation in many cities around the world and consistent with technologies widely utilized in the industry.

Level 4 (1 proposal)

2getthere is the only company in this category. 2getthere manufactures automated, small-capacity GRT shuttles in a number of cities around the world. Their first-generation vehicle, which can carry eight seated passengers and four standees, has been operating as a parking lot shuttle at Schiphol

Airport, the main international airport in the Netherlands, since 1997. The proposal recommended its third-generation GRT, such as that operating at Rivium Business Park in Rotterdam, which would seat eight and permit 16 standees.

Level 3 (6 proposals)

The Boring Company (TBC) represent has constructed a 1.14-mile R&D test tunnel at its Hawthorne headquarters in Los Angeles County, and has been contracted to design, construct, and operate its Loop system for the Las Vegas Convention Center. The company claims to have drastically reduced the cost of tunneling, though the advantages over prior technology have not yet been thoroughly demonstrated in a project setting.

Level 2 (4 proposals)

Plenary Glydways Transit Solutions is an example within this category that proposed small automated PRT and GRT vehicles operating on an above-grade right-of-way. The technology is not currently in operation, but the company is currently in the process of implementing an indoor pilot and building an outdoor proof of concept. Glydways anticipates a full-scale system prototype by the end of 2020.

Level 0/1 (6 proposals)

Several of the proposals received (Citytram, Hotspur Design, JPods, SwiftAPM, The General Transportation Fund, and TriTrack Motors) either provided little detail about the current status of the technology or were in a very early conceptual stage of development.

VEHICLE CAPACITY

The RFI requested proposals for transit systems that would operate on a grade-separated guideway and would be able to be delivered and operated at a lower cost than traditional transit projects. The majority of the proposals presented technologies that would operate relatively small vehicles without human operators. This ranged from currently operational APMs with capacity for 20 or more passengers to small PRT vehicles in which fewer than five people could ride at a time. Below are examples of proposed vehicles grouped by vehicle size.

Description of Vehicle Capacities

- 10+ Person Capacity (10 proposals)
- 6-9 Person Capacity (3 proposals)
- 5 or Fewer Person Capacity (6 proposals)

10+ Person Capacity	6-9 Person Capacity	<6 Person Capacity
-2getthere -Bombardier -BYD -CyberTran -Hotspur Design -Hyperloop -Miller Hudson/GA -Primerail -SwiftAPM -Virgin Hyperloop	-Modutram -Supraways -The Boring Co.	-Chamara -Citytram -Jpods -Plenary Glydways -TriTrack Motors -The Gen. Tr. Fund

10+ Person Capacity (10 proposals)

For example, Hyperloop Transportation Technologies (HTT) proposed a version of its technology, called Urban Hyperloop (as distinct from Full-Speed Hyperloop). The vehicles would operate on wheels in a contained guideway, which could be upgraded to be vacuum-sealed to eliminate atmospheric friction. The vehicles, which HTS refers to as “capsules,” would fit inside a tube with a 13-foot diameter and would be able to carry 28-50 passengers with space for luggage. Passengers would have a similar amount of person space as if they were riding a bus. The vehicles’ top operating speed is 125 mph.

6-9 Person Capacity (3 proposals)

Modutram, one of the companies in this category, proposed a technology called AutoTrén, a system of driverless-mini-trains running on an elevated guideway. The GRT200 vehicles may accommodate up to eight seated passengers with several pieces of luggage or, if equipped with a luggage rack, six passengers and several large suitcases. Vehicles are powered by interchangeable battery packs, rather than an electrified guideway. They are able to reach a top speed of 45 mph, though the recommended cruising speed is 35 mph.

5 or Fewer Person Capacity (6 proposals)

One of the companies in this category, TriTrack Motors proposes dual-function, 3-wheeled vehicles that can operate in mixed traffic at speeds up to 40 mph, as well as autonomously on a separated guideway, on which they can would reach 180 mph. The vehicle has a weight limit of 920 lbs., allowing four adults and luggage. Batteries would be carried on the vehicles themselves and swapped between vehicle and charging infrastructure by “battery mules,” self-directed machines that would respond as needed to ensure all vehicles had sufficient charge.

SYSTEM THROUGHPUT

One of the benefits of transit is its ability to transport large numbers of people in the same direction efficiently within a constrained space. In traditional transit settings, this is due to the fact that many people travel within the same large transit vehicle. However, a similar total passenger throughput may be achieved by a system in which smaller vehicles arrive and depart more frequently, which has the advantage of decreasing total passenger waiting time. While several proposals assumed this model, these forms of very high-frequency PRT have not been fully realized in real-world transit settings to date. Many of the proposals received did not explicitly state a maximum passenger throughput; however, throughput could in some cases be inferred from the stated vehicle capacity and headways. It should be noted that subject matter experts found some of the throughput estimates to be unreasonably high, typically due to assumptions of very short vehicle headways and dwell time. Throughputs noted here are referenced directly or inferred from the proposals and do not reflect concurrence or independent assessment by the review team.

The proposals were grouped into categories of maximum passengers per hour per direction (pphpd). For context, the existing directional passenger throughput of existing Bay Area transit systems is also provided[1]:

- BART (through Transbay Tube): 46,000 pphpd
- VTA Light Rail (through downtown San José): 4,080 pphpd
- Coliseum-Oakland International Airport Line; 1,130 pphpd
- East Bay BRT: 960 pphpd

Stated Maximum Throughputs

- More than 20,000 pphpd (2 proposals)
- Between 10,000 and 20,000 pphpd (6 proposals)
- Between 5,000 and 10,000 pphpd (4 proposals)
- Between 2,500 and 5,000 pphpd (5 proposals)
- No throughput provided (2 proposals)

>20,000 pphpd	10,000 - 20,000 pphpd	5,000 - 10,000 pphpd	2,500 - 5,000 pphpd	Not provided
-Bombardier -Chamara	-BYD -Miller Hudson/GA -ModuTram -Primerail -TriTrack Motors -Virgin Hyperloop	-CyberTran -Hotspur Design -Plenary Glydways -Supraways	-2getthere -Citytram -Hyperloop -SwiftAPM -The Boring Co.	-Jpods -The Gen. Tr. Fund

More than 20,000 pphpd (2 proposals)

For example, Bombardier's proposal included several types of vehicles, all allowing high-capacity passenger throughput within large vehicles. The INNOVIA Monorail 300 system, an autonomous

[1] Throughput assumptions are as follows, assuming existing headways and current vehicle configurations. BART: 23 trains per hour, 10-car trains, 200 passengers per car. VTA Light Rail: 8 trains per hour, 3-car trains, 170 passengers per car. Oakland Airport Line: 10 trains per hour, 113 passengers per train. East Bay BRT: 8 buses per hour, 120 passengers per bus. Note that maximum throughput for these systems may be higher.

vehicle running on a separated guideway on rubber wheels, can move more than 40,000 passengers per hour per direction.

Between 10,000 and 20,000 pphpd (6 proposals)
An example of companies in this category is BYD (Build Your Dreams) widely known for manufacturing electric buses, proposed two technologies; an autonomous monorail called SkyRail; and the smaller APM, SkyShuttle. Both would operate on grade-separated elevated guideways and would be powered using on-board iron phosphate batteries. Cars have a capacity of 75-79 (SkyRail) and 50 passengers (SkyShuttle), between seated travelers and standees. The proposal suggests that the vehicles would run at two-minute headways during the peak hour and five-minute headways off-peak. Assuming 8-car configurations, this translates to a throughput of between 12,000 and 19,000 passengers per hour per direction.

Between 5,000 and 10,000 pphpd (4 proposals)
The company Supraways represents this group of companies. They proposes a system of suspended pods, called "Supras," which would run on an overhead guideway. The vehicles are small and battery-powered, seating between seven and nine passengers, and would provide direct point-to-point transportation for riders. Assuming headways of five seconds, the system's theoretical capacity would be between roughly 5,000 and 8,400 passengers per hour per direction.

Between 2,500 and 5,000 pphpd (5 proposals)
For example, SwiftAPM proposes running coaches suspended from an overhead guideway, powered by internal batteries charged at the boarding station. These vehicles are planned to have a passenger capacity of 20-25 people and their luggage. Assuming a typical dwell time of 10 seconds, single platform would allow 2,500 riders per direction per hour.

No throughput provided (2 proposals)
The proposals submitted for The General Transportation Fund and JPods included neither passenger throughput estimates nor headway and vehicle capacity assumptions that would allow throughput to be derived.

SCALABILITY

The RFI issued by the City of San José identified two deployments of the transit technology: 1) Diridon Station to San José Airport, and 2) Diridon Station to De Anza College via Stevens Creek Boulevard to the City and its partners are also interested in the ability to more broadly serve Silicon Valley with these technologies as part of future project phases. Therefore, the proposals were considered for their capability to expand deployment of the technology to additional to-be-determined corridors.

Scalability would be primarily influenced by the impact to the initial operating system as a result of expansion and whether a range of vendors could complete the expansion. Systems that require the initial vendor to execute all expansions as a result of proprietary technology associated with high-cost fixed infrastructure are generally considered less scalable than those where replacement or expansion of the vehicle fleet can be done by other vendors while continuing to use the initial system.

Ensuring that more than one vendor can complete an expansion is critical in reducing risk to the public agencies.

The proposals can be roughly divided into four groups, based on the difficulty of scaling up the technology to a wider deployment. The number of proposals that were assigned to each group, as well as a representative example from each group are shown below.

Scalability Categories

- Does Not Require Additional Infrastructure for Expansion and Operational Configuration Easily Replicated by Others (Assumed to be Highly Scalable) (2 proposals)
- Expansion Requires Additional Infrastructure but with Limited Impact to Initial Operational System and Operational Configuration Easily Replicated by Others (Assumed to be Reasonably Scalable) (6 proposals)
- Requires Additional Infrastructure and Modification to Initial Operational System and/or Proprietary Operational Technology (Assumed to be Less Scalable) (10 proposals)
- Not Described (1 proposal)

Does Not Require Additional Infrastructure for Expansion (Assumed to be Highly Scalable) (2 proposals)

Technologies that operate on existing streets are likely to be highly scalable. Existing example of this include a public bus system or TNCs such as Uber and Lyft. In either case, if the system sees particularly high demand, more vehicles can be brought online with little notice, allowing the system to carry more passengers. Expansion to new service areas can be completed with a new vehicle fleet, allowing for involvement from new vendors.

The 2getthere proposal identified a system that could operate at-grade or elevated. All of the propulsion and guidance is located within the vehicle. This flexibility would make it easier for expansion as the vehicles could operate in mixed-flow in additional corridors or take advantage of additional dedicated guideway. The service would not be limited to a certain network size or configuration.

Expansion Requires Additional Infrastructure but with Limited Impact to Initial Operational System and Operational Configuration Easily Replicated by Others (Assumed to be Reasonably Scalable) (6 proposals)

These systems require a new guideway (aerial or tunnel) for system expansion, but because the propulsion is on board the vehicle and the guideway is passive (it only provides physical support/guidance and does not transmit power or information to the vehicle), it both minimizes impact to the initial system and allows for greater flexibility selecting vendors for the expansion. An increase in frequency may be achievable but would be limited by the capabilities of the constructed guideway.

TBC proposed using twin-bore tunnels to create a dedicated transitway below grade. A number of access points could be created at various locations along the alignment, with different station configurations and sizes. This technology could be expanded to additional corridors through additional tunnel construction, dependent on the suitability of the soil and any below-grade obstructions.

Requires Additional Infrastructure and Modification to Initial Operational System and/or Proprietary Operational Technology (Assumed to be Less Scalable) (10 proposals)

These systems both require new guideway for expansion (all proposals in this category were aerial) and either the expansion would require re-configuration of the initial system or, because of a unique configuration of the guideway itself, would limit any expansion to be completed only by the initial vendor. These technologies in some cases had a powered track that would require an overall integrated technology system or had proprietary technology for the vehicle-guideway interaction.

Virgin Hyperloop would operate vehicles in a vacuum tube with offline stations feeding into a mainline tube. The ability to add vehicles or expand the system would require modifications to the tube itself as it is a single inter-connected system.

Not Described (1 proposal)

The proposal submitted by JPods did not contain sufficient detail to determine the level of scalability.

MAINTENANCE AND STORAGE

Transit systems typically require a centralized storage and maintenance facility to store vehicles when not in use and to perform regular repair and upkeep. Siting such a facility can often pose a challenge due to the space-intensive nature of vehicle storage and a maintenance floor. Additionally, for any transit vehicle that can only travel on its dedicated guideway (unlike a bus, which can run on public streets), the facility must be located at some point along the alignment, further limiting potential sites. Storage requirements can potentially be higher for systems relying on a large number of vehicles, particularly those offering point-to-point service on-demand with high frequencies. Some proposals provided more detail than others about the storage needs of their vehicles, though none went so far as to propose a specific site or size for a facility.

Maintenance and Storage Categories

- Off-line Storage and/or Maintenance Facility (15 proposals)
- Not Described (4 proposal)

Off-line Storage and Maintenance Facility (15 proposals)

Every proposal that described storage and maintenance accommodations noted the need for a maintenance facility and some form of off-line storage. The strategy for meeting storage needs varied significantly between proposals. The range of proposals included smaller distributed storage areas near stations, hubs of storage facilities near the alignment (such as in existing parking structures), and larger off-line storage/maintenance facilities. Because each proposal that covered the topic had a different approach to storage and maintenance, no further categorization was possible.

Unlike many of the other proposed technologies, ModuTram's GRT200 vehicles are not proposed for an off-site storage facility (the proposal suggests that the vehicles will be kept on parking tracks located within or close to stations). The network's control system adjusts the number of vehicles in operation to match current travel demand and routes any unneeded vehicles to parking tracks located within or near stations. An off-line maintenance facility is required, however, which would need to be connected to the guideway network, ideally at a central location. The design of the facility would be modular and could be expanded as needed with each module accommodating up to 40 vehicles. The facility would contain all necessary tools and machines required for full vehicle maintenance

Not Described (4 proposal)
Several proposals (Hotspur Design, JPods, General Atomics, and The General Transportation Fund) did not provide detail on how and where vehicle would be stored and maintained.

Costs

When considering the cost of a transit project, both capital costs (encompassing land acquisition, construction, and vehicle development) and operating costs must be considered.

CAPITAL COSTS

Capital costs varied widely across submissions, ranging from estimates of $0.5M per mile of guideway to $400M per mile. However, those proposals that both were sufficiently-documented and represented innovative and lower-cost technologies fell into a narrower range, typically between $20M to $50M per mile of grade-separated guideway. This is far lower than legacy technology capital projects now in planning or construction, such as San Francisco Central Subway Project (estimated at $940M per mile), the BART Silicon Valley Phase II (roughly estimated at $930M per mile) or the VTA Eastridge to BART Regional Connector-Capitol Expressway Light Rail Project (estimated at $190M per mile). The subject matter experts found some of the estimates received to be overly optimistic and should be considered with great caution.

Claimed capital cost savings over existing transit solutions were attributed to several factors, including:

- Passive track (non-powered) with self-propelled and intelligent battery-powered vehicles
- Very small vehicle sizes and lighter vehicles, requiring less structural infrastructure and ROW space
- For aerial guideway proposals, frequent column spacing (i.e. short spans) which would lower structural infrastructure requirements
- For tunneling proposals, a smaller diameter tunnel than is typical

It was not possible to categorize the proposals into specific cost categories. The proposals varied widely in how they accounted for capital costs. Some proposals itemized costs by guideway, stations, and vehicles, while others provided a comprehensive, all-inclusive estimate or didn't provide any estimate at all. Some included right-of-way acquisition, while others did not. Seven (7) proposals did not provide any capital cost estimate. Two examples with more thorough cost estimates are noted below.

Chamara Consulting

Chamara Consulting proposed an electromagnetic propulsion system on an elevated track with three to five person vehicles operating every three seconds. The proposal identified costs as $23M per mile for the guideway, $1M to $2M per station, and $2.4M for the entire vehicle fleet. The proposal pointed to smaller vehicles and more compact stations resulting in cost savings relative to existing transit options.

Plenary Glydways

Plenary Glydways proposed small automated PRT and GRT vehicles operating on an above-grade right-of-way. Propulsion would be on the vehicle with multi-level stations. Costs were estimated at $51M to $56M per mile for the guideway, $0.85M per station (smaller station with 8 bays), and $25k to $40k per vehicle. Cost savings relative to existing modes of transit were associated with a smaller vehicle allowing for a smaller guideway structure and autonomous, battery-powered vehicles.

OPERATING COSTS

All of the proposals received describe systems in which vehicles travel between origin and destination autonomously, i.e. without a human operator. The move toward autonomous transit could permit the deployment of smaller vehicles running at higher frequencies than is currently financially efficient. Only six of the proposals provided estimates of operating costs, which ranged from $1.6M per year to $21M year[2]. For context, the existing BART to OAK Automated Guideway Transit (AGT) connector has an annual operating cost of $6.5M[3]. Due to the insufficient amount of information provided, no categorization of the proposals was attempted. Below are examples of two proposals, describing their plan to minimize operating costs.

Swift APM

Swift Tram Inc. + Black & Veatch Inc. proposed an APM suspended from a cylindrical guideway and powered by on-board batteries, which would charge at boarding stations from roof-mounted solar PV panels. Annual operations and maintenance costs are estimated at $2.5M, with materials and supplies costing an additional $100K. Cost savings over traditional transit system were stated as attributable to several factors. The Swift system elevated guideway is constructed out of fabricated steel tubes with tracks welded to the interior of the tubes. The guideway is supported by 26 foot-tall towers poured in concrete. Because the vehicles themselves are self-powered, the guideway itself is purely mechanical with no wiring or utilities. The proposal states that maintenance costs would be very low and that the guideway would require inspection and cleaning once a year. The vehicles would be cleaned daily at the maintenance facility.

2getthere

Like Swift, 2getthere vehicles are self-powered, meaning the guideway itself would be less expensive to maintain than those for HRT or LRT systems, which require either third rail or catenary electrical systems. Unlike some of the other companies that submitted proposals, 2getthere already has

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[2] These costs are not directly comparable, given that the different proposals imagine widely varying levels of service, and not enough information was provided for a meaningful comparison based on cost per service hour.
[3] BART Budget Pamphlet FY2019

working vehicles in operation, which should lead to greater in confidence of the company's estimates of operating and maintenance costs in any future submittals (though they did not estimate operating cost in this document).

Financing and Delivery

FUNDING SOURCES

The RFI asked proposers for innovative funding solutions. Traditional transit projects rely on heavy public-sector capital investment for design and construction with ongoing public investment for operations beyond what is recovered at the fares. Emerging trends are for cities to engage in public-private partnerships (P3) to finance transit through a mix of public and private money. Proposals received in this RFI included examples of both legacy and innovative funding models.

Public Finance	Private or Self-Finance	Public-Private Partnership	Not Indicated
-2getthere -Chamara -Citytram -CyberTran -Supraways -The Boring Co.	-TriTrack Motors -Jpods -Plenary Glydways -The Gen. Tr. Fund	-Bombardier -BYD -Hotspur Design -Miller Hudson/GA -ModuTram -Primerail -SwiftAPM -Virgin Hyperloop	-Hyperloop

Public Finance (6 proposals)

Six of the proposals suggested a system in which construction would be publicly financed using current typical public agency-led financing strategies.

Private or Self-Finance (4 proposals)

Four of the proposals stated that they would privately finance the construction and operation of the transit system. TriTrack Motors specifically stated that it would charge mileage tolls to fund the proposed system or would sell a monthly subscription allowing unlimited use (full financial details about whether the proposed $199/month would be sufficient to fund construction and operation was not included).

Public-Private Partnership (8 proposals)

The remainder of the proposals that included a discussion of funding sources recommended a P3 arrangement between a public entity and the private transit provider in which funding could be leveraged from both sides to provide necessary up-front costs.

No Funding Sources Indicated (1 proposals)

DELIVERY/RISK MANAGEMENT

The RFI requested proposals that identified innovative solutions not only for transit technology but also means of project delivery. However, generally, the proposals received did not propose new delivery strategies that would greatly accelerate schedule or reduce delivery costs. Many proposed a Design-Build-Operate-Maintain (DBOM) structure, in which the same entity would be responsible for all facets of the project from initiation and design through a pre-determined duration of system operations. The financing strategies included in most proposals represented a public-private partnership with significant risk borne by the public. However, a few included alternative strategies. The two with notable innovative delivery strategies discussed in their submission are noted below.

JPods

The proposal submitted by JPods imagines a network of self-driving vehicles carried overhead on a grade-separated guideway, traveling non-stop directly from origin to destination. The vehicles would be solar-powered by PV panels mounted on the top side of the elevated guideway. The ambitious proposal suggests that, rather than a simple linear track from Diridon Station to San José Airport and along the Stevens Creek Boulevard corridor, an entire network of JPods track could be built across Santa Clara County, funded by $6B in private investment without the need for additional public funds. Reviewers found these claims to be not fully substantiated through discussion of operational details or functional viability.

The Boring Company

TBC states that it will deliver projects on a firm-fixed price basis, meaning that any cost overruns are borne by the company rather than the public agencies. After that point, TBC would operate and maintain the system on an annual firm-fixed price. TBC suggest that it is amenable to other financing arrangements, but that that would depend on the nature of the eventual RFP.

REGULATORY AWARENESS

None of the entities submitting proposals operate a public system currently in California, which is notable given the complexity of the regulatory structure in the State. Several companies are currently developing test systems in the United States and/or have existing systems internationally, and others have yet to bring their proposed technology to market. Most of the proposals did not reference the many layers of environmental and regulatory review required for construction in California, though some were more thorough in their consideration of potential impacts than others. This is noteworthy because the robust environmental and regulatory review required in California is likely to dictate longer schedules and higher costs than the proposers may be considering. It also may preclude certain technologies from being implemented due to non-compliance. Three (3) of the proposals did not mention regulatory hurdles at all, with a number of other proposals from international firms with little to no United States experience. Below are examples of proposals that demonstrated a greater and lesser understanding of the regulatory environment present in the project area.

Plenary Glydways

The proposal’s section on key requirements for implementation demonstrated an understanding of the regulatory process, including the need to conduct a survey of soil conditions, underground and overhead utilities, as well as study the effect on nearby circulation and green space. The proposal also cataloged the potential negative impacts during construction, detailing the degree of impact on noise and vibration, dust and debris, parking constraint, road closures, pedestrian obstructions, and security. Other non-physical impacts that might occur were also listed, such as the interruption of sightlines and displacement of local TNC workers.

Primerail

The proposal submitted by Primerail described an APM called TieTran ROVE (standing for The Intelligent Electric TRANsit RObotic VEhicle). The system would be characterized by autonomous vehicles running on rubber tires in an enclosed elevated guideway. The shuttles would have a capacity of approximately 30 people with a guaranteed headway of 10 to 30 seconds between vehicles, providing a seven to nine-minute trip between Diridon Station and San José Airport. The company has a test track in Bangalore, India but has not yet developed a working system. Like many of the other proposals received, the proposal did not demonstrate a thorough understanding of California environmental regulations and glossed over some points that would likely present substantial barriers, such a community opposition and environmental impacts. Little detail was given about timelines for different steps of regulatory approval.

TIMELINE

Few of the entities that submitted proposals are currently able to deploy their proffered solution in the near term. Most proposals indicated that technology would be ready for use (ready for start of construction) within one to five years, but some of these estimates were deemed optimistic by reviewers. The timeline for implementation for many technologies generally fell in the range of four to eight years, though the subject matter experts noted that these estimates might be treated with some skepticism. Given the disparity in awareness and consideration of the hurdles for implementation, categorization of the timelines was not attempted. Seven (7) of the proposals didn't provide any estimate on timeframe. Below are representative examples of project timelines found in the proposals.

Virgin Hyperloop One

One of two proposals involving hyperloop technology, Virgin Hyperloop One (VHO) proposes an elevated or tunneled low-pressure tube which pods would travel through with little air resistance. The current design imagines pods carrying between 10-30 passengers autonomously. Turnouts would allow pods to divert from the main trunk, allowing passengers to travel point-to-point from the station of origin to the station of destination without stopping at intermediate stations.

VHO completed a full-scale prototype in Nevada in 2017 and has been refining the system since then. Because the technology has yet to be deployed in a real-world setting, VHO is working with several states to establish a hyperloop certification center. Though VHO states that it sees support from the federal government, the proposal estimates that the Virgin Hyperloop System would be ready for deployment in five to seven years, assuming that regulatory and safety milestones are achieved.

BYD

BYD provided a relatively detailed breakdown of their proposed timeline, estimating 44 months from NTP until operation, encompassing final design, train manufacture, guideway and station construction, systems installation, and testing. This schedule assumes no delays due to litigation, funding shortages, or unforeseen technical challenges. .

CyberTran

Headquartered in the Bay Area city of Richmond, CyberTran proposes Ultralight Rail Transit (ULRT), which would serve as a point-to-point transportation system with stations off-line or installed in buildings such as airport terminals, allowing users to travel to their destination without having to stop at intermediate stations.

CyberTran has built three physical test tracks and has conducted computer simulations of proposed operations. After environmental clearance and right-of-way acquisitions (a process which commonly takes several years), CyberTran estimates that the system can be deployed within five years using a DBOM framework. This would include 1.5 years for 65% design; 2 years for final design, utility relocation, and guideway construction; and 1 year for testing and construction of the maintenance facility.

Areas of Uncertainty

The solutions proposed are generally not currently in operation in the United States. All of the proposals carry significant uncertainty in their ability to deliver in the time and budget proposed. A general theme found in the proposals was a limited understanding of the regulatory environment . This resulted in timeframes and costs that the proposal reviewers frequently found to be unrealistic. Additionally, there was little consideration given to system failure or emergency management protocols .

Notable Proposals

The 19 proposals received by the City and reviewed by the subject matter experts comprised a wide range of vehicle type, technological readiness, and ability to meet the needs of the region. Several of these proposals appeared to represent a promising combination of technology, delivery innovation, and readiness and are noted below.

The proposals noted in this section are not endorsed in any way by the reviewers nor are they identified at being more cost effective or implementable than other proposals received, or other technologies in the marketplace that were not proposed as part of the RFI. Proposal content was not independently verified for accuracy. This section highlights several proposals that, in the opinions of the reviewers, most closely aligned with the City's objectives; however, these are not necessarily the only proposals that would meet the City's stated objectives.

The five notable proposals are as follows (listed alphabetically):

- 2getthere
- BYD
- Modutram

- Plenary Glydways
- The Boring Company

2getthere

2getthere currently operates four permanent deployments internationally, with several more planned in the coming years. Vehicles operate using existing technology, operate at relatively low speeds, and without drivers. This proposal was the only one submitted by a company that has an existing GRT/PRT deployment and experience operating and maintaining such a system. As such, the cost and timeline estimates were considered by proposal reviewers as being reasonable.

BYD

Known in the US primarily for its work with battery-electric buses, BYD is currently operating three APM systems internationally, with several more in development and testing. Driverless vehicles would run on an elevated guideway with columns at roughly 100-foot intervals. Because the system would operate with on-board batteries, track electrification would not be necessary, decreasing cost and complexity of development. The proposal was deemed aggressive but possible depending on environmental clearance and litigation.

Modutram

ModuTram proposes a system called AutoTrén, a system it calls an Automated Transit Network (ATN) providing high-capacity transit for up to six seated passengers riding in driverless battery-powered electric mini-trains on elevated guideways. Passengers would indicate their destination upon boarding and would be taken directly to their destination station without the need for intermediate stops. The company currently operates a full-scale test facility in Mexico. Due to the fact that the system does not have any real-world deployments yet, there is some uncertainty about the system cost as well as the assertion that the company could privately finance construction.

Plenary Glydways

Plenary Glydways Transit Solutions (PGTS) would develop a system consisting of a fleet of autonomous electric vehicles operating on a dedicated guideway. The vehicles would be small but would operate at high frequency, with the proposal promising up to 10,000 persons/hour in each direction at a low cost. PGTS proposes a DBOM model in which the company would take on responsibility for all aspects of the project including financing for a 30 to 40-year term. Proposal reviewers found the submission to be reasonably comprehensive and well-articulated. However, the company does not yet have a physical test facility, and feasibility of vehicle storage was not fully addressed. Therefore, the technology has great uncertainty regarding readiness and cost.

The Boring Company

TBC has stated that its tunneling technology operates at a fraction of the cost of existing models. The proposal for San José would construct a small dual-bore tunnel with driverless electric vehicles operating on rubber tires. Stations would be located on siding tracks, allowing riders to experience point-to-point service as the vehicle would skip any intermediate stations. The vehicles themselves would be Tesla Model X or a modified version of existing production vehicles. Stations would be below-grade and accessed via vehicle elevator. The company currently operates a test track at its

Hawthorne headquarters in Los Angeles County and is currently developing a working facility at the Las Vegas Convention Center. The proposal lacked details for how the tunneling cost savings were realized. Several other aspects of the proposal were deemed questionable, such as including tunnels with radii not currently achievable by TBMs and vehicle operating speeds that are likely infeasible in a transit environment. Additionally, there are concerns regarding the ADA accessibility of the proposed vehicles. However, the proposal suggests a firm-fixed price proposal that would potentially limit agency risk and add potentially significant cost savings.

Evaluation Summary

Below are some general themes from the 19 proposals reviewed:

- There was a significant emphasis on vehicle technology itself, detailing the specifications and dimensions of the vehicles.
- While many of the proposals had not yet demonstrated the capabilities of their technology through real-world implementation, the proposals included a range of transit service technologies with high frequency and high throughput.
- The proposals claimed substantial cost savings relative to legacy transit systems through a variety of means. These claims deserve further investigation to confirm the magnitude of savings and ensure compliance with local standards and regulations.
- Comparatively little innovation was demonstrated with respect to project delivery, which was one of the goals of the RFI. Many of the proposed projects suggested a DBOM framework with public financing.
- Many of the proposals relied entirely on untested technologies that do not exist beyond scale model form. With the technology being thus far untested, many of the cost estimates should be considered with some level of caution. It is likely that when considering California's rigorous regulatory environment, actual costs will be higher.
- Almost none of the proposals included a thorough discussion of capital risk management, namely which entity would be responsible in the event of cost overruns, a significant concern given the untested nature of many of the proposed technologies.
- Few of the proposals gave a great deal of consideration to emergency preparedness or made more than passing reference to ADA.

Attachment A: Summary Assessment Table

Automated Transit Network

Feasibility Study

for Clemson, Greenville and Mauldin

FINAL REPORT

August, 2018

PRT Consulting, Inc.

in association with:

Dan Boyle and Associates

Engineering Services Group

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

Automated transit network (ATN) systems use small driverless vehicles on dedicated guideways to transport passengers quickly and conveniently to their destinations. Small vehicles require light infrastructure which is relatively unobtrusive and inexpensive. Numerous small stations are offline (on sidings), allowing non-stop travel and facilitating short walking distances. Public workshops and surveys found that an ATN (GreenPod) system would meet the transportation needs of most travelers better than most other modes.

Mode Preference	
Mode	**Score**
GreenPod	457
Light Rail	410
Car	392
Bus Rapid Transit	356
Gondola	342
Bus	308
AutonomousShuttle	281
Streetcar	278

Figure 1-1. Mode Preference Scores from Public Workshops

ATN systems proven in public service have capacities ranging from 2,000 to 7,000 passengers per hour per direction (pphpd) and maximum speeds ranging from 25 to 43 miles per hour. The maximum speed assumed in this study is 35 mph while the maximum capacity needed is within the capabilities of existing systems and can readily be increased based on pending changes to the standards.

This feasibility study was initiated for the Greenville Urbanized Area in response to recent studies in both Clemson[1] and Greenville[2] that suggested significant potential for ATN ridership. It utilized results from a public survey along with a Logit model to determine ridership. The model was tested in Clemson by using it to determine the expected ridership of the Red Route CATbus system. The projection came within one percent of the actual ridership.

An Clemson ATN solution comprising 47 stations and 24.5 miles of one-way track was developed as an alternative to the CATbus Red Route. It was found the ATN solution would attract 8,423 daily riders which is 130% more than the 3,662 than currently use the CATbus Red Route. The capital cost of the ATN solution was estimated at $253 M (about $10.3 M per mile) and the annual O&M costs at $2.7 M. The annual revenue, based on an average fare of $3.50 per trip, is $7.9 M. Thus, the fare-box recovery ratio is 2.92, far higher than for conventional transit but not sufficient to cover capital cost amortization. The benefits of the ATN solution include:

- A 23% decrease in SC-93 traffic
- Reduced need for road widening and maintenance, congestion mitigation and parking facilities
- Improved mobility/accessibility

[1] http://www.catbus.com/images/stories/clemson-reimaging-study-final-report-may-2017_protected.pdf

[2] http://gpats.org/wp-content/uploads/2018/08/GCEDC-Personal-Rapid-Transit-Evaluation-Addendum-to-2010-Multimodal-Transit-Corridor-Alternatives-Feasibility-Study.pdf

- Real estate value and economic uplift with property tax revenue increases
- Increased safety, resiliency and sustainability

The ATN solution was found to have substantially lower costs per trip than typical light rail projects indicating that it should compete well for Federal Transit Administration funding. If the community wishes to move ahead with an ATN solution it should undertake a detailed study which would be a necessary precursor to raising the funds needed – particularly federal funding.

Other solutions were examined in Clemson including ATN and A-Taxis/Shuttles on the University of Clemson Campus and an ATN or gondola solution linking Highpointe and The Pier to the Campus.

A Greenville city-wide ATN solution was developed that comprised 75 miles of one-way guideway and 141 stations. Using the model that was verified in Clemson, it was found the ATN solution would attract 99,885 daily riders. The capital cost of the ATN solution was estimated at $1,281 M (about $17.1 M per mile) and the annual O&M costs at $48.8 M. The annual revenue, based on an average fare of $3.50 per trip, is $118.5 M. Thus, the fare-box recovery ratio is 2.43, far higher than for conventional transit and possibly sufficient to cover capital cost amortization. The benefits of the ATN solution include a reduction in 72,340 daily automobile trips providing a significant reduction in congestion. Other benefits are similar to those mentioned earlier for Clemson. The potential benefits of the Greenville ATN system are very significant and appear to far outweigh the relatively small amount of funding and risk that could be involved in investigating them further.

The Greenville ATN system could easily be extended into Mauldin. Because Mauldin has about the same population density and because of the network effect, the combined systems will likely be more viable than a standalone Greenville system

All ATN solutions investigated were found to have far higher feasibility than typical light rail projects. The more widespread the solution, the more feasible it was found to be. However,

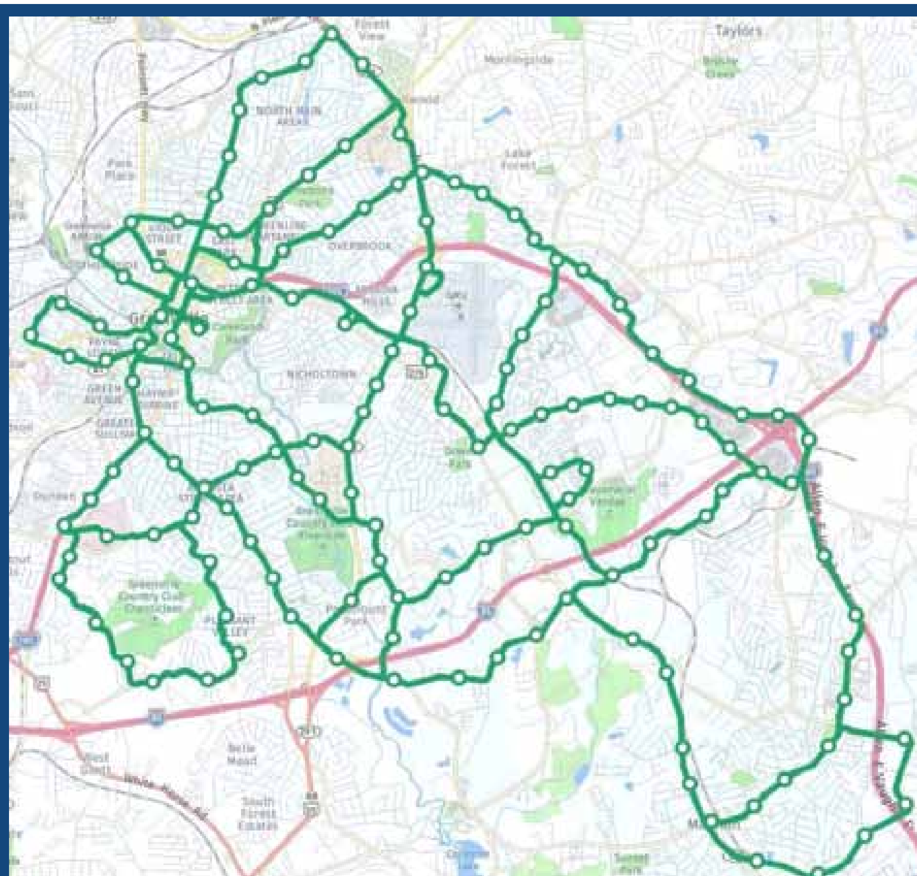

Figure 1-2. Combined Greenville-Mauldin ATN Layout

PRT consulting

spreading out into less dense areas will likely reduce feasibility as will concentrating ATN within and along corridors.

If Clemson, Greenville and/or Mauldin wish to implement ATN solutions, they will need to decide what questions remain to be satisfactorily answered before they are comfortable committing to ATN. Having done that, they can decide how best to answer those questions.

The most pressing initial question seems to be where to build an initial system not as extensive as the ones studied in detail here but sufficient to demonstrate the viability and benefits of ATN. The most practical solution seems to be an ATN connection from the Pier and Highpointe, across Lake Hartwell to the Clemson University Campus. The existing causeway is incapable of handling the bus traffic needed to support expanded student housing and the ATN guideway would more than double its capacity at a cost that is likely to be significantly less than the cost of widening both the causeway and bridge.

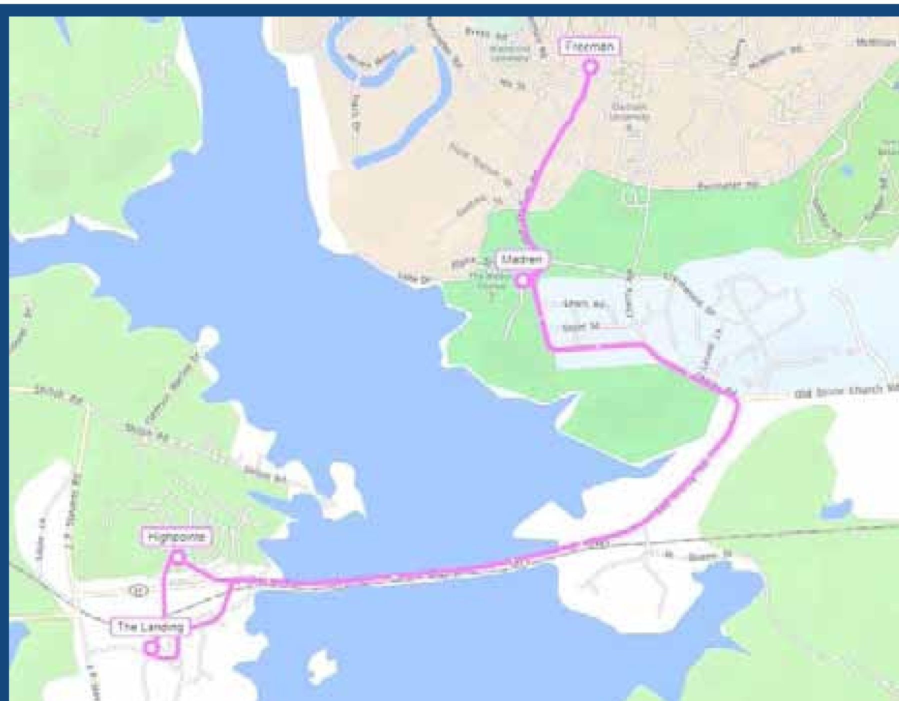

Figure 1-3. Possible Initial ATN Deployment Connecting Highpointe and the Pier to Clemson University Campus

The ATN connection will provide unmatched connectivity to Campus from new student housing. There is little doubt that most students will use the system for at least one round trip a day. At the same time, the ability of the system to handle high demand (up to about 15,000 pphpd in the future) substantially increases the viability of additional housing being built across the lake from the Campus. This could both increase the ability of the Campus to grow and encourage the developer to help pay for the system. In addition, this added growth should not result in pressure to add more parking on Campus.

ATN potentially delivers a real opportunity to increase the overall quality of life in each community involved. Relieving congestion and providing mobility to almost everyone will have a significant impact on personal wellbeing and the overall economy. Installing high-quality transit throughout the community could be likened to providing electricity to each home. We might soon wonder how we managed without it.

2. INTRODUCTION

The study "Transportation Options for Greenville"[3] by PRT Consulting found that a citywide ATN deployment could "improve mobility and safety while reducing congestion and bringing widespread economic benefits". While this was a positive result, insufficient budget was available for the study to investigate some key issues (such as in-depth ridership analyses, fare strategies/subsidies, right-of-way and permitting requirements) affecting the ability to move forward. The two primary issues addressed by this study are the financial feasibility of an ATN deployment and public acceptance of the technology. The two issues are interlinked in that public acceptance in the form of using the system for daily transportation is essential to financial feasibility

A significant aspect of the financial feasibility of an ATN system is the ridership that can be expected and the fare box revenue that ridership will generate. This is recognized in the Request for Proposals (RFP) for this project in that it states: "Use the Horizon 2040 report and TDM, plus a mode split component…". Unfortunately, developing a mode split application for the GPATS travel demand model (TDM) would require more than the entire resources for this project. The project team developed (and previously applied) a method to estimate the impact on transit mode share from improvements in wait and travel times with a new service. This methodology gives the most reliable results when used in conjunction with data from a situation where the transit mode split is known and substantial. In the GPATS area this favors the Clemson CATbus service area.

In this study, suitable ATN station locations and guideway layouts in prime locations within the Clemson CATbus Red Route service area were determined. These locations are accurate enough for analysis purposes but are by no means intended to be final. Operating characteristics of commercially-available ATN systems were then used to determine changes in walking, waiting and travel times. These results allowed use of the model to adjust the present CATbus mode split to reflect the anticipated ATN mode split and thus obtain the projected ATN ridership. A public survey was used to help calibrate the model for determining mode split relative to automobile trips. This calibration was verified by using the model to determine the bus mode split, which was found to be within one percent of the actual result.

Knowing the projected ridership enabled determination of ATN capital and operating costs, comparison with current equivalent bus system costs and thus estimation of the financial feasibility of an ATN deployment in Clemson. The projected ridership also facilitated estimating the impacts of the ATN deployment on overall transit ridership and congestion relief. It should be noted that costs shown are approximate estimates only and are not based on detailed analysis or design.

Having calibrated the model against actual bus use in Clemson, it was then applied to the car/ATN mode split in Greenville and used to determine the projected ridership on an ATN layout. Once again, it must be emphasized that the Greenville guideway and station layouts are for analysis only and are not intended to be final.

Other aspects of the study include investigating expansions of the ATN systems in Clemson and Mauldin. In addition, it includes an investigation of a Gondola solution to cross Lake Hartwell in Clemson.

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[3] http://www.advancedtransit.org/wp-content/uploads/2017/03/FutureTransportationOptionsGreenvilleSC-WhitePaper-Muller-Mar2017.pdf

3. AUTOMATED TRANSIT NETWORKS (ATN)

3.1 DEFINTION AND DESCRIPTION

ATN DEFINITION

- **Small driverless vehicles**
- **Exclusive guideways**
- **Offline stations**
- **On-board switching**

ATN CHARACTERISTICS

- **Short wait times**
- **Mostly nonstop**
- **Seated travel**
- **High reliability**
- **Very safe**

Automated transit networks (ATN) is an umbrella term for two concepts that are now merging into one. These are personal rapid transit (PRT) and group rapid transit (GRT). PRT was conceived to use small (2 – 6 seated passengers) driverless vehicles containing individuals or parties travelling together nonstop from origin to destination and not sharing rides with strangers. GRT uses large driverless vehicles (up to 20 or even30 seated and/or standing passengers) which often wait before departing to encourage ride sharing and stop at intermediate stations if necessary. Modern PRT systems generally have 4 to 6 seats, encourage ride sharing and may make an intermediate stop or two. Other terms for these systems include Podcars (commonly used in Sweden) and Pod Taxis (commonly used in India). This study refers to these systems as ATN as well as GreenPods.

The June 2014 report Personal Rapid Transit[2] includes a detailed comparison of PRT with cars and conventional transit that is summarized by Table 3-1 on the following page.

ATN systems proven in public service have capacities ranging from 2,000 to 7,000 passengers per hour per direction (pphpd) and maximum speeds ranging from 25 to 43 miles per hour. Higher capacities and speeds up to 20,000 pphpd and 60 mph are under development now that the American Society of Civil Engineers has agreed to adapt their Automated People Mover Standards to better apply to ATN systems. The maximum speed assumed in this study is 35 mph while the maximum capacity needed for Clemson is 1,000 pphpd and for Greenville is 7,000 pphpd.

3.2 SOLUTIONS NOT YET PROVEN IN PUBLIC SERVICE

Numerous ATN systems are in various stages of development ranging from being mere concepts to having engineering design completed and prototype systems in various stages of development. Some of the better-known names include Jpods, Metrino, PRT International, Skytran, Swift ATN and TransitX. Taxi 2000 recently closed its doors after decades of being unable to fund a full-scale test track demonstrating full functionality, the hurdle that is holding many of the previously-mentioned systems from emerging onto the market.

Some of these emerging suppliers make aggressive claims regarding the costs and capabilities of their systems. These claims have typically not been proven in practice and have therefore been ignored in this study. Should high speeds and capacities become viable at very low costs, this will further enhance the feasibility of the solutions discussed here.

Table 3-1. Comparison between Transit, Car and PRT (Source: PRT Consulting)

Attribute	Transit		Car		PRT	
Technology Level	Mature	✔	Mature	✔	Emerging	●
Total Trip Time	Poor	✖	Acceptable	●	Acceptable	●
Operating Cost/Passenger	Poor	✖	Poor	✖	Acceptable	●
Infrastructure Capital Cost/Passenger	Poor	✖	Poor	✖	Acceptable	●
Accident Potential and Cost Savings	Acceptable	●	No	✖	Yes	✔
On-Demand 24/7	No	✖	Yes	✔	Feasible	✔
Transfers	Yes	✖	No	✔	No	✔
Seated Travel	Yes, with limits	●	Yes	✔	Yes	✔
Private	No	✖	Yes	✔	Yes	✔
Non-Stop Travel	No	✖	No	✖	Yes	✔
Vehicle Waits for passenger	No	✖	Yes	✔	Less than 1 min	✔
ADA Compliant	Acceptable	●	No	✖	Yes	✔
Safe and Secure	Acceptable	●	No	✖	Yes	✔
User Friendly	Acceptable	●	Acceptable	●	Yes	✔
Snow & Ice	Varies	●	Poor	✖	Mostly	●
Minimal Walking	Not Often	✖	Yes	✔	Mostly	●
Environmentally Friendly	Somewhat	●	No	✖	Yes	✔
Energy Efficient	Somewhat	●	Somewhat	●	Yes	✔
Visually Appealing	Acceptable	●	Acceptable	●	Acceptable	●
Operates inside buildings	No	✖	No	✖	Possible	●

Legend: Poor ✖ Acceptable ● Good ✔

3.3 SOLUTIONS PROVEN IN PUBLIC SERVICE

3.3.1 The Ultra PRT System


Figure 3-1. Ultra PRT Vehicle on Elevated Guideway

The Ultra system is rubber-tired, battery-powered, and runs on an open guideway. The front wheels are steerable, and the vehicle keeps itself on the guideway without any physical lateral guidance (using lasers), simplifying switching, which is accomplished by steering. This system has been in operation at London's Heathrow International Airport since April 2011. The commitment to using off-the-shelf technology, wherever possible, coupled with a rigorous testing and development program, has allowed the Ultra system to be the first modern PRT system to win a commercial contract. Heathrow Airport has expressed its satisfaction with the system by including significant expansion in its budget. However, it is understood that construction of a new runway may obliterate the existing system and alter the plans for expansion.

The Ultra vehicle was designed for four adults, plus luggage. However, Heathrow has opted to replace the bucket seats with bench seats, allowing the vehicle to carry a family of six. Commuter versions of this vehicle are anticipated to include two jump seats allowing six adults to be accommodated.

Open guideway PRT, such as that used by Ultra and 2getthere, tends to be more economical, but the rubber/guideway interface can be problematic during inclement weather conditions. Ultra has plans to address this issue, by using a glass fiber reinforced plastic grating as the riding surface. Preliminary testing by PRT Consulting in the winters of 2006 and 2007 has shown this solution to be very successful in mitigating the effects of Colorado snowfall.

Ultra PRT Ltd. Is understood to be under new ownership that is aggressively marketing the system in Asia. They are reducing costs by implementing vehicle construction in India and other means. They are also developing a next generation control system to allow higher speeds and shorter headways intended to increase capacity while reducing costs.

3.3.2 The 2getthere PRT System

2getthere, a Dutch company, has been operating an automated GRT-like shuttle bus system, in cooperation with Frog Navigation Systems in Rotterdam, Holland, since 1999. Their true PRT system was the first of its kind when it went into operation in Masdar City in the United Arab Emirates in November 2010. They are delivering their second GRT system in Dubai in the United Arab Emirates.

2gethere's PRT system is of the open guideway type, with somewhat similar attributes to those of the Ultra system.

Figure 3-2. 2getthere PRT Vehicles in Station

3.3.3 The Vectus PRT System

Vectus is a subsidiary of POSCO, one of the world's largest steel manufacturers. Despite being a British company owned and operated by Koreans, Vectus chose to establish a full-size test track, with an off-line station, in Sweden, in order to prove operability in winter weather conditions and to meet the rigorous Swedish safety requirements. They have now accomplished both of these goals and moved on to implement a system in South Korea.

Figure 3-3. Vectus PRT Vehicles in Station

The Vectus system is of the captive-bogey type, where the undercarriage, or bogey, is not steerable, but has wheels which run along vertical side elements, thus, keeping the vehicle on the guideway. Switching is accomplished by movable wheels mounted on the vehicle. The test track vehicles were propelled (and braked) by linear induction motors mounted in the guideway. Mounting the motors in the guideway reduces the weight of the vehicles but increases the cost of the guideway. This is advantageous for high-capacity systems, but expensive for low-capacity systems. Their first application in Suncheon Bay, South Korea, uses conventional rotary motors which obtain wayside (third rail) power. Propulsion batteries are not required, allowing the vehicles to be lighter in weight.

The Vectus Vehicle is designed to carry four or six seated adults, plus their luggage. In an urban transportation mode the vehicle can also accommodate up to six standees.

3.3.4 The Modutram PRT System

While not yet in public service, the Modutram system has been included here because of the extensiveness of its test track and demonstration program. A public project is understood to be imminent.

Modutram, is being developed as a university effort with considerable funding from the Mexican government. This system is comprised of rubber-tired vehicles operating on a steel track. The vehicles have electric motors that are battery-powered.


Figure 3-4. Modutram PRT Vehicles Leaving Station

The Modutram system has been designed specifically for the Mexican climate and is not initially intended to be capable of operating satisfactorily in snow and ice conditions. Development has progressed fairly smoothly from the initial design through a small test track to a larger test track with two stations and, more recently, a demonstration system that carries passengers in six-passenger vehicles.

Modutram appears well suited for urban operations. The system is designed for speeds up to 40 mph with minimum headways of 3 to 4 seconds. Vehicles can be physically coupled together to increase capacity.

A video of a number of different ATN systems in public operation can be viewed here: www.youtube.com/watch?v=8IM5299tXcw More information can be found here: www.prtconsulting.com and here: www.advancedtransit.org

4. PUBLIC OUTREACH

Public outreach efforts were undertaken to inform citizens of the study and the opportunities for improved mobility offered by ATN. More importantly, public feedback was sought to learn what the public desires in transportation, the propensity to use ATN and the sensitivity to cost. Numerous transit studies have found that the primary reasons people choose a mode of transportation (assuming they have a choice) are time and money. However, they also have definite mode preferences and will typically choose a car over a bus given identical trip times. This makes sense because, for example, a car waits for you (not the other way around) and a trip may also be about a follow-on destination which may not be served by bus.

The public outreach efforts included two public workshops and a web-based survey (see Appendix A for the survey questions). In all over 300 useable surveys were returned. 19% of respondents live in Clemson, 51% in Greenville, 18% in Mauldin and 25% live elsewhere.

The answers indicated that people actually preferred ATN to cars. However, since this has not been verified in practice, it was assumed that the modal preference for ATN was the same as for car.

Attribute	Votes
Safe	18
Reliable	17
Cost-effective	13
Convenient	13
Frequency	9
Comfortable	6
Sustainable	6
Effective	5
County-wide	5

Attribute	Votes
Minimal Transfers	4
ADA Compliant	4
Multi-Modal	3
Fun entertaining attractive	2
Quiet	2
Respect for privacy	2
Secure	2
Facilitates Sponsorhip	1
Direct	1

Figure 4-1. Transportation Attribute Votes

Advantage was taken of the workshop environment to have participants decide which modes best fit their transportation needs. The exercise involved the participants developing a list of attributes by which to evaluate the different modes. They then voted on the attribute most important to them. Each attribute was then weighted according to the votes it received as shown in Figure 4-1. The different modal options were then discussed and rated for their ability to meet each attribute. Multiplying the rating by the weight for each attribute and adding the results for each mode provided modal scores. The results are illustrated in Figure 4-2. Autonomous Shuttles and Streetcars ranked low partly because participants favored county-wide systems.

Mode Preference	
Mode	Score
GreenPod	457
Light Rail	410
Car	392
Bus Rapid Transit	356
Gondola	342
Bus	308
AutonomousShuttle	281
Streetcar	278

Figure 4-2. Mode Preference Scores

In considering the attributes of different modes, Figures 4-3 and 4-4 were discussed in the workshops.

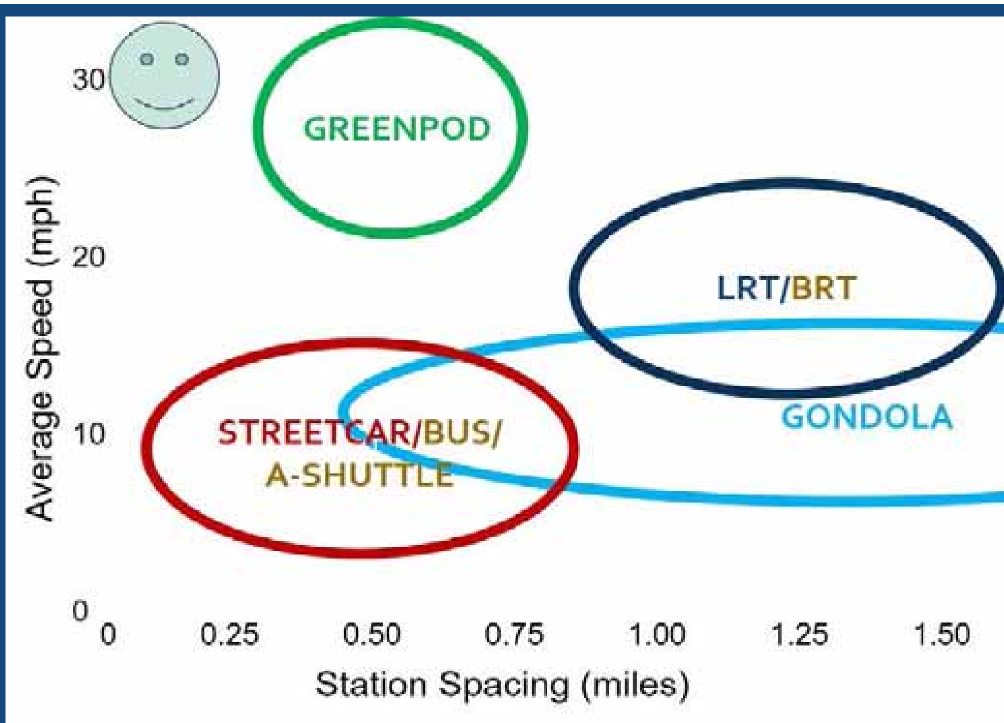

Figure 4-3. Average Speed vs Station Spacing

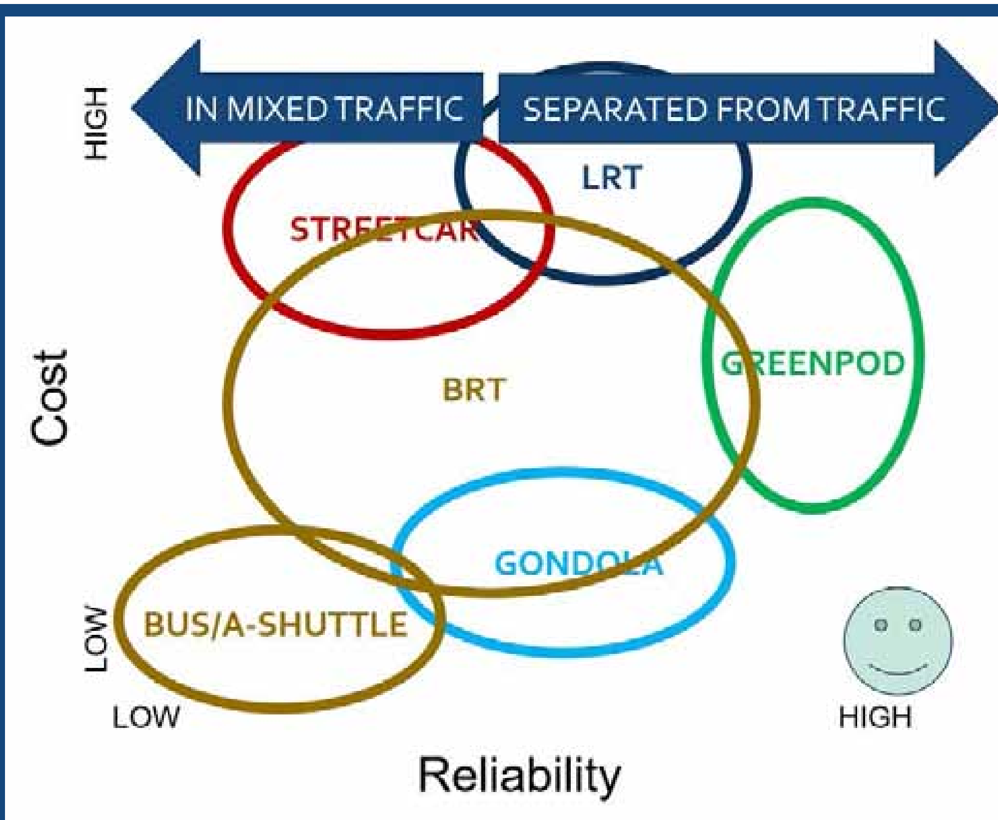

Figure 4-4. Cost vs Reliability

5. CLEMSON

5.1 BACKGROUND

The Clemson Area Transit System (CATbus) recently took a new and fresh look at its transit system through a project titled Clemson Reimagining Study which was completed in 2017. This study highlighted the need to consider new transit technologies that can provide greater capacity than even very frequent bus service in critical locations. Consideration of an ATN solution was indicated along the Old Greenville Highway (Highway 93) between Clemson University and Cambridge Drive (Ingles). This corridor is currently served by the Red Route which suffers from frequent overcrowding of buses. This section outlines the investigation of an ATN solution to replace all, or part of, the Red Route service.

5.1.1 Existing Red Route layout and service characteristics

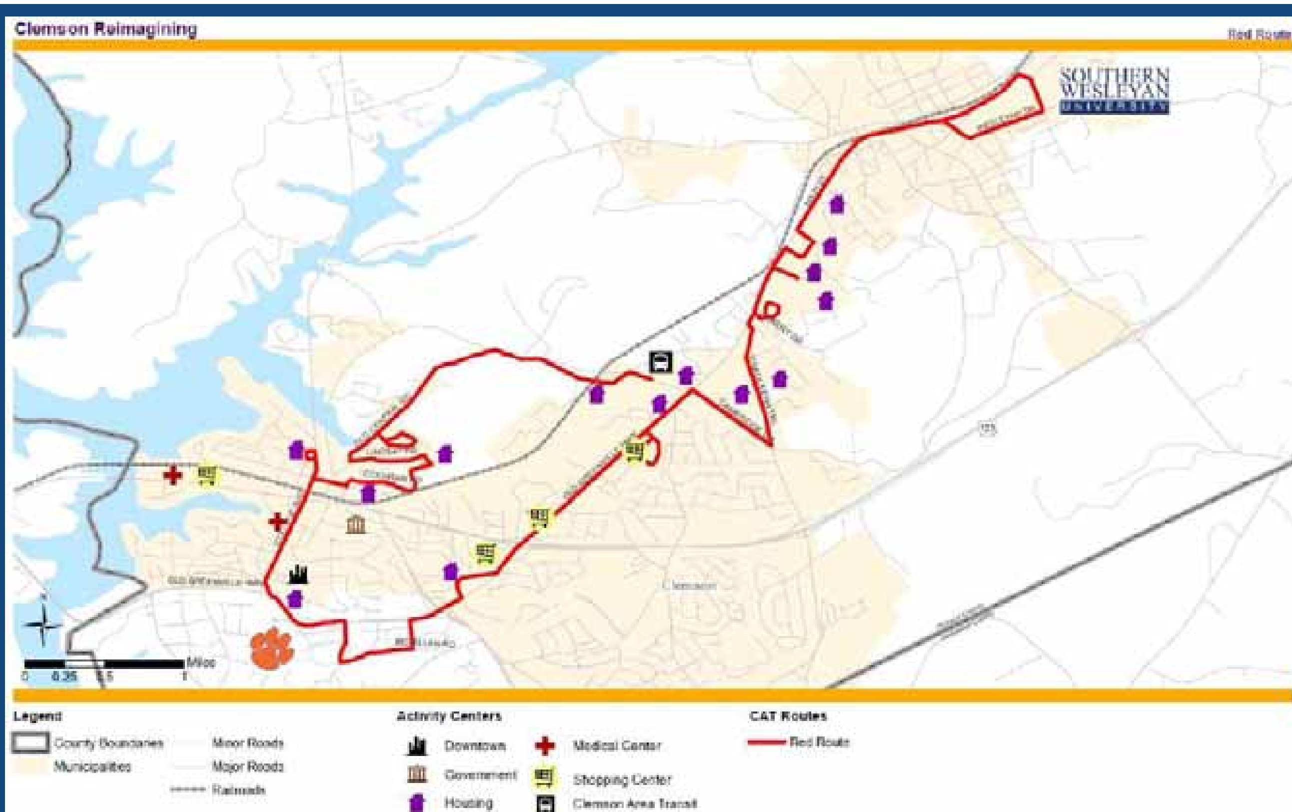

Figure 5-1. Red Route layout.

Credit: Dan Boyle & Associates

Figure 5-1 depicts the Red Route layout. It is 13 miles long and has 36 stops. It operates every 30 minutes throughout most of the day, with added vehicles (known as Red Express) supplementing service at key times and 60-minute frequencies at slack times. This route suffers from frequent bus overcrowding which could be alleviated by having fifteen-minute headways. However, Highway 93 is becoming increasingly congested with related impacts to service reliability. For this reason, the Clemson Reimagining Study recommended that an ATN solution be considered for at least part of this route from Clemson to Cambridge Drive, Ingles.

5.2 POTENTIAL ATN LAYOUT & OPERATING CHARACTERISTICS

Key considerations in developing an ATN alternative for the Red Route include:

1. ATN is likely to be more cost-effective with a larger layout rather than a smaller one
2. A system comprised of interconnected one-way loops can approximately double the service area while only increasing costs by about 20% over a two-way corridor-type alignment.
3. Frequent offline stations will have only a small impact on costs while boosting ridership and not slowing through traffic
4. Routes should follow existing road rights-of-way wherever possible.

With these considerations in mind, the layout depicted in Figure 5-2 was developed. It has 47 stations served by 24.5 miles of one-way guideway. Bus routes typically have stops about one quarter mile apart providing short walking distances along the route but considered to serve people walking up to about one half a mile from each side of the route. ATN stations are typically spaced about one half mile apart blanketing the service area rather than a corridor. The Clemson layout is somewhat of a hybrid between a network and a corridor and the station spacing is closer to one quarter mile on average. Further analysis may find that fewer stations can provide adequate service without a reduction in ridership.

The ATN system will have an average wait time of around one minute (two minutes during peak periods) and a travel time of 16 minutes from Southern Wesleyan University to downtown Clemson. This compares to waiting times up to 30 or even 60 minutes on the Red Route with a travel time of 37 minutes. Assuming an average peak period bus waiting time of 15 minutes, the total bus time is 52 minutes compared to a total ATN time of 17 minutes.

This trip time disparity becomes even more stark when accounting for the fact that passengers perceive out-of-vehicle times to be twice what they actually are.[4] Thus, the perceived total trip time for bus is 64 minutes compared to 18 for ATN. This is 3.5 times lower for ATN and will result in more ATN trips

It is commonly understood that bus passengers will seldom walk more than a half mile to a stop. El-Geneidy found that only 25% walk more than 0.25 miles. The ATN 0.25-mile service area is 30% higher than the Red Route 0.25-mile service area and, for this reason alone, ATN trips are expected to be approximately 30% more than bus trips.

[4] Liu, R et al (1997), “Assessment of Intermodal Transfer Penalties Using Stated Preference Data”, *Transportation Research Record* 1607 pp 74-80

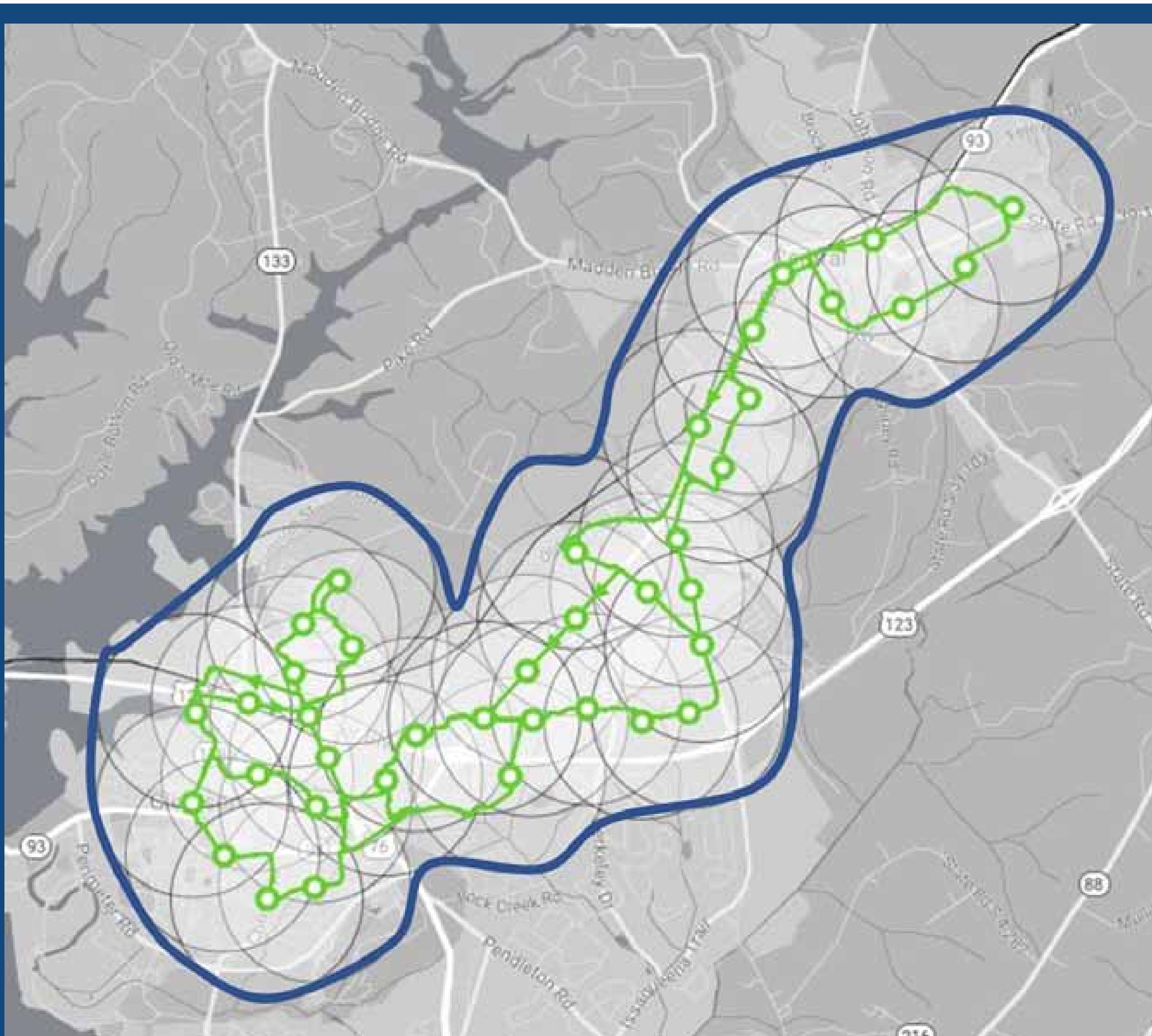

Figure 5-2. Red Route ATN Alternative Showing the Service Area Within One-Half Mile.

5.3 METHODOLOGY TO DETERMINE ATN RIDERSHIP

Both the shorter trip times and the larger service area compared to the Red Route bus service have been considered in projecting the ATN ridership. A description of the methodology used follows.

The Greenville-Pickens Area Transportation Study Traffic Activity Zone (GPATS TAZ) map (Figure 5-3) was overlaid with the Red Route and then the ATN Alternative. This enabled determination of the population within each TAZ which is within a 0.25-mile walking distance of each mode as well as that within a 0.5-mile walking distance. Populations further than 0.5 miles from a transit stop were ignored. It also enabled determination of which bus stops or ATN stations serve which TAZs.

Knowing the bus boardings and alightings at each stop along with the average trip lengths enabled development of an average weekday (Friday) bus trip demand matrix by TAZ. The automobile trip demand matrix for the same TAZs was extracted from the GPATS model. For each TAZ pair, the vehicle trips were adjusted according to the proportion of the population served by bus (within one-half mile). These vehicle trips were then converted to passenger trips using an average vehicle occupancy of 1.5. This enabled determining the bus mode share for each TAZ pair.

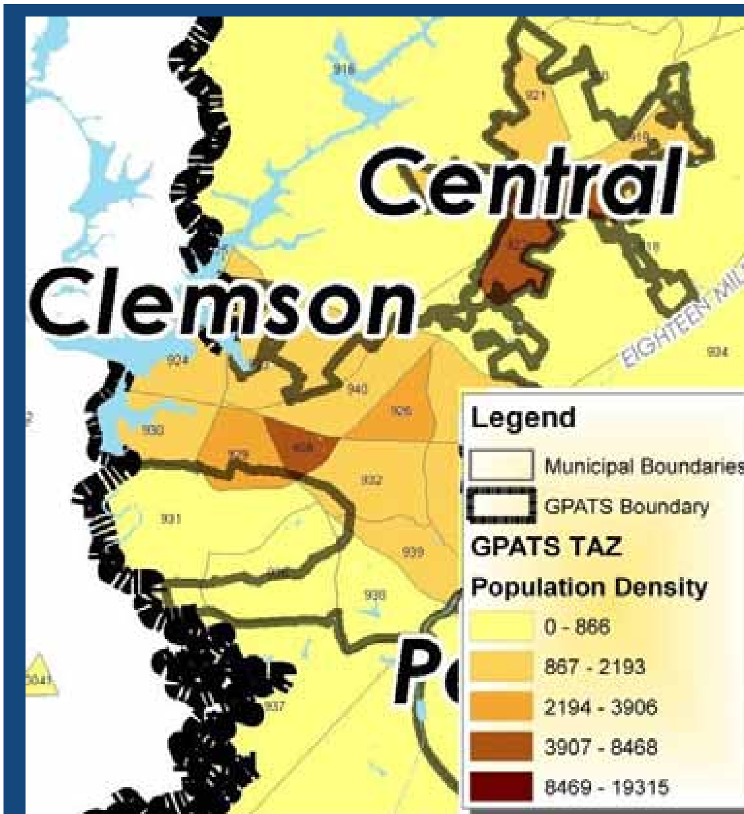

Figure 5-3. Clemson Transportation Activity Zones

5.3.1 Logit model factors

The logit model used to determine mode share is based on generalized travel costs. These are comprised of the in-vehicle times, the perceived out-of-vehicle times (walking and waiting) and the perceived monetary costs. The factors used for the different modes are discussed below. The actual out-of-vehicle times have been doubled to derive the perceived out-of-vehicle times since this has been shown to be a common perception in numerous studies. The monetary costs have been converted to time using a value $13.30 per hour (USDOT 2012 factored up to 2018). A web-based survey of Greenville County residents was undertaken (see Appendix A). This survey asked stated-preference questions that facilitated calibration of the model.

5.3.1.1 Car

According to Google Maps, the trip between Central and Clemson takes an average of 9 minutes in either direction at 6:30 AM on a Friday. This average time increases by 25 % to over 11 minutes by 9:30 AM. This increased trip time continues through the day peaking at about 15 minutes (a 50% increase) in the middle of the day and only going below 25% after 11:00 PM. The average travel time by car has been assumed to be 11 minutes which results in an average speed of 25 mph. This speed has been used to calculate the car travel times between zones. An additional 4 minutes has been added to allow getting to SC 93, finding parking, etc., when determining the total in-vehicle time. A walking/waiting time allowance of three minutes has been used.

The perceived cost of an automobile trip is often less than the actual total cost of the trip because drivers discount the cost of ownership, insurance and perhaps even repairs. For this study we have assumed the perceived cost to be $0.10 per mile (the cost of gas at 30 mpg and $3.00 per gallon) plus $1.00 for parking (a Clemson University annual parking permit costs $162).

5.3.1.2 Bus

The CATbus schedule shows the bus time from Southern Weslyan University to Downtown Clemson is 37 minutes. This results in an average speed of 12.5 mph which has been used to determine the in-vehicle times between zones.

The time between buses on Fridays is 30 minutes. The average waiting time has been assumed to be 15 minutes. A maximum walking distance of ½ mile has been assumed resulting in an average walking time of 5 minutes at each end of the trip.

The bus usage is covered by fees included with tuition and there are no monetary costs associated with each trip. Therefore the bus trips have been assumed to be perceived as free.

5.3.1.3 ATN

All commercially-available PRT systems are capable of at least a 25-mph top speed. Vectus can obtain 43 mph and Modutram around 35 mph. Other existing suppliers are working to increase top speeds. Most emerging suppliers are projecting top speeds well in excess of 35 mph. This study has based PRT trip times on a top speed of 35 mph with average speeds constrained by geometry as determined using Podaris software.

The average waiting time for PRT has been assumed to be one minute which is considered fairly conservative for PRT. A maximum walking distance of ½ mile has been assumed resulting in an average walking time of 5 minutes at each end of the trip.

The average monetary cost of PRT trips has been assumed to be $3.50 per trip (see following discussion of fare sensitivity).

5.3.2 ATN Trip demand models

5.3.2.1 Bus-based model

For each TAZ pair the bus trips were factored up to ATN trips using the modal out-of-vehicle and in-vehicle times and a Logit model developed by Liu et al[5] and calibrated using the results of the public survey.

The ATN trips for each TAZ pair were adjusted based on any increase or decrease in the service populations within 0.50 miles of the ATN Route compared to the Red Route. The resulting ATN demand (9,545 daily trips) reflected a 36% ATN/car mode split. This 2015/2016 trip demand is based on a fare-box cost of $3.50. The existing bus ridership is 3,239 trips (a 13% mode share) but there is no charge for the use of the bus system. The equivalent ATN trip demand with a fare-box cost of $0.00 is 11,744 (the ATN system is anticipated to attract more than three times as many riders).

5.3.2.2 Car-based model

In order to help verify the above ridership estimate, a web-based survey of Clemson residents was undertaken (see Appendix A). This survey asked stated preference questions that enabled development

[5] Liu, R et al (1998). "Simulation of the Effects of Intermodal Transfer Penalties on Transit Use". *Transportation Research Record* 1663 pp 88-95.

of a mode split model between car and ATN based on in-vehicle, out-of-vehicle travel times and costs (note that car ownership and operating costs, other than gas and parking, were ignored). This model was then applied to the average daily person trips between TAZ pairs to determine average daily ATN person trips.

This method resulted in a slightly lower ATN mode share compared to the bus-based model method (32% vs. 36% (compared to 13% for the bus)). The lower mode share has been used in the following analyses.

To help confirm the accuracy of the car-based model, it was used to determine the bus mode share. A mode share of 14% was found which is close to the actual 13%.

Some might question the validity of any transit system obtaining a 32% mode share. It must be remembered that this is transit with exceptionally low wait times and a large service area within a short walk of a station. Figure 5-4 shows how these results compare with mode share results from numerous studies around the world undertaken by different researchers using a variety of methodologies.

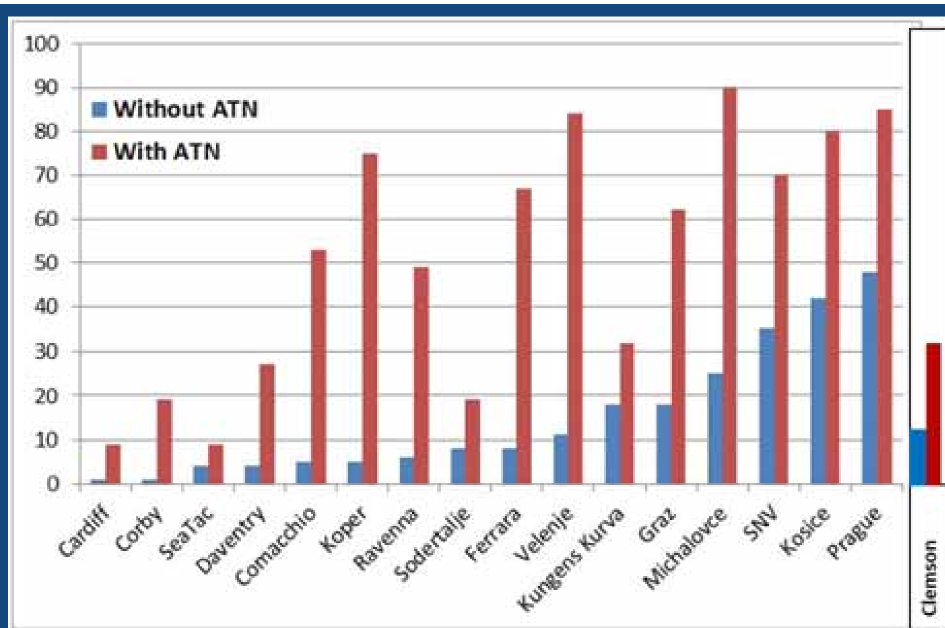

Figure 5-4. Transit Mode Share With and Without ATN

5.3.3 Mode preference

The above analyses took mode preference into account. Mode preference is the number of minutes an average traveler is willing to invest in order to use their preferred mode. Car drivers have been found to use their cars even when a bus trip takes 25 minutes less time[6]. A web-based survey of area residents undertaken with this project found that people would use a GreenPod even if the trip was six minutes longer than a car trip. This implies that the preference for ATN over bus would be even higher than 25 minutes. In order to be conservative, the following mode preferences were use in the ridership analyses:

Conservative Mode Preferences used in this study:

- ATN over bus = 20 minutes
- ATN over car = 0 minutes

[6] Swedish Transport Administration, Transek-Report 2004:1

- Car over bus = 20 minutes

The public survey results and the Swedish Transportation Administration results imply the following mode preferences:

Implied Mode Preferences:
- ATN over bus = 31 minute
- ATN over car = 6 minutes
- Car over bus = 25 minutes

The resulting modes splits and riderships using the different mode preferences are shown below in Table 5-1.

Table 5-1. Results Based on Different Mode Preferences

	ATN				BUS					
	Conservative		Implied		Conservative		Implied		Actual	
	Trips	Mode Share	Trips	Mode Share	Trips	Mode Share	Trips	Mode Share	Trips	Mode Share
Bus-based	9,545	36%	11,277	43%						
Car-based	8,423	32%	9,727	37%	3,662	14%	3,256	13%	3,239	13%

The Implied Mode Preferences do a better job of predicting the actual bus trips. They result in a 12% increase in ATN ridership. However, the Conservative Mode Preferences have been used in this study. In a further cautionary step, the car-based model has been used in place of the bus-based model. The car-based model using the Conservative Mode Preferences results in 8,423 daily ATN trips while the bus-based model using the Implied Mode Preferences results in 11,277 daily ATN trips – an increase of 34%.

5.4 TRIP DEMAND

The resulting ATN passenger trip demand matrix by TAZ is shown in Table 5-2. For ATN simulation purposes, the demand matrix was then converted to a station-based matrix by converting TAZ trips to stations serving the TAZ on a uniform basis.

Table 5-2. ATN Daily Person Trip Demand by TAZ

Zone	916	940	923	924	929	930	931	932	928	926	927	918	922	919	Total
916	1	2	3	6	5	4	3	1	3	1	1	1	5	1	38
940	2	223	34	61	73	47	44	58	72	79	51	46	135	16	942
923	3	27	70	101	74	62	43	15	31	14	7	12	30	4	492
924	6	53	105	232	146	118	64	31	68	30	15	19	57	8	950
929	5	64	81	145	194	149	92	48	89	38	20	17	57	8	1,006
930	4	43	62	109	138	160	65	28	53	25	13	14	45	7	765
931	3	44	47	64	94	64	151	35	57	28	21	12	52	8	680
932	1	55	17	30	47	26	30	47	47	33	15	14	41	5	409
928	3	66	38	77	100	58	57	49	101	37	18	17	48	6	674
926	1	75	14	28	36	23	24	29	34	44	28	18	51	6	411
927	1	48	8	14	19	12	17	13	16	24	28	21	58	7	286
918	1	44	14	19	17	13	11	12	16	17	19	42	113	13	353
922	5	138	35	59	58	44	47	38	48	49	57	93	477	81	1,230
919	1	17	4	9	8	7	7	5	6	6	7	11	77	24	188
Total	36	900	531	955	1,009	786	655	408	642	425	299	336	1,247	194	8,423

5.4.1 Peak hour and annual trips

The ATN average weekday trips were then factored to peak hour using the ratios of peak hour inbound and outbound bus trips (average = 0.061) to average weekday bus trips. The present ratio of daily to annual bus trips is 1:189. However, this ratio is probably not indicative of an ATN system that is expected to be utilized by the general public in addition to students. Assuming trips per day on weekends average one half of weekday trips, the ratio is 1:312. To be conservative, an average ratio of 1:250 has been used.

The peak hour ATN station-to-station person trips were adjusted to match the bus peak hour imbalance between outgoing and incoming trips and then used in a simulator to determine the extent of ridesharing and thus vehicle occupancies (using a maximum vehicle capacity of six adults). Various numbers of vehicles were then modeled to determine how many are required to achieve two-minute average, ten-minute maximum peak hour wait times.

The number of vehicles needed to provide a peak-hour two-minute average wait were used in the estimation of capital costs. Since service levels during the remainder of the day should be higher, this is thought to result in an average overall waiting time of under a minute and thus be reflective of the assumptions made in determining the ridership.

The total annual trips were used to determine annual fare-box revenues and operating costs.

5.4.2 Fare sensitivity analysis

Increasing the fare increases the revenues until sufficient riders are discouraged by the high fares that the revenues start to decline. Figure 5-5 shows this relationship. While the revenue peaks at around $10 per ride, this is at the expense of a significant number of riders. If it is decided to charge a fare, it should probably be in the range of $ 2 to $ 5 per ride. A fare of $3.50 per ride has been assumed in this study.

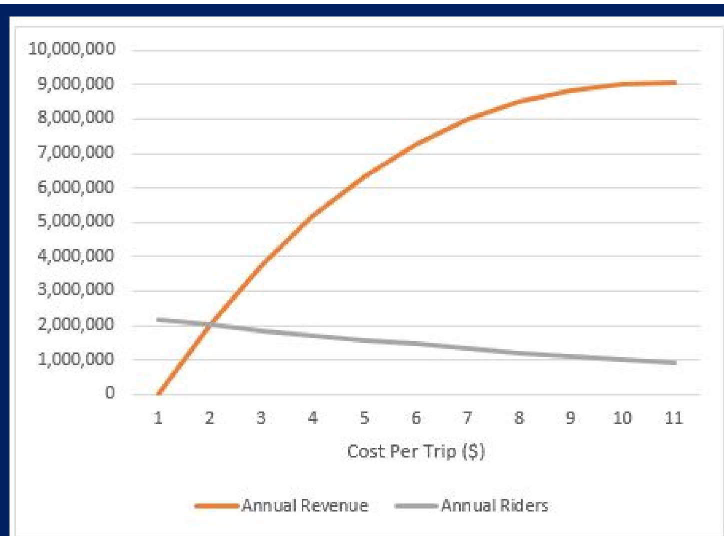

Figure 5-5. Relationship between fare per trip, ridership and annual revenue.

Assuming that the average fare is $3.50 per ride results in about a 20% loss in ridership compared to a fully-subsidized fare of $0.00. If some of the fare was recovered by, for example, including it in tuition or lodging costs and the remainder was subsidized by local, state and/or federal governments, the perceived cost per ride would approach zero and most of the 20% loss in ridership could be recovered. This would effectively lower the cost per rider and render the system even more cost effective. Thus, the assumption of $3.50 per ride is a conservative one.

5.5 SIMULATION RESULTS

The ATN network was simulated to determine the number of vehicles needed to provide satisfactory service during the peak hour for the CATbus Red Route (from 12:53 AM to 1:52 AM on a Friday). This unusual peak traffic was less directionally balanced than typical and quite difficult for the system to handle efficiently. This difficulty was exacerbated by the length of the system and the relatively low ridership (in relation to that length) which made it difficult to quickly respond to service calls and thus keep waiting times low.

PRTsim, the simulator used, was developed in the 1990s specifically to generically (i.e. in a way not constrained by the requirements of any one PRT system) simulate PRT systems. It has been used to simulate well over thirty PRT networks around the world. A summary of the findings is presented below.

5.5.1 Simulation results

5.5.1.2 Parameters

Peak hour person trips simulated	473
Guideway miles	
Stations	47
Vehicles	65
Minimum headway (seconds)	3
Average speed (mph)	27
Maximum wait for ride share matching (mins)	1
Maximum acceptable intermediate stops	2
Maximum acceptable detour for pickup (percent)	20
Study period (mins)	60

5.5.1.3 Results

Average wait time (mins)	2.4
Percent waiting less than 10 minutes	97
Average ride time (mins)	8.5
Maximum ride time (mins)	28.7
Average passenger delay (mins)	0.0
Average trip length (miles)	3.31
Maximum trip length (miles)	10.31
Average speed (mph)	23
Percent of empty departures	20
Percent of departures with one passenger	44
Percent of departures with two passengers	19
Percent of departures with three passengers	10
Percent of departures with four passengers	4
Percent of departures with five passengers	2
Percent of departures with six passengers	1
Passengers carried per vehicle hour	5.9
Percent of used fleet running empty	28
Maximum percent of link capacity used	29
Vehicle miles empty	418
Vehicle miles with passengers	737
Passenger miles	1,278
Passenger miles/vehicle miles (average occupancy)	1.11

The high proportion of empty vehicle miles and resulting low average vehicle occupancy are indications of the difficulties involved with providing short waiting times on this system. The result is that it has relatively high capital and operating costs on a per-passenger basis as outlined in the following section.

The total daily vehicle and passenger miles traveled were determined to be 18,934 and 20,950 respectively.

Figure 5-6 shows peak period guideway loading. Further investigation will likely reveal ways to optimize the routing and station locations. In addition, it seems likely that the number of stations could be reduced without negatively impacting ridership.

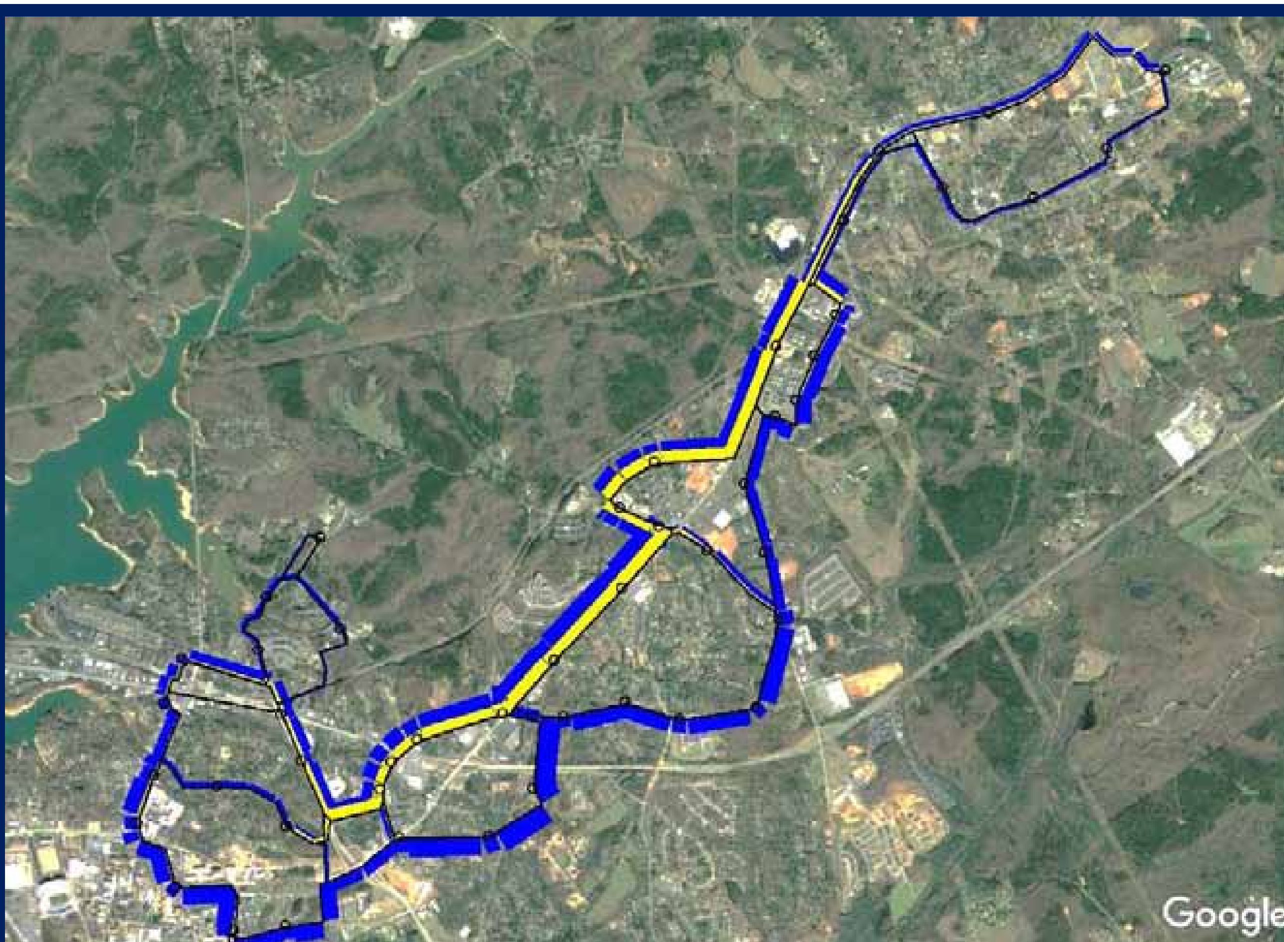

Figure 5-6. Guideway Loading. Blue represents occupied vehicles, yellow represents empty vehicles.

5.6 ESTIMATED CAPITAL, OPERATING AND MAINTENANCE COSTS AND FARE-BOX REVENUES

5.6.1 Unit prices

The ATN industry is still emerging and unit prices have not yet stabilized. Widespread unit price information is not publicly-available. Costs for most installed systems are available but it is often not clear exactly which parts of the systems they cover. Recent large procurements are indicating that costs are coming down significantly. Newly emerging suppliers are claiming very low costs but have not yet proven them in practice. Four sources of unit prices were considered for this project:

1. Unit prices from the bids received at the Greenville – Spartanburg International Airport (GSP)
    a. The GSP project was far smaller than this one and the prices are therefore likely to be on the high side
2. Unit prices from bids in the East and Middle East
    a. While the total prices are publicly known, the unit prices are confidential and cannot be published in this report
    b. These prices have been adjusted to reflect the US market
3. Operating and maintenance costs from the Morgantown PRT system[7]
4. Estimated system costs from emerging suppliers

The fourth source was not used. The first two sources were used for capital and operating costs and the results presented here represent an approximate average of unit prices from these sources. The third source was utilized in developing operating and maintenance (O&M) costs in place of the GSP O&M costs since the Morgantown system has a long history of carrying a significant number of passengers.

5.6.2 Costs and revenues

In order to estimate the life-cycle capital and operating costs it has been assumed that the system goes into public service January 1, 2022 and has a 30-year life. Growth projections are based on the GPATS Traffic Demand Model (TDM) which shows automobile trips for 2015 and 2040. The growth has been assumed to be straight line from 2015 to the end of 2052 at the same rate as the GPATS TDM from 2015 to 2040. Trip times, costs, revenues and mode splits have all been fixed at those used above which approximately reflect the 2015 to 2018 timeframe. In practice, the PRT system is likely to have increased ridership due to increased road congestion (which has been an ongoing trend).

The ATN system depicted in Figure 5.2 has 47 stations and 24.5 miles of elevated one-way track. Simulation indicates this system will require 76 GreenPods (including spares) in order to meet the 2022 peak demand. The capital cost of this system is estimated to be $253 M (about $10.3 M per mile)[8] and the annual O&M costs are estimated to be $2.7 M. The annual revenue, based on an average fare of $3.50 per trip, is $7.9 M. Thus, the fare-box recovery ratio is 2.92. It should be noted that a ratio above 1.0, where the fares more than cover the operating costs, is almost unheard of in the US.

[7] PRT Facilities Master Plan, Gannett Fleming, June, 2010
[8] This relatively low cost per mile is attributable to the low number of pods required per mile.

The O&M cost per trip of $1.18 is 38% lower than the CATbus Red Route O&M cost per trip of $1.92. This seems reasonable since the automated system requires relatively fewer personnel.

If the capital costs were to be amortized over 30 years at a 5.0% interest rate, the annualized capital cost would be $16.2 M. Added to the annual O&M cost of $2.7 M, this results in total annual costs of $18.9 M which result in an annual shortfall of $11.0 M. The annual O&M costs and annualized capital costs of the Red Route bus system total $1.68 M (excluding costs for bus stops and maintenance facilities, etc.). Deducting these costs (since this system will be redirected) results in a net annual shortfall of $9.3 M. This would be the total annual net cost of the system which would need to be covered by local, state and/or federal government subsidies and/or other forms of revenue such as advertising and station area development/commercialization, increased property tax revenues from property value uplift, economic development, etc.

5.7 BENEFITS

Now that we have an understanding of the costs involved, we need to examine the benefits to see if they outweigh the costs. We will focus on the quantifiable and/or monetizable benefits first. These include congestion relief, increased mobility and real estate value uplift.

5.7.1 Estimated congestion relief

Knowing the average daily, bus and ATN person trips along SC-93 (3,239 and 8,423), the reduction in car trips with the ATN in place of the bus system was determined. It was found that 3,456 (= 8,423-3,239/ car occupancy of 1.5) car trips would be removed from SC-93 on a daily basis. The existing (2015) traffic count is 14,839 so this reduction to 11,383 comprises a 23% decrease in traffic.

The existing capacity of this portion of SC-93 is 37,253 so 14,839 represents a 40% vehicles-to-capacity (V/C) ratio and 11,383 a 30% ratio. GPATS has indicated they would like the V/C ratio to remain below 40%.

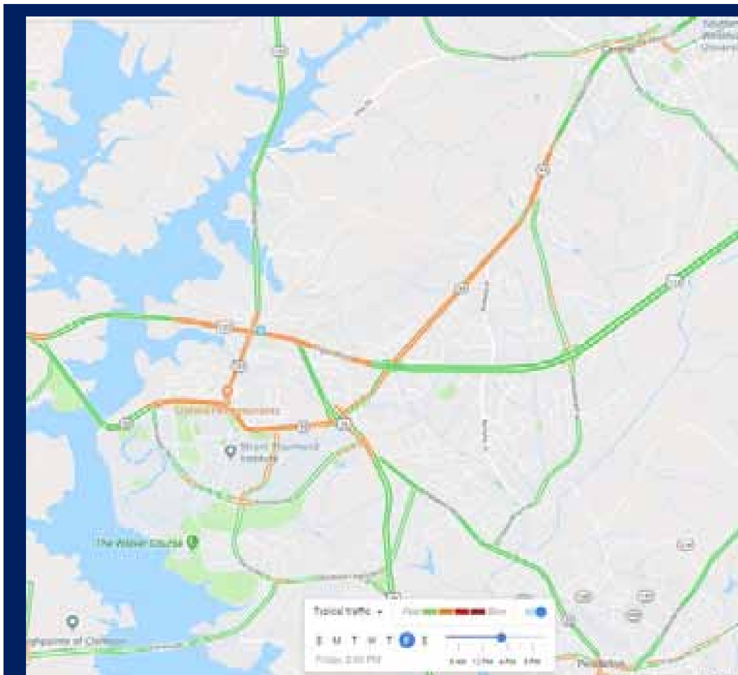

Figure 5-7. Congestion at 3:00 PM on a typical Friday

In 2040 the SC-93 traffic count is projected to be 19,370 (an annual growth rate of 1.07%) while the capacity is projected to go down to 32,678. Thus, the V/C ratio is projected to be 59%. Assuming the ATN mode split remains the same (and it should increase if no capacity improvements are made to SC-93), 4,511 daily car trips will be removed from SC-93 in 2040. This means that the theoretical traffic count will be 14,858 – essentially unchanged from what it is today. The V/C ratio would be 45%. However, it should be noted that the reduction in traffic from these trips will likely be offset to some extent by other trips diverting to this route as it becomes relatively less congested.

Any congestion relief brought about by the ATN system will not only improve mobility and accessibility but also obviate the need for road improvements to deal with growing congestion. While GPATS does not consider SC-93 to be congested, they do recognize that trying to mitigate congestion by spreading the peak periods is unlikely to work in a situation where much of the traffic is due to students whose classes all begin and end at the same time. Studying traffic on Google Maps at different times of the day shows widespread congestion as illustrated in Figure 5-7.

In summary, the congestion relief potential is quite good, but the impacts could be dampened by trips diverted from other routes. The more widespread the ATN network becomes, the less of a factor diverted trips will be.

5.7.2 Reduced road transportation facility requirements

5.7.2.1 Road widening and congestion mitigation projects

Even if some of the congestion relief on SC-93 is nullified by traffic diverting from other routes, the ATN system will relieve the need for overall congestion mitigation measures to the extent it removes car trips from all roads.in the area.

5.7.2.2 Road maintenance

Removing buses from SC-93 will result in a noticeable reduction in maintenance required. Road damage increases exponentially with size of vehicle, for example, one bus trip can do equivalent damage to up to 7,000 car trips. Furthermore, elevated structures have much longer (typically 50 years) design lives than at-grade pavements (typically 20 years). Transporting passengers in lightweight pods rather than heavy buses or even cars, will reduce infrastructure maintenance needs considerably.

5.7.2.3 Parking facilities

Each automobile needs approximately three to four parking spaces – one at home, one at work and one or more elsewhere. Removing automobiles from traffic will reduce the need for parking spaces (one surface stall costs around $5,000 while one parking deck stall costs around $25,000). This could free up prime real estate for redevelopment for higher purposes. It would also improve walkability among facilities.

5.7.3 Improved mobility/accessibility

The area within one-half mile of an ATN station will have significantly improved mobility and accessibility. People with access to cars will experience reduced congestion. Those without access to cars (and only about 35% of the general population can drive/own a car) will have greatly improved mobility. They will be within half a mile of a station from which they can quickly and comfortably access any one of another forty-six stations covering an urbanized area of nearly nine square miles. This will facilitate access to jobs, school, shopping, entertainment and health care. This improved mobility and accessibility will undoubtedly lead to an economic uplift that is difficult to quantify directly. However, there is substantial evidence of the impacts of fixed guideway transit on property values as discussed in the following section.

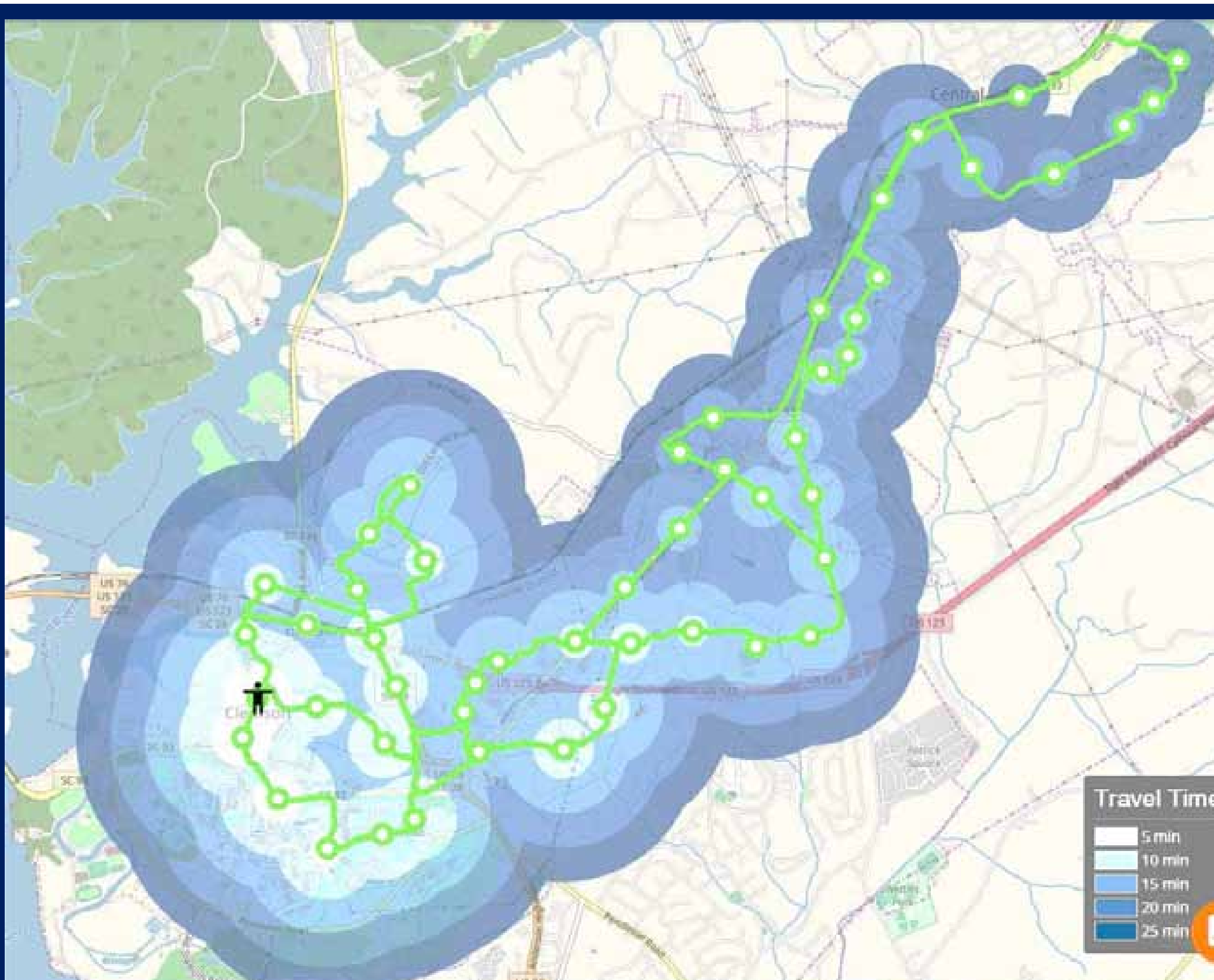

Figure 5-8. ATN Travel Times From Downtown Clemson

Figure 5-8 shows the travel times from Downtown Clemson on the ATN system. All stations can be reached in less than 21 minutes. The entire area within the dark blue outline can be reached in 25 minutes with a combination of riding and walking.

5.7.4 Real estate value uplift

There are many papers on the topic of real estate uplift caused by fixed-guideway transit. The one relied on here (TCRP Report 102[9]) is thought to be one of the most authentic. TCRP Report 102 found "…average housing value premiums associated with being near a station (usually expressed as being within ¼ to ½ mile of a station) are 6.4% in Philadelphia, 6.7% in Boston, 10.6% in Portland, 17% in San Diego, 20% in Chicago, 24% in Dallas and 45% in Santa Clara County." Similarly, the uplift for commercial properties ranged from 3.7% to 37%. The ATN system considered here has more stations, less waiting time and higher average speeds than most rail and light rail systems and the impacts could therefore be even higher. To quantify the potential results of these impacts, an uplift of ten percent in property values

[9] Federal Transit Administration, TCRP Report 102, Transit-Oriented Development in the United States, 2004

(residential and commercial combined) is examined below. Consideration of uplifts of twenty or thirty percent can be accomplished by simply multiplying the numbers below accordingly.

5.7.4.1 Ten percent uplift in property values

The total market value of all properties in the ½-mile service area is $1,189 M An uplift of ten percent thus represents $119 M. This is 47% of the projected capital cost of the system. It has been suggested that if Multi-County Industrial Park (MCIP) agreements were used to monetize this uplift, increased property tax revenue could repay capital costs over time. These amounts should be considered by the community when deciding whether or not to invest in the ATN system.

The total value of residential property taxes for the ½-mile service area is $5.88 M. A ten percent uplift will therefore bring an additional amount of $588,200 to community coffers annually. This amount is 11% of the projected annual O&M costs.

5.7.5 Other benefits

5.7.5.1 Economic uplift, commercial activity and community safety

As mentioned previously, the improved mobility and accessibility should result in an economic uplift. The potential to collocate small commercial neighborhood businesses such as coffee shops, service and convenience stores with ATN stations should also help the economy. In addition, the fact that the stations, guideways and vehicles will be under 22/7 CCTV monitoring should create mostly crime-free zones around stations and along guideways – throughout the ½-mile service area. On a local level, crime has the following types of negative economic impact:

- business impact (crime reduces competitiveness of companies and investments)
- tourism impact
- impact on quality of life/social capital
- impact on property value

Crime adds up to an overall negative economic impact which could be significantly reduced.

While it seems clear that an ATN system will bring economic benefits, these are difficult to quantify and monetize (other than the uplift in property values and taxes).

5.7.5.2 Increased safety

ATN systems are extremely safe having completed over 200 million injury-free passenger miles. In this many miles cars would have killed three people and injured 190. To the extent people transfer to the ATN system, safety will be improved – not only for riders but for pedestrians also. While it is possible to quantify the community savings of this improved safety, it is difficult to monetize those savings.

5.7.5.3 Improved resiliency

ATN systems will typically keep operating in inclement weather except severe thunderstorms, wind speeds over 60 mph and severe ice storms. The Morgantown PRT system only shuts down in severe snow storms after all other systems have shut down and people can no longer reach the stations. Once shut down, the infrastructure will withstand the worst weather conditions required by code. Being mostly elevated, the infrastructure will be very resilient to flooding. Typically, power sources will be redundant and can include back-up generators. If the system includes solar generation and battery-powered vehicles, this offers another level of immunity from power failures.

5.7.5.4 Higher sustainability

The ATN system will be far more sustainable than the existing road/automobile system. It will use about one third the energy per passenger mile and the vehicles will be electrically powered (probably using on-board batteries). The potential to incorporate solar panels into stations and guideways is good.

Space needed is minimal and consists of a slender column every sixty to one hundred feet and a small station every quarter to half a mile. Stations can be elevated and served by stairs and elevators or they can be at, or close to, grade.

Noise, vibrations and electro-magnetic interference are all substantially less than for conventional transit.

Visual intrusion of overhead guideways is seen as a problem by some. However, the clear majority of those questioned found this to be outweighed by the transportation benefits provided. Some see small vehicles gliding silently overhead as an appealing art form.

The system should last more than fifty years. The Morgantown PRT system in West Virginia had a design life of twenty-five years. It is still in public service, using upgraded control technology with the original (refurbished) vehicles and infrastructure, after forty-three years.

5.8 NEGATIVE FACTORS

Every transportation mode has negative factors. Cars get caught in traffic, pollute and kill tens of thousands of people in the US every year. Light rail is expensive, and stations are typically a mile or more apart. Streetcars are slow. Buses stop frequently, require transfers and the time between buses can be long. Bicycles don’t work well in bad weather or on steep terrain. Walking is becoming more dangerous and roads and rail lines can be difficult to get across.

ATN typically requires elevated guideways which are seen by some as visual pollution. In addition, these guideways may require trimming or removal of trees. Passengers traveling on elevated guideways may be able to see down into areas previously considered private. Guideways are relatively permanent infrastructure that is difficult to move.

While there are positive aspects to some of these issues and mitigation measures can be taken, in the end the community must decide if the benefits outweigh the costs, including the negative factors.

5.9 FEASIBILITY

While this system is larger than commercially-available ATN systems presently in public service, they were all designed to be scaled up and this system is clearly constructible and similar in number of vehicles to the Morgantown PRT system. Issues with rights-of-way and existing utilities, while not addressed here, are not expected to be unduly problematic.

This study indicates this system does not have the financial viability to pay for its own operating and capital costs but that does not make it infeasible. No US urban transit system does that. In fact, few, if any, have the ability to cover their own operating costs, as indicated for this system.

In considering the feasibility of this solution, a comparison with the Red Route bus system is appropriate. The Red Route bus operating costs per boarding is $1.92 while the equivalent ATN operating costs per boarding are estimated at $1.18. Capital amortization costs per boarding for the Red Route are $0.83 while the ATN is estimated at $7.87[10]. The flaw in this comparison is that the bus system utilizes public roads for which it does not pay either the capital or operating costs. Also, the bus capital costs are for buses only and ignore the cost of stops, maintenance facilities, etc., while the ATN costs are all-inclusive.

While the ATN system is unique, the existing system it most closely resembles is light rail. A comparison with light rail projects currently being considered for funding by the Federal Transit Administration (FTA) is therefore appropriate. Those projects are shown in Table 5-3 below.

Table 5-3. Light Rail Projects Listed by FTA for Potential Funding

State	City	Project	Status[1]	Technology[2]	Miles	Stations	Costs (US$ M)			Daily Trips	Annual Trips (M)
							Capital	Local	Ann O&M		
AZ	Phoenix	NW Ext PH II	NSPD	LRT	1.5	3	319	162	2.99	6,400	2.12
AZ	Phoenix	South Central Extensi	NSPD	LRT	4.8	7	704	359	17.75	8,700	2.86
MN	Minneap	METRO Blue Line exte	NSE	LRT	13.5	11	1,563	784	27.50	16,500	5.49
MN	Minneap	Southwest LRT	NSE	LRT	14.5	15	1,857	928	29.40	18,900	6.29
NC	Durham	Durham-Orange LRT	NSE	LRT	17.8	18	2,476	1,238	28.73	14,400	4.05
WA	Seattle	Federal Way Link Ext	NSPD	LRT	7.8	3	2,165	1,665	20.23	22,200	7.09
WA	Seattle	Lynnwood Link Exten	NSE	LRT	8.5	4	3,069	1,897	23.46	44,500	14.33
WA	Tacoma	Tacoma Link Extensic	SSPD	LRT	2.4	6	215	175	6.27	4,000	1.18
LRT Totals					70.8	67	12,368	7,208	156.33	135,600	43.41

1. NS = New Starts; SS = Small Starts; PD = Project Development; E = Engineering. NSE = bigger and more advanced than SSPD
2. LRT - Light Rail Transit

These projects average $18.35 capital amortization cost and $3.60 operating cost per trip in contrast to the ATN costs of $7.87 and $1.18 respectively. On this basis, this project is not only feasible, but should compete very well with light rail projects for federal funding.

5.10 PHASING

Community acceptance of a new technology is likely to be facilitated if a small initial portion can be built to demonstrate viability and acceptance. The problem with phasing the Red Line Route is that a small portion of this project is unlikely to serve a useful function and could be seen as just a curiosity. Nonetheless, an initial implementation could play a vital role in getting community support for a larger project and helping to prove the ridership model. For these purposes, the initial project must be large enough to perform a real transportation purpose and bring tangible community benefits. The connection between student housing complexes at Highpointe and The Pier over to the University of Clemson Campus layout shown in Figure 5-15 could provide a suitable first phase.

[10] Items were amortized over about 2/3rds of their expected life at 5%.

5.11 CONCLUSIONS AND RECOMMENDATIONS

The above results indicate that ATN is a viable way of improving service along the Red Route. It costs more than bus service up front but far less than light rail. Annual O&M costs are less than bus and light rail. Costs for projected parking spaces can be avoided. The project should compete well for federal funding.

Projects of this nature take many years to implement and, if this solution is desired by the community, it would probably be wise to start moving in this direction fairly soon.

5.12 IMPLEMENTATION STEPS

This study has highlighted an alternative to the Red Route bus service that appears feasible and capable of attracting and carrying more than three times the ridership, which should in turn alleviate congestion, increase property values and taxes and bring general social and economic advantages. The entire eight square mile ATN service area will have better transit than most transit-oriented developments.

No analysis or study can accurately predict the future and this one is no exception. The results provided here are intended to be conservative but need to be verified through more exhaustive work using tried and true models not available for this study. In addition, there are many details that this project has not investigated and many questions that remain unanswered. For these reasons, if it is decided to move forward with an ATN solution, one of the first steps should be to undertake a detailed planning study that includes the following tasks:

- Community outreach
- Optimization of station locations and guideway routing
  - Analysis of alternatives
- Station alternatives (elevated/at-grade)
- Phasing alternatives
- Permitting requirements
- Right-of-way needs
- Utility relocations
- Maintenance/storage/control facility requirements and location
- Detailed ridership determination using/adapting the GPATS TDM
- Cost/revenue study
- Funding/financing/revenue alternatives and requirements
- System ownership and governance
- Procurement alternatives

It seems unlikely that the community can raise the capital to build this project without federal assistance. Even if federal assistance is obtained, it will usually only cover 50% of the capital cost or less. If federal funding is used, it will impose additional requirements on the project which will likely include requirements for the previously-mentioned study.

An early step needs to lead to a decision as to how the project is to be funded and whether or not federal funding is to be used. An analysis of the impacts of accepting federal funding may be wise. It would be good to know how procurement requirements such as Buy America may impact the suppliers who can bid, the prices to be paid and the project schedule.

Another early step should be one that decides how to phase the project. Building a small portion of the project first for demonstration purposes may help alleviate some local concerns. On the other hand, a small system will be less economically viable and waiting to start expanding the system could increase mobilization costs. A more economical solution may be to have a representative group visit an existing project already in public service. Care would have to be taken to avoid this trip being perceived as a vacation/boondoggle for a select few. Another alternative would be to build an initial small system away from the Red Route such as the connection between the Clemson Campus and Highpointe/The Pier. This much shorter route is anticipated to have a relatively high travel demand.

5.13 OTHER ADVANCED TRANSIT OPPORTUNITIES

5.13.1 Introduction

The CATbus Red Route was deliberately chosen for this analysis of an ATN alternative because:

- It is struggling to meet demand and difficult to expand since adding more busses without additional infrastructure improvements could exacerbate existing congestion
- There is a good set of data regarding its operating characteristics and passenger demand
- It serves a defined area with known populations and automobile travel characteristics

However, there are several other areas that may be as good, or better for an ATN application. Some of these are discussed below. It should be noted that transit utility increases rapidly with the service area (number of stations). The most viable ATN deployment for the Clemson urbanized area will thus likely be one that combines the Red Route with the other alternatives addressed here into one large, interconnected network capable of taking passengers anywhere in the service area without requiring transfers.

5.13.2 University of Clemson Campus

5.13.2.1 ATN solution

A problem with the Red Route bus or ATN service is that, while it brings passengers to the Campus, it is not integrated with on-Campus circulation. As depicted in Figure 5-9, the Orange, Purple and Blue Routes currently serve most of Campus with buses every five to twelve minutes. Similar coverage could be provided by an ATN extension to the Red Route ATN system as depicted in Figure 5-10. This extension would comprise of 4.6 miles of guideway and 12 stations. Capital costs would be in the order of $70 M. The significant advantage of the combined systems would be accessibility to and from Campus with no need to transfer.

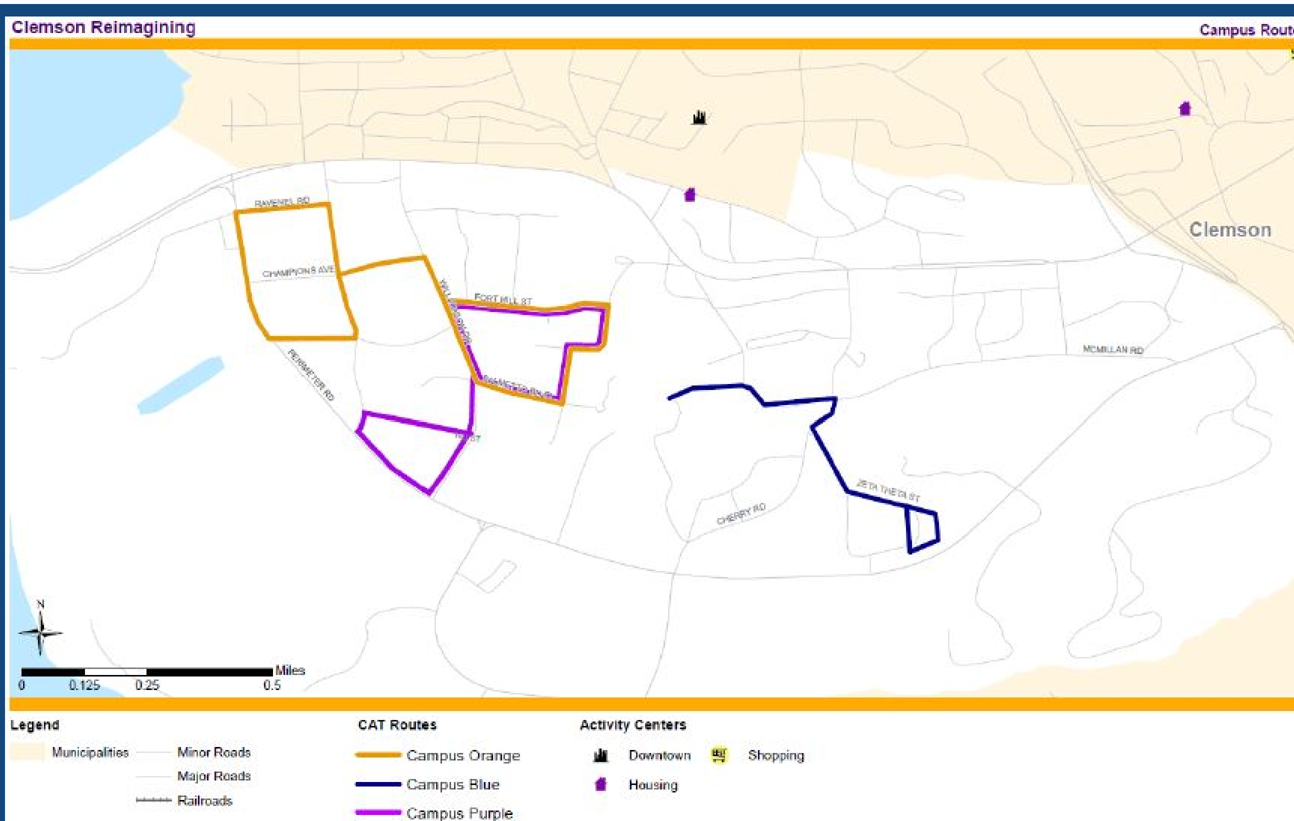

Figure 5-9. Campus Bus Routes.
Credit: Dan Boyle & Associates

Figure 5-10. University of Clemson Campus ATN Layout

Should it be desired to build the Campus layout first, the return loops would have to be included. One way of doing this would be to construct a portion of the Red Route at that time. While the return loops become slightly circuitous, they have the advantage of connecting the Campus to Downtown as depicted in Figure 5-11. This layout has 7.8 miles of guideway and 20 stations.

Campus/Downtown accessibility is illustrated in Figure 5-12. As can be seen, any station can be reached from Byrnes Hall in less than six minutes and the entire area shaded dark blue can be reached by riding and walking in ten minutes.

Figure 5-11. University of Clemson Campus ATN Layout Including Downtown Link

5.13.2.2 A-Taxi/Shuttle solution

Another way of connecting the Campus to the Red Route and improving Campus circulation could be through the use of autonomous taxis or shuttles (A-Taxis/A-Shuttles). The FHWA recently funded the first automated vehicle grant for Greenville to deploy A-Taxis/Shuttles on public roads. The deployment is currently taking place on a university campus (CU-ICAR), a high-end mixed-use development (Verdae) and a low-income 100-year old neighborhood (Parker). These vehicles have a good potential to provide so-called first/last mile connectivity to other transit systems including ATN in Clemson, Greenville and Mauldin.

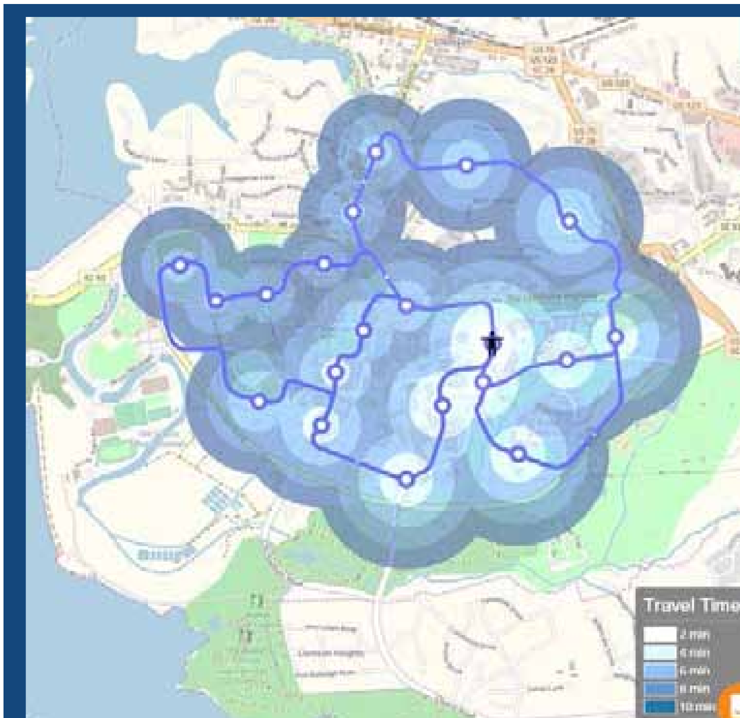

Figure 5-12. University of Clemson Campus and Downtown ATN Travel Times

A-Taxis/Shuttles have the advantage of utilizing existing streets and therefore requiring less new infrastructure for deployment than ATN systems. However, this is also a disadvantage. These systems will operate in mixed traffic and can easily add to congestion. This will be particularly true with early deployments where maximum speeds could be as low as 12 mph.

A-Taxis/Shuttles will be most useful for short trips in areas with little or no congestion. They could thus potentially assist with Campus connectivity helping connect the buildings to parking lots, sports facilities, etc. However, like the shuttle bus system, they will require a transfer to link to off-campus modes.

The primary functional difference between A-Taxis/Shuttles and conventional taxis and shuttles is that it becomes more economical to utilize smaller vehicles when drivers are not required. Many small vehicles can often provide higher levels of service with less waiting and intermediate stopping.

Figure 5-13. A-Shuttle by Navya

5.13.3 CU Campus to Highpointe and the Pier

Existing CATbus service to Highpointe and the Pier operates on hourly and half-hourly schedules with connections to Miller Hall and Strom Thurmond Institute on weekdays and Downtown Clemson on Thursday, Friday and Saturday nights. While the trip from Highpointe to Campus only takes ten minutes, the congestion can cause bad backups at times, which are only anticipated to get worse. Additional construction is anticipated to result in an additional 3,000 to 4,000 beds, or more, in the area. Even running 12 large buses would only accommodate 980 passengers and hour. Adding buses is problematic because West Cherry Road is already congested and the causeway over Lake Hartwell is narrow and difficult to widen, so different options are needed.

5.13.3.1 ATN solution

The most significant barrier to serving Highpointe and the Pier with ATN is constructing the guideway over the causeway and bridge crossing Lake Hartwell (see Figure 5-14). However, these issues are considered relatively easy to address.

Figure 5-14. Causeway and Bridge Over Lake Hartwell

The bridge has a span of about 525 feet with six piers. It is possible that the existing structure is adequate to support the relatively light weight of an ATN guideway but determining this would take a detailed investigation. ATN guideway piers could be drilled into the lake bottom adjacent to the road bridge piers. The remainder of the guideway structure would then be no different than a conventional elevated guideway. The additional cost of the deeper piers is unlikely to significantly add to the overall cost of the system.

Like the bridge, there are two possible options for the causeway. It appears that there is sufficient room to build an at-grade guideway between West Cherry Road and the parallel railroad line. This guideway would have to be protected from road traffic and this could be economically accomplished by installing a guard rail. However, the guideway may be close enough to the rail line to require protection from it too. This may need to take the form of a relatively expensive barrier wall. Even with the guardrail and barrier wall, this option may be less expensive than an elevated option. However, another issue that may need to be addressed could be any need to have an ability to access the rail line from the roadway.

The second option for crossing the causeway is to build an elevated system adjacent to the road. The columns could be placed immediately outside the existing guardrail on the north side away from the rail line. Some tree and bush trimming would likely be required but there appear to be no major issues involved with this option.

A possible alignment for an ATN solution along with possible station locations is shown in Figure 5-15. This connection comprises 8.0 track miles of guideway and 4 new stations. Note that, unlike most of the other layouts, this one would be comprised mostly of double guideway with a one-way loop connecting the Highpointe and The Pier stations. There are a total of 4.2 route miles. The number of stations has been deliberately kept low to keep the costs down. Stations are provided to serve the Pier, High Pointe, the Madren Center and Freeman Hall only. However, the guideway geometry should take account of and allow for the later addition of more stations, if deemed necessary. Connecting to the Hendrix Student Center instead of Freeman Hall would be possible for a small additional cost. However, both will be connected once the Campus ATN circulator system is added.

Assuming a peak demand of 2,000 passengers per hour per direction, it would require 160 vehicles and have capital costs in the order of $119 M and annual operating costs of about $5M. The annualized cost of capital should be about $8 M for a total annual cost of the system of about $13 M equating to a per-ride cost of around $3. The maximum theoretical capacity could be increased to around 5,000 passengers per hour per direction by simply adding more vehicles. Further increases would be possible by coupling vehicles together and/or reducing headways.

A big advantage of this solution is the connectivity it would provide to Campus and Downtown ATN stations with no need to transfer. The travel time from the Pier to Freeman Hall would be eight minutes. Figure 5-16 shows that, from the Pier, any station can be reached within sixteen minutes and the entire area shaded dark blue can be reached by riding and walking in twenty minutes.

This alignment will more than double the capacity of the causeway across Lake Hartwell and it should be of considerable benefit to both Oconee and Pickens Counties. The cost of the ATN system is anticipated to be significantly less than the cost of widening the causeway and existing bridge.

Selecting this Campus to Highpointe/the Pier connection as the initial phase of ATN deployment simplifies the process previously described in that the question of ridership and other benefits deriving from the system is less complex. The ATN connection will provide unmatched connectivity to Campus from new

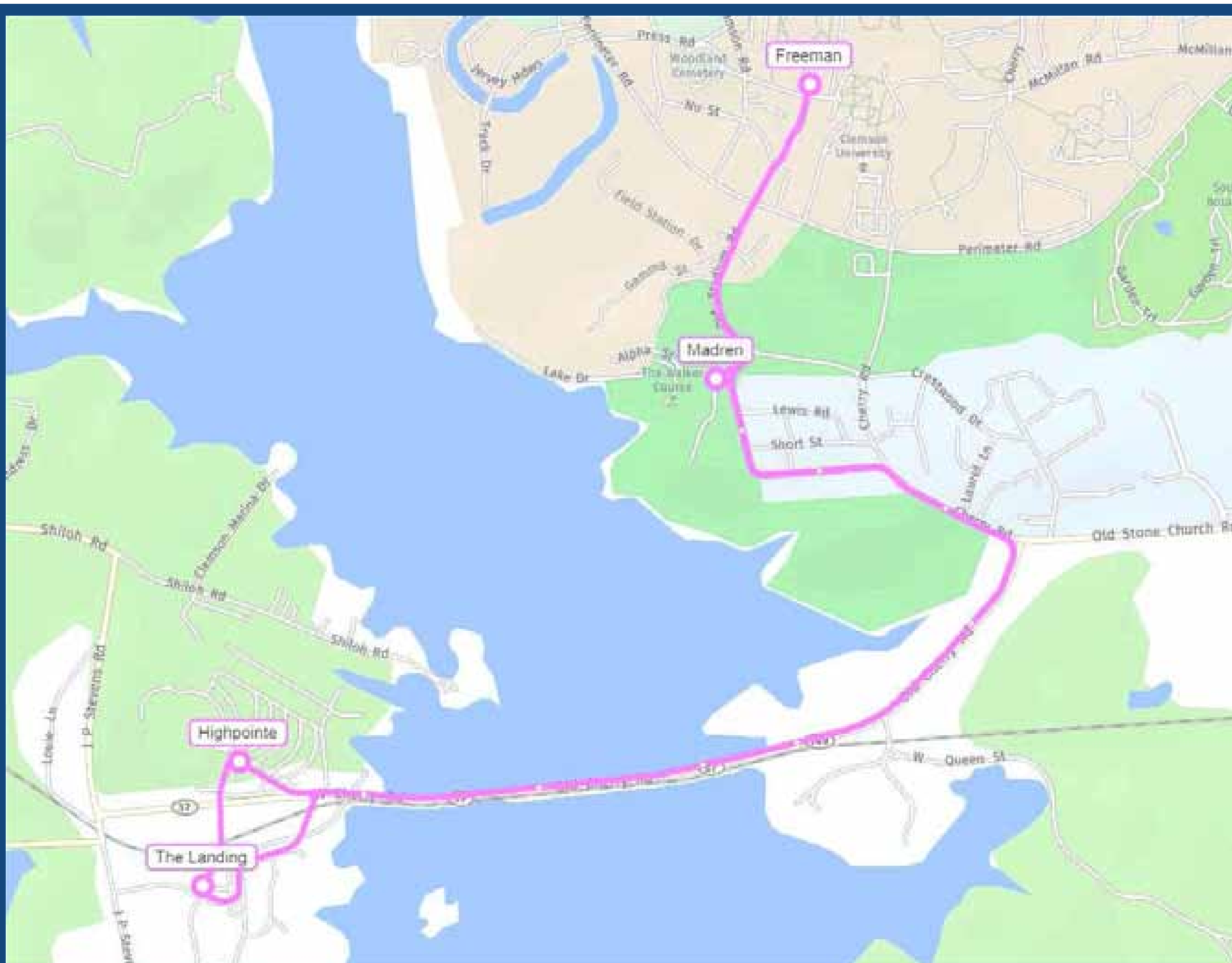

Figure 5-15. ATN Connection between Highpointe and the Pier and Clemson University Campus

student housing. There is little doubt that most students will use the system for at least one round trip a day. At the same time, the ability of the system to handle high demand (up to about 15,000 pphpd in the future) substantially increases the viability of additional housing being built across the lake from the Campus. This could both increase the ability of the Campus to grow and encourage the developer to help pay for the system. In addition, this added growth should not result in pressure to add more parking on Campus.

A complicating factor of this alignment is the probable need for a permit from the Corps of Engineers for any piers that have to be drilled into Lake Hartwell. While it seems likely that this permit can be obtained, the process may be lengthy.

Probably the most effective way to undertake this project would be through a public private partnership (P3) wherein the private partner is responsible to design/build/finance/operate/maintain the system and is paid an availability fee for keeping the system available at a prescribed capacity level during prescribed hours and to prescribed performance levels. The private partner can be procured by means of solicited or unsolicited proposals with the unsolicited process being somewhat simpler. Ownership and operations/maintenance can be handed over to the public entity responsible for the system (probably CATbus) after any period of time deemed to be suitable (anywhere from one to thirty years is typical).

The detailed study outlined in Section 5.12 will still need to be undertaken but, with this initial project, some aspects could be turned over to the private partner. This is to say that the decision to proceed with the project could be based largely on the results of this report plus only those aspects that are felt to be needed to support the decision. Proposals for the work could be obtained by simply putting the word out that unsolicited proposals would be considered. If not already in place, a procedure for accepting unsolicited proposals should first be developed. This procedure could require that the successful proposer undertake all the public outreach, planning and engineering tasks at their expense. However, which tasks to hand over should be carefully considered. Tasks such as public outreach, determination of right-of-way requirements, system ownership and governance, and Corps of Engineers permitting may be best accomplished prior to forming a public private partnership. Once all permits are obtained, the time for design, construction/manufacturing, testing, safety certification and system deployment should be about two-and-a-half to three years.

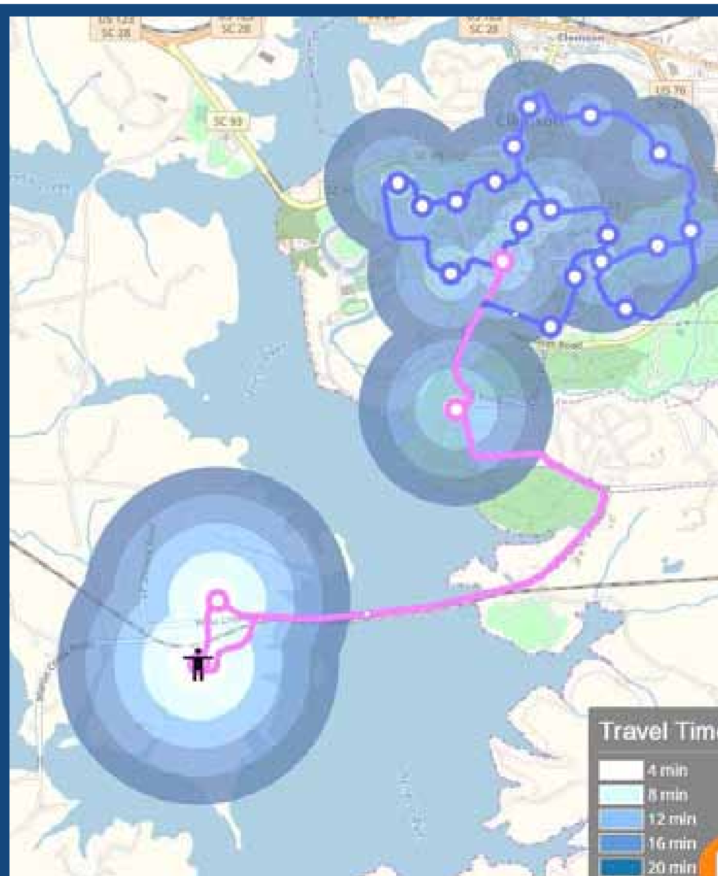

Figure 5-16. ATN Travel Times from the Pier

5.13.3.2 Gondola solution

Another option to improve service to Highpointe is to use an aerial ropeway – a gondola or tramway. Such systems provide additive capacity as they travel above traditional traffic lanes with supporting towers generally sited periodically in convenient locations. The vehicles are motor-less cabins pulled along by a haul rope to which the cabins are attached. The haul rope is pulled by electric motors located in one or more of the stations, providing an environmentally sound solution.

As currently contemplated, the aerial ropeway would have stations near the Pier, Highpointe, the Madren Center and the Hendrix Center. Four different ropeway technologies were evaluated as candidates for a potential solution. Like all transit modes, characteristics of aerial ropeways can vary from installation to installation. However, as an initial screening tool, the general characteristics of each of the four technologies were considered and are summarized below.

Reversible Tramway

Reversible tramways generally use large vehicles in a to-and-fro operation. The Roosevelt Island Tramway and the Portland Aerial Tramway are two of the more visible examples of aerial tramways in the United States. Each vehicle shuttles back and forth along one side of the towers between stations. The cabins reverse direction after unloading and loading at a station and they are therefore not well suited for multiple-station configurations. Further, since the vehicles travel back and forth, the headways between vehicles is very much dependent upon the distance between stations. Accordingly, the system capacity achieved by reversible tramways is typically low compared to continuously circulating gondolas.

Since connecting the Pier and Highpointe to the other facilities will require multiple stations and since the relative capacity of reversible tramways is low, they are given no additional consideration in this study.

Monocable Gondola

Monocable gondolas are perhaps the most common and most familiar of the ropeway types considered. Such systems are very much like those found at ski resorts where protection from the weather is desirable. Such systems utilize a single rope (*mono*cable) to provide both the propulsion between stations and the vertical support of the cabins.

The major difference between gondolas and reversible tramways is that gondola cabins circulate continuously along the closed loop of haul rope, only turning back at end stations. Because of this operation, many cabins may be placed on the rope, achieving lower headways than those of reversible tramways. These headways may be as low as roughly 8 seconds, with cabins typically carrying 8-12 passengers. Because of the low headways and the cabin size, monocable gondolas regularly achieve capacities of 3,000 passengers per hour per direction (pphpd). Certain newer installations describe capacities in excess of 4,000 pphpd.

Bicable Gondola

As their name suggests, bicable gondolas share many of the characteristics of monocable gondolas but utilize two ropes. A haul rope provides motion while a second stationary rope provides additional vertical support for the cabins. The cabins have rollers which ride on this second rope, analogous to how a train's wheels ride along a track. Accordingly, this second rope is called a *track rope*.

Owing to the support provided by the second rope, bicable gondolas generally have larger cabins than monocable gondolas and may have larger spans between towers. Also owing to the second rope, the towers are more complicated to support the ropes and maintenance efforts are greater.

Tricable Gondola

Tricable gondolas use three ropes: one haul rope and two track ropes. The use of two track ropes provides substantial wind stability and allows for both larger cabins and longer spans. Tricable gondola cabins typically accommodate more than 30 passengers each and may come with headways lower than 30 seconds. This combination of large cabins and low headways can provide capacities in excess of 5,000 pphpd.

Much as the size, complexity, cost and maintenance increase from monocable to bicable, tricable gondolas are substantially larger, more complex and more maintenance intensive than are bicable gondolas. In broad terms, tricable gondolas should be expected to be 2-3 times as capital intensive as are monocable gondolas. Nevertheless, many of the North American aerial transit proposals focus on tricable gondolas due to their high capacity, large cabins and low cost relative to traditional transit solutions.

Direct Alignment

Two different alignments were reviewed to reach Highpointe from across Lake Hartwell. The first is a direct route across the lake, as shown in Figure 5-17. In such an alignment, the water crossing between the Madren Center and Highpointe is roughly 2,500-3,000', depending on the exact location of the crossing. There are three primary alternatives to achieve such a crossing: (1) place multiple towers of conventional height within Lake Hartwell to support the gondola, (2) place tall towers near the shore but within the lake, and (3) span the entire distance across the lake with two large towers placed on the respective banks of the lake.

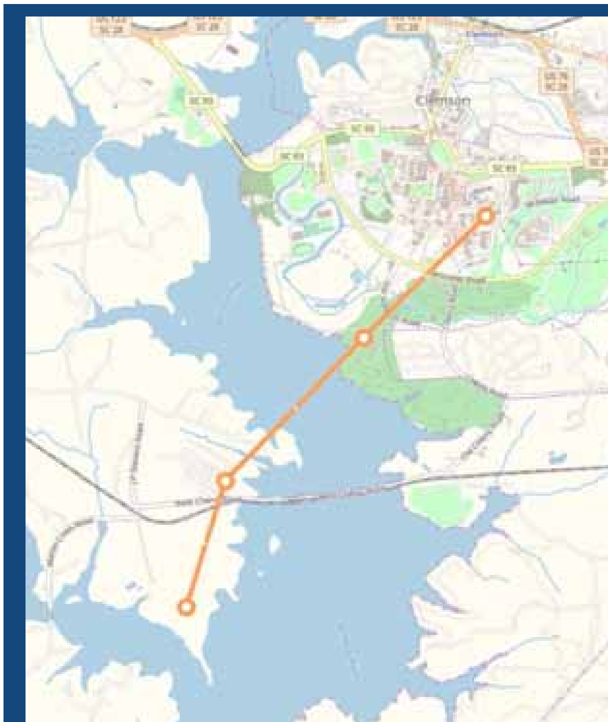

Figure 5-17. Gondola Direct Alignment

At the conceptual level, placing many towers within Lake Hartwell is considered undesirable and potentially not permissible. The spacing between towers is flexible and can be related to their height, but reasonable solutions would have monocable towers at spacing of a few hundred feet. To provide 30' of clearance below the cabins to the lake surface, the towers would need to be roughly 70 feet to the rope support height. Such a solution would require 7-10 towers within the lake and is considered the least desirable solution.

The second option, placing a single large tower a few hundred feet into the lake near each end of the crossing, reduces the disturbance within the lake. Placing these towers somewhat into the lake reduces the open span length to around 1800'. Due to the length of the crossing, these towers would need to be on the order of 160-180 feet in height to accommodate the rope sag and maintain clearance above the water.

The final option of the direct route would use even taller towers on the banks of the lake to span the entire length of the water crossing. This may not be technically possible with a monocable system and would certainly result in tower heights greater than those for the second option described above.

Considering the large water crossing across Lake Hartwell and the presumed difficulty – public, permitting and construction – of placing many towers across an otherwise-unobstructed portion of the lake, at this high level of evaluation it is suggested that a tricable gondola would be the best solution for a direct crossing. This results primarily from the ability of tricable systems to better manage large spans and thereby reduce the number of towers needed. If it is believed that placing multiple towers across this portion of the lake would not be a significant implementation issue, a monocable direct solution could be considered and may provide a more economical solution.

For the contemplated tricable direct system, towers near the water's edge or slightly into the lake would be on the order of 170-200 feet in height. For the conceptual analysis, cabins with capacity of 32 passengers at headways of 30 seconds were assumed, resulting in a system capacity of 3,840 pphpd. The system could be installed with a lower initial capacity and it could be designed for capacities in excess of 5,000 pphpd. Figure 5-18 shows the resulting trip times within the immediate area including walking. Notably, the Pier can reach Hendrix Center within 11 minutes. While much of the campus area is accessible to the Pier in just over 20 minutes, the smaller number of stations (as compared to an ATN solution) reduces the area accessed for any given walk shed time.

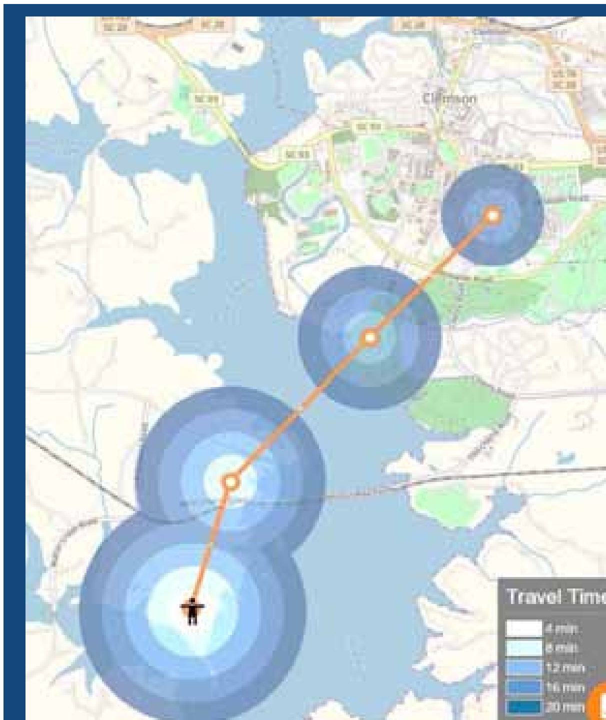

Figure 5-18. Gondola Direct Route Travel Times from the Pier

The system involves just under 3 miles of ropeway and has 4 stations. In very rough approximations, this tricable direct route solution could be expected to cost $130 M and might have operating costs of roughly $6 M annually. These approximate capital and operating costs are based on a number of factors including recent relevant ropeway projects completed, operating transit ropeways, relevant urban ropeway proposals for which cost figures are available and gross industry per-unit (mile or hour) cost approximations.

Indirect Alignment

The second alignment investigated is one which parallels the existing crossing of W Cherry Road, as shown in Figure 5-19. In this scenario, the gondola alignment passes along W Cherry Road, has a stop near Highpointe and continues on toward the Pier. While this alignment is less direct and requires an additional station, it eliminates the issues with the long water crossing. Tower placement across the water would be near the existing roadbed depending on the exact alignment chosen.

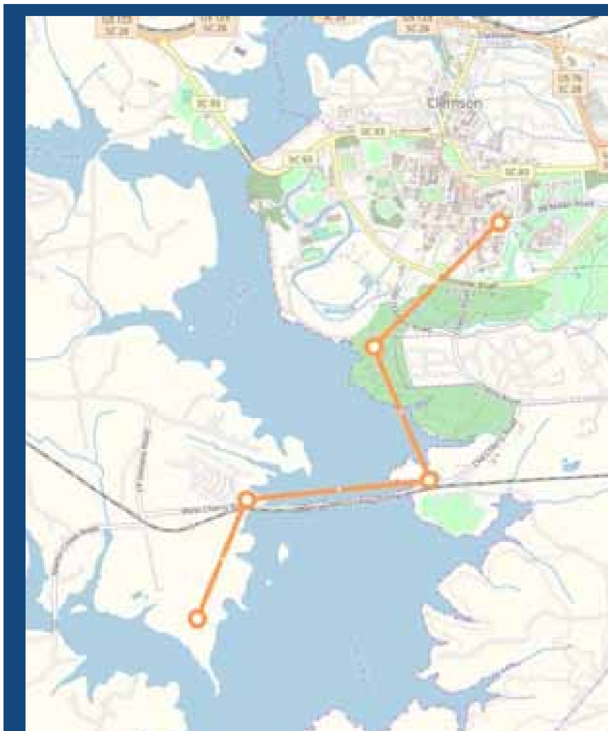

Figure 5-19. Gondola Indirect Alignment

Considering the economics of monocable systems over other gondolas, and the assumption that roughly 3,000 pphpd is adequate capacity, it is suggested that a monocable gondola is the best fit for an indirect alignment. Such a system would involve 5 stations across roughly 3.5 miles of ropeway. The additional station results from aligning the ropeway with W. Cherry Road for the lake crossing. Towers would generally be on the order of 70 feet in height every few hundred feet. Larger towers would be used where there are significant obstacles or needs for longer spans; towers approaching 150' in height could easily be used where needed. For the analysis, 10-passenger cabins with 12 second headways were assumed, resulting in a system capacity of 3,000 pphpd. Higher capacities are possible. Figure 5-20 shows the resulting trip times within the transit area. As compared to the direct alignment, travel times are slightly longer, reflected by the reduced areas accessible for any fixed time. Generally, however, much of the campus area is accessible in slightly more than 20 minutes from the Pier.

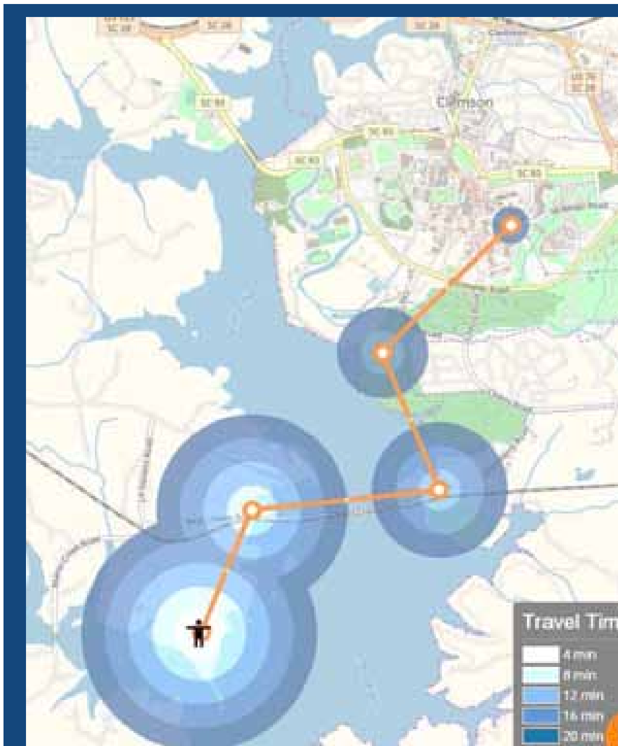

Figure 5-20. Gondola Indirect Alignment Travel Times from the Pier

Such a system could be expected to cost roughly $45 M to build with an annual operating cost of $5 M.

5.13.3.3 ATN- Gondola comparison

Table 5-4. Gondola and ATN Comparison of Alternatives.

Attribute	ATN	Gondola Direct	Gondola Indirect
Number of Stations	4	4	5
The Pier to Campus (mins)	8	11	17
Capacity	5,000 – 15,000	3,500 – 5,000	3,000 – 4,000
Capital Cost	$119 M	$130 M	$45 M
Annual Operating Cost	$5 M	$6 M	$5 M
Network Connectivity	Good	Poor	Poor

5.13.4 Combined solutions

As stated previously, transit solutions work best when they cover large areas with no need for transfers. Combining the above ATN solutions provides greatly improved mobility and accessibility. Figure 5-21 shows that almost all stations can be reached in 20 minutes from Downtown and the entire area shaded dark blue can be reached by riding and walking in thirty minutes.

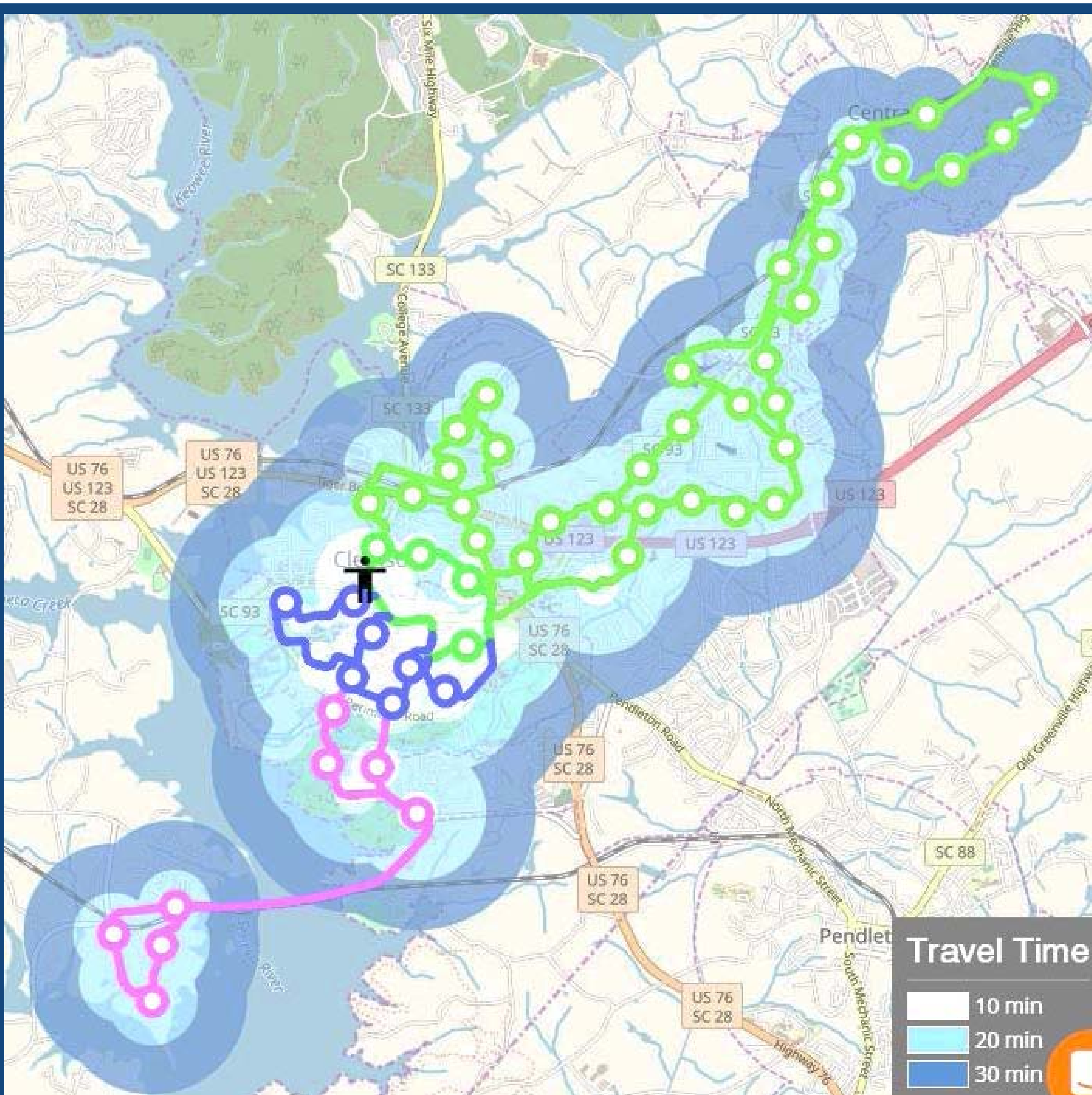

Figure 5-21. ATN Travel Times from Downtown Clemson

6. GREENVILLE/MAULDIN

6.1 INTRODUCTION

This analysis has many similarities to the one discussed previously for Clemson. Since it is likely that many readers will be interested in one or the other, and not both, there is quite a fair amount of repetition of the Clemson analysis here. However, the situation, and thus, the results, is quite different.

As for the Clemson study, this work focuses on one area (the City of Greenville) and then discusses the possible inclusion of Mauldin.

6.2 BACKGROUND

Greenville is a progressive City with a beautiful downtown area. It has a population of about 68,000 and an area of 28.8 square miles with a relatively low population density of 2,368 per square mile. Condé Nast Traveler's "Best Small Cities in the U.S." ranked Greenville 3rd in 2017. It was the fourth fastest-growing city in the United States between 2015 and 2016, according to the U.S. Census Bureau.

Greenville has studied ATN previously but has mostly focused on relatively small applications. The impetus for this study grew from some very conceptual work that indicated that a fairly large deployment would likely be more viable. Viability depends mostly on fare-box revenues and this analysis is focused on determining what those revenues are likely to be and whether they will be sufficient to pay for the operating and maintenance costs with enough left over to pay off all, or some, of the capital costs.

6.3 POTENTIAL ATN LAYOUT & OPERATING CHARACTERISTICS

Key considerations in developing an ATN alternative for Greenville include:

1. ATN is likely to be more cost-effective with a larger layout rather than a smaller one
2. A system comprised of interconnected one-way loops can approximately double the service area while only increasing costs by about 20% over a two-way corridor-type alignment.
3. Frequent offline stations will have only a small impact on costs while boosting ridership and not slowing through traffic
4. Routes should follow existing road rights-of-way wherever possible
5. Including Mauldin in the detailed analysis would make it far more complex
6. Stations should be located such that the service area within one half mile of a station covers most of the City of Greenville.

With these considerations in mind, the layout depicted in Figure 6-1 was developed. It has 75 miles of one-way guideway and 141 stations.

The ATN system will have an average wait time of around one minute (three minutes during peak periods) and travel times averaging 15 minutes compared to 11 minutes for the same trip by car.

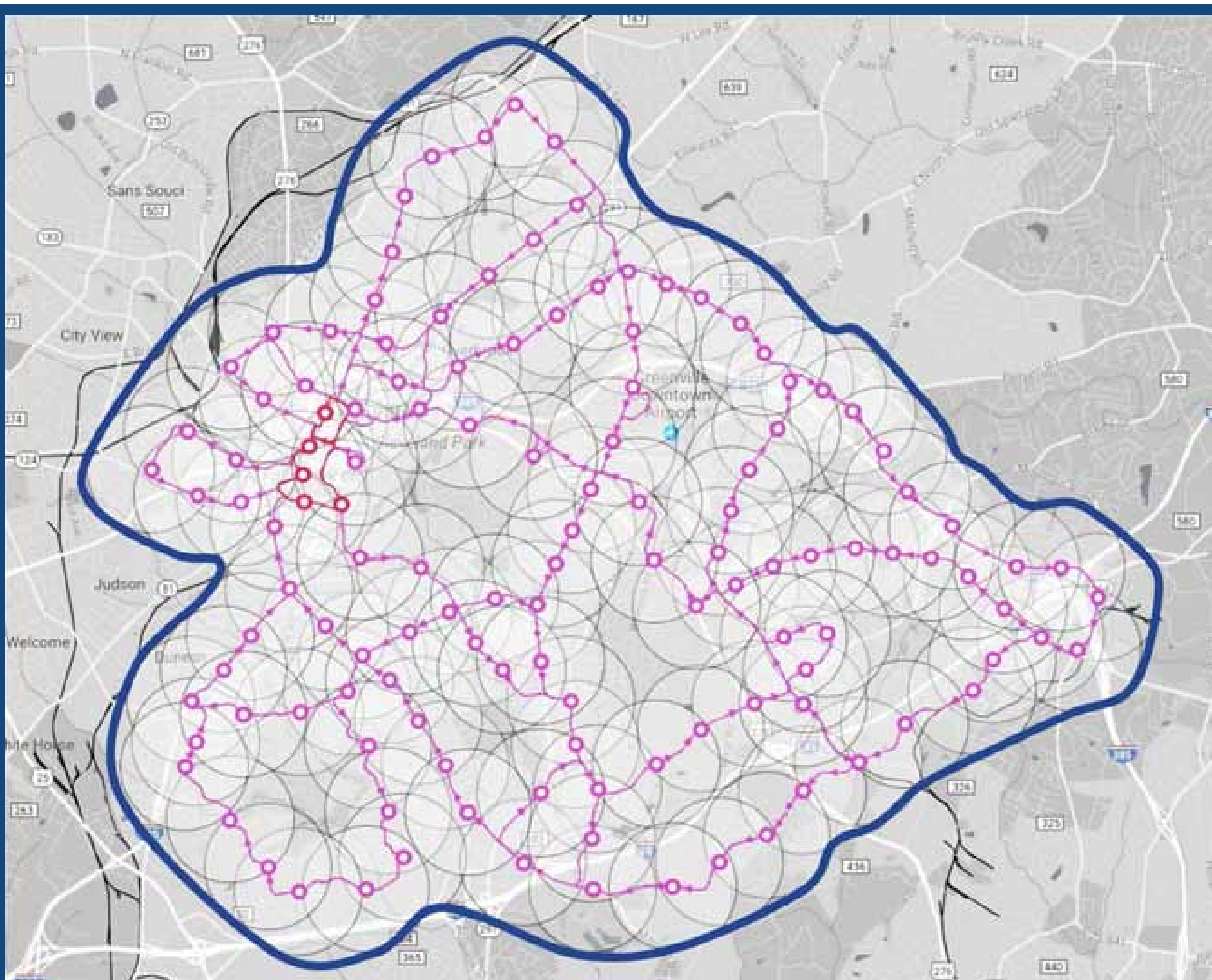

Figure 6-1. Greenville ATN Alternative Showing the Service Area Within One-Half Mile.

6.4 METHODOLOGY TO DETERMINE ATN RIDERSHIP

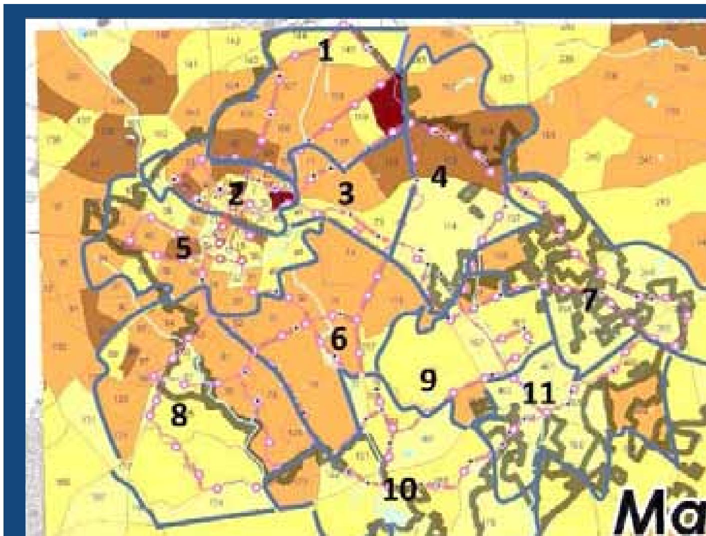

Figure 6-2. Greenville TAZs and Zones 1 - 11

The ½-mile service area covered by the Greenville ATN system includes far too many TAZs to be analyzed with the methods available for this study. The impacted TAZs were therefore consolidated into 11 zones (as depicted in Figure 6-2) and the vehicle trips between each TAZ pair were consolidated into trips between each of the 121 zone pairs. These trips were then factored up to person trips using an average vehicle occupancy of 1.5. In order to apply the car-based Logit model discussed under the Clemson section, the following analysis of car and ATN trip times was undertaken.

6.4.1 Car

Google Maps was used to determine the average trip times between the centroids of the zones. To include an allowance for congestion that is representative without reflecting the worst case, trips were assumed to take place at 10:00 AM on a Thursday. Within-zone trips were assumed to cover roughly 2/3rds of the zone length at 25 mph.

A walking/waiting time allowance of three minutes was used.

The perceived cost of an automobile trip is often less than the actual total cost of the trip because drivers discount the cost of ownership, insurance and perhaps even repairs. For this study we have assumed the perceived cost to be $0.10 per mile (the cost of gas at 30 mpg and $3.00 per gallon) plus $1.00 for parking.

6.4.2 ATN

ATN trip times to and from the station closest to the zone centroid were based on a top speed of 35 mph with average speeds constrained by geometry as determined using Podaris software.

The average waiting time for PRT has been assumed to be one minute which is considered fairly conservative for PRT. A maximum walking distance of ½ mile has been assumed, resulting in an average walking time of 5 minutes at each end of the trip.

The monetary cost of PRT trips was assumed to average $3.50 per person trip.

6.5 TRIP DEMAND

The resulting ATN passenger trip demand matrix by Zone is shown in Table 6-1. These trips represent a 32% mode split to ATN. For ATN simulation purposes, the demand matrix was then converted to a station-based matrix by converting Zonal trips to stations serving the Zone on a uniform basis.

Table 6-1. ATN Daily Person Trip Demand by Zone

ZONE	1	2	3	4	5	6	7	8	9	10	11	Total
1	195	446	222	640	784	268	348	334	85	65	67	**3,454**
2	262	584	416	842	2,247	604	507	889	247	143	119	**6,858**
3	169	369	336	841	462	474	383	250	125	88	85	**3,581**
4	583	868	759	5,019	1,175	1,603	2,305	822	993	348	423	**14,897**
5	730	2,246	320	1,152	5,238	1,190	689	2,740	326	319	171	**15,121**
6	249	638	334	1,266	1,263	2,299	670	1,436	544	367	184	**9,248**
7	273	481	308	2,035	645	727	7,503	464	1,245	544	1,279	**15,503**
8	348	916	260	771	2,647	1,086	470	7,554	312	406	165	**14,934**
9	83	200	133	912	332	689	1,297	342	1,204	363	468	**6,023**
10	69	180	97	420	406	530	457	632	426	1,118	247	**4,581**
11	70	146	83	496	205	280	1,181	229	598	396	2,001	**5,685**
Total	**3,031**	**7,073**	**3,267**	**14,393**	**15,403**	**9,749**	**15,810**	**15,691**	**6,104**	**4,156**	**5,208**	**99,885**

6.5.1 Peak hour and annual trips

The ATN average weekday trips were then factored to peak hour and annual trips. Rather than use the Clemson peak hour factor of 0.077, or the commonly used factor of 0.10, a more conservative 0.12 factor was assumed. In order to determine the annual ridership, it was assumed that the average weekday ridership applied to 52 x 5 weekdays and that half that ridership applied to each weekend day (52 x 2 x ½).

6.5.2 Fare sensitivity analysis

Increasing the fare increases the revenues until sufficient riders are discouraged by the high fares that the revenues start to decline. Figure 6-3 shows this relationship. While the revenue peaks at around $10 per ride, this is at the expense of a significant number of riders. If it is decided to charge a fare, it should probably be in the range of $ 2 to $ 5 per ride. A fare of $3.50 per ride has been assumed in this study.

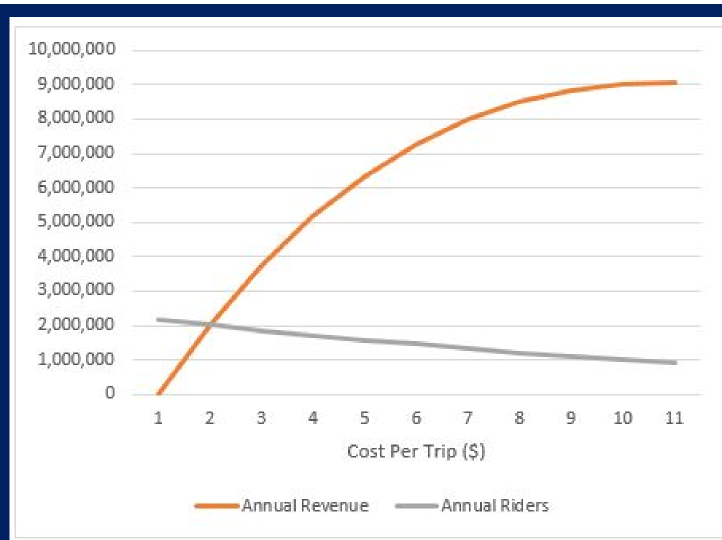

Figure 6-3. Relationship between fare per trip, ridership and annual revenue.

Assuming that the average fare is $3.50 per ride results in about a 20% loss in ridership compared to a fully-subsidized fare of $0.00. If some of the fare was recovered by, for example, including it in tuition or lodging costs and the remainder was subsidized by local, state and/or federal governments, the perceived cost per ride would approach zero and most of the 20% loss in ridership could be recovered. This would effectively lower the cost per rider and render the system even more cost effective. Thus, the assumption of $3.50 per ride is a conservative one.

6.6 SIMULATION RESULTS

The ATN network was simulated to determine the number of vehicles needed to provide satisfactory service during the peak hour (12% of the daily trips were assumed to travel in the peak hour).

PRTsim, the simulator used, was developed in the 1990s specifically to generically (i.e. in a way not constrained by the requirements of any one PRT system) simulate PRT systems. It has been used to simulate well over thirty PRT networks around the world. A summary of the findings is presented below.

6.6.1 Simulation results

6.6.1.1 Parameters

Peak hour person trips simulated	11,652
Guideway miles	75

Stations	141
Vehicles	1,610
Minimum headway (seconds)	1
Average speed (mph)	27
Maximum wait for ride share matching (mins)	5
Maximum acceptable intermediate stops	2
Maximum acceptable detour for pickup (percent)	20
Study period (mins)	60

6.6.1.2 Results

Average wait time (mins)	2.9
Percent waiting less than 7 minutes	95
Average ride time (mins)	17.6
Average passenger delay (mins)	0.0
Average trip length (miles)	7.0
Average speed (mph)	24
Percent of empty departures	7
Percent of departures with one passenger	39
Percent of departures with two passengers	26
Percent of departures with three passengers	14
Percent of departures with four passengers	8
Percent of departures with five passengers	4
Percent of departures with six passengers	2
Passengers carried per vehicle hour	6.5
Maximum percent of link capacity used	60
Vehicle miles empty	16,001
Vehicle miles with passengers	30,361
Passenger miles	71,447
Passenger miles/vehicle miles (average occupancy)	1.51

Note that the average vehicle occupancy of 1.51 is 36% higher than found at Clemson – an indication of the more efficient layout at Greenville.

The total daily vehicle and passenger miles traveled were determined to be 386,350 and 595,392 respectively.

It should be noted that this simulation assumed a minimum headway (time between vehicles) of one second as opposed to the three seconds used on the Clemson simulation. While no PRT system is yet operating at such short headways, changes to the ASCE Automated People Mover Standards currently in process will theoretically allow such short headways and suppliers are known to be developing controls systems capable of achieving them. To put this in context, anyone who has ever driven on a freeway has probably experienced one half second headways at 60 mph.

The simulation showed that 60% of the key link's capacity was used. By 2052 this will be approaching 100%. This means that a small part of the system will be at its limits of capacity and a few extra miles of guideway may need to be added or other capacity-enhancing measures taken.

6.7 ESTIMATED CAPITAL, OPERATING AND MAINTENANCE COSTS AND FARE-BOX REVENUES

6.7.1 Unit prices

The ATN industry is still emerging and unit prices have not yet stabilized. Widespread unit price information is not publicly-available. Costs for most installed systems are available but it is often not clear exactly which parts of the systems they cover. Recent large procurements are indicating that costs are coming down significantly. Newly emerging suppliers are claiming very low costs but have not yet proven them in practice. Four sources of unit prices were considered for this project:

1. Unit prices from the bids received at the Greenville – Spartanburg International Airport (GSP)
    a. The GSP project was far smaller than this one and the prices are therefore likely to be on the high side
2. Unit prices from bids in the East and Middle East
    a. While the total prices are publicly known, the unit prices are confidential and cannot be published in this report
    b. These prices have been adjusted to reflect the US market
3. Operating and maintenance costs from the Morgantown PRT system[11]
4. Estimated system costs from emerging suppliers

The fourth source was not used. The first two sources were used for capital and operating costs and the results presented here represent an approximate average of unit prices from these sources. The third source was used for operating and maintenance (O&M) costs in place of the GSP O&M costs since the Morgantown system has a long history of carrying a significant number of passengers.

6.7.2 Costs and revenues

In order to estimate the life-cycle capital and operating costs it has been assumed that the system goes into public service January 1, 2022 and has a 30-year life. Growth projections are based on the GPATS Traffic Demand Model (TDM) which shows automobile trips for 2015 and 2040. The growth has been assumed to be straight line from 2015 to the end of 2052 at the same rate as the GPATS TDM from 2015 to 2040. Trip times, costs, revenues and mode splits have all been fixed at those used above which approximately reflect the 2015 to 2018 timeframe. In practice, the PRT system is likely to have increased ridership due to increased road congestion (which has been an ongoing trend).

The ATN system depicted in Figure 6.1 has 141 stations and 75 miles of elevated one-way track. Simulation indicates this system will require 1,796 GreenPods in order to meet the 2022 peak demand with spares. The capital cost of this system is estimated to be $1,281 M ($17 M per mile) and the annual operating and maintenance (O&M) costs are estimated to be $48.8 M. The annual revenue, based on an average fare of $3.50 per trip, is $118.5 M. Thus, the fare-box recovery ratio is 2.43. It should be noted that a ratio above 1.0, where the fares more than cover the O&M costs, is almost unheard of in the US.

[11] PRT Facilities Master Plan, Gannett Fleming, June, 2010

The O&M cost per trip of $1.23 is 36% lower than the CATbus Red Route O&M cost per trip of $1.92. This seems reasonable since the automated system requires relatively fewer personnel.

If the capital costs were to be amortized over 30 years at a 5.0% interest rate, the annualized capital cost would be $82.5 M. Added to the annual O&M cost of 48.7 M, this results in total annual costs of $131.2 M which results in an initial annual shortfall of $12.7 M.

In order for the system to break even over its thirty-year life, the fare needs to be raised to $3.70 or other means of income need to be added.

6.8 BENEFITS

Since the community may decide on an average fare less than the $3.70 per ride needed to break even, we need to examine the benefits to see if they outweigh the costs. We will focus on the quantifiable and/or monetizable benefits first. These include congestion relief, increased mobility and real estate value uplift.

6.8.1 Estimated congestion relief

According to the GPATS TDM (assuming straight line growth), there will be 227,486 daily automobile trips in 2022 that start and end within the ATN one-half mile service area. This number would be reduced by 72,340 by the implementation of the ATN system.

By 2052 the TDM indicates (by extrapolation) there will be 324,402 daily automobile trips (an annual growth rate of 1.19%). Assuming ATN the mode split remains the same (and it should increase if no capacity improvements are made), 103,159 daily car trips would be removed from city streets. This will leave 221,243 daily car trips which is 6,243 (2.7%) less than in 2020. In other words, The ATN system should keep Greenville congestion at, or below existing levels for over thirty years.

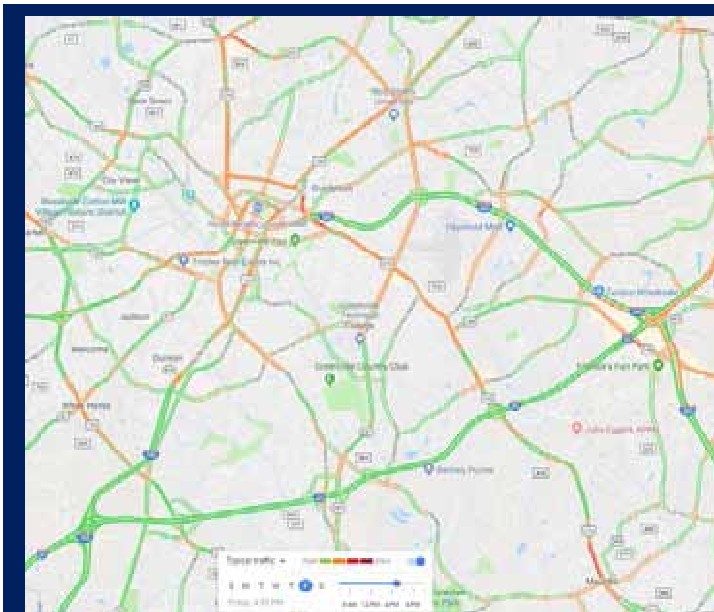

Figure 6-4. Greenville congestion at 5:00 PM on a typical Friday

It should be noted that the reduction in traffic from these trips will be city-wide and there should thus not be much impact from traffic diverting from nearby roads onto city streets that are now relatively free of congestion unless, of course, the nearby routes become significantly congested.

Another way of looking at the congestion relief is to study the impact on a specific road. Laurens Road (Highway 276) stands out as one that is in the middle of the service area and is presently congested (see Figure 6-4). Interpolating from the TDM indicates it will carry 38,748 vehicles per day in 2022 with a capacity of 33,291, resulting in a V/C ratio of 1.16. In 2052, these numbers are expected to become 42,216 vehicles per day, 28,215 capacity and 1.50 V/C ratio. Clearly this road has both present and future capacity issues.

As a reasonably conservative way to estimate the trips the ATN system would remove from Laurens Road, the number of trips between Zones 9, 7 and 11 in the southeast and 2, 3, 5 and 6 (see Figure 6-2) in the northwest were determined. Most of these trips would probably use Laurens Road in the absence of an ATN solution. Trips between a number of other zone pairs would also probably use Laurens Road but the proportion is uncertain and they have been ignored. Adjusting for the average car occupancy of 1.5, we find 5,518 daily automobile trips will be removed in 2022 and 6,140 in 2052. This is sufficient to reduce the volume to below the capacity in 2022 but not 2052. However, there are probably many ATN trips that have been excluded from this rough analysis. An analysis at the TAZ level is likely to be able to find and quantify these trips.

6.8.2 Reduced road transportation facility requirements

6.8.2.1 Road widening and congestion mitigation projects

Since the ATN system could keep Greenville congestion levels at, or below, present levels for over thirty years, it should remove most needs for road widening and congestion mitigation projects during that time.

6.8.2.2 Road maintenance

The ATN system would obviate the need for buses within the service area. Buses could, of course, be re-allocated to provide feeder service from outlying areas. Removing buses will result in a noticeable reduction in road maintenance required. Road damage increases exponentially with size of vehicle, for example, one bus trip can do equivalent damage to up to 7,000 car trips. Furthermore, elevated structures have much longer (typically 50 years) design lives than at-grade pavements (typically 20 years). Transporting passengers in lightweight pods rather than heavy buses or even cars, will reduce infrastructure maintenance needs considerably.

6.8.2.3 Parking facilities

Each automobile needs approximately three to four parking spaces – one at home, one at work and one or more elsewhere. Removing automobiles from traffic will reduce the need for parking spaces (one surface stall costs around $5,000 while one parking deck stall costs around $25,000). This could free up prime real estate for redevelopment for higher purposes. It would also improve walkability among facilities.

6.8.3 Improved mobility/accessibility

The area within one-half mile of an ATN station will have significantly improved mobility and accessibility. The present Greenlink bus system serves a much wider area but the level of service is such as to only attract 1,076,667 annual passenger trips[12]. This represents approximately one percent of the annual car passenger trips within the city limits and is an indication of how difficult it is to provide good quality bus service in an area of relatively low density.

[12] Greenlink Comprehensive Operations Analysis, August, 2017

People with access to cars will experience reduced congestion. Those without access to cars (and only about 35% of the general population can drive/own a car) will have greatly improved mobility. They will be within half a mile of a station from which they can quickly and comfortably access any one of another one hundred and forty stations covering an urbanized area of over thirty-nine square miles. This will facilitate access to jobs, school, shopping, entertainment and health care. This improved mobility and accessibility will undoubtedly lead to an economic uplift that is difficult to quantify directly. However, there is substantial evidence of the impacts of fixed guideway transit on property values as discussed in the following section.

Figure 6-5 shows the travel times from Downtown Greenville on the ATN system. All stations can be reached in less than 31 minutes. The entire area within the dark blue outline can be reached in 40 minutes with a combination of riding and walking.

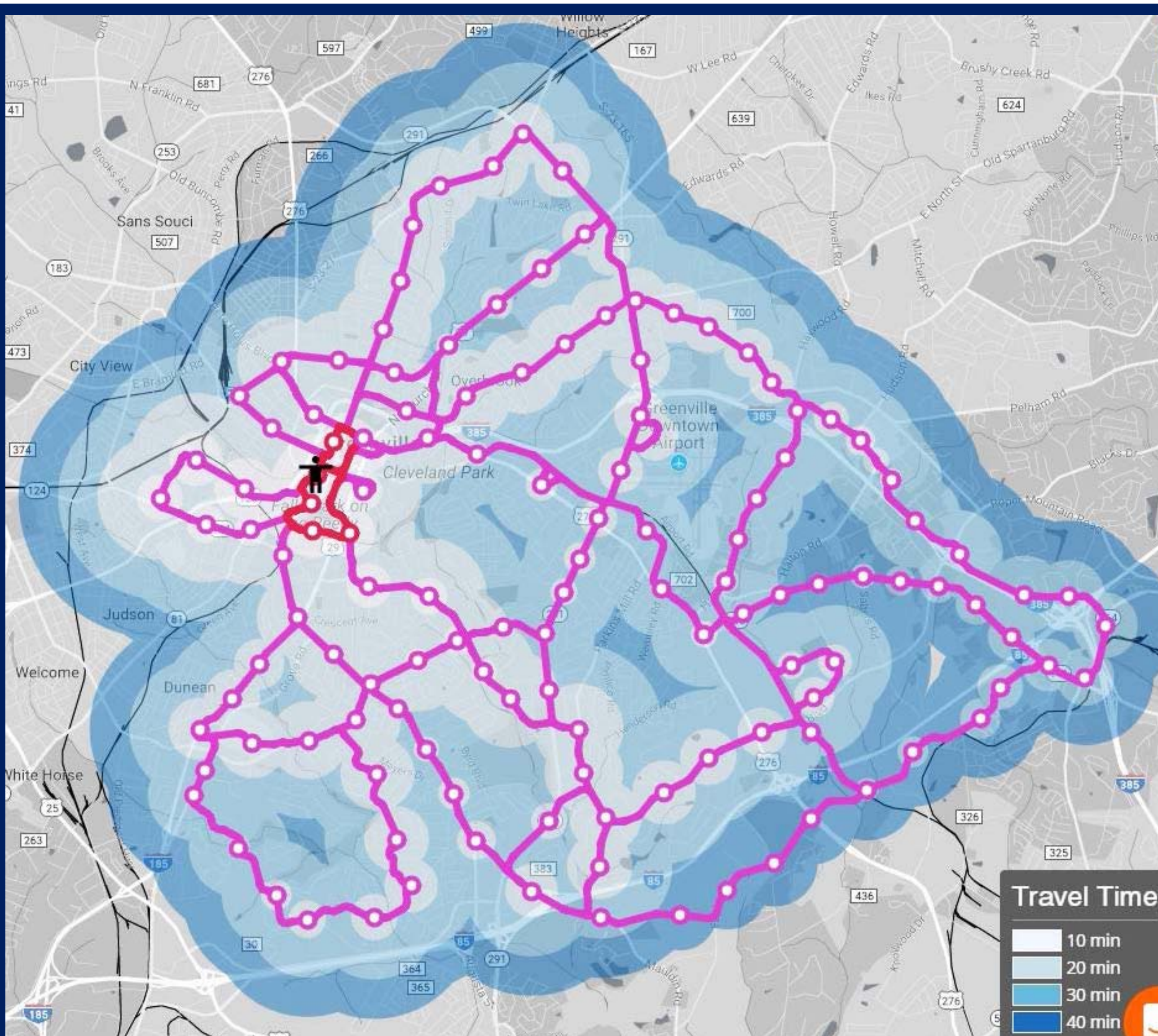

Figure 6-5. ATN Travel Times from Downtown Greenville

6.8.4 Real estate value uplift

There are many papers on the topic of real estate uplift caused by fixed-guideway transit. The one relied on here (TCRP Report 102[13]) is thought to be one of the most authentic. TCRP Report 102 found "…average housing value premiums associated with being near a station (usually expressed as being within ¼ to ½ mile of a station) are 6.4% in Philadelphia, 6.7% in Boston, 10.6% in Portland, 17% in San Diego, 20% in Chicago, 24% in Dallas and 45% in Santa Clara County." Similarly, the uplift for commercial properties ranged from 3.7% to 37%. The ATN system considered here has more stations, less waiting time and higher average speeds than most rail and light rail systems and the impacts could therefore be even higher. To quantify the potential results of these impacts, an uplift of ten percent in property values (residential and commercial combined) is examined below. Consideration of uplifts of twenty or thirty percent can be accomplished by simply multiplying the numbers below accordingly.

6.8.4.1 Ten percent uplift in property values

The total market value of all properties in the ½-mile service area is $11,057 M. An uplift of ten percent thus represents $1,106 M. This is 87% of the projected capital cost of the system. It has been suggested that if Multi-County Industrial Park (MCIP) agreements were used to monetize this uplift, increased property tax revenue could repay capital costs over time. These amounts should be considered by the community when deciding whether or not to invest in the ATN system.

The total value of residential property taxes for the ½-mile service area is $141.5 M. A ten percent uplift will therefore bring an additional amount of $14.1 M to community coffers annually. This amount is 29% of the projected annual O&M costs.

6.8.5 Other benefits

6.8.5.1 Economic uplift

As mentioned previously, the improved mobility and accessibility should result in economic uplift. The potential to collocate small commercial neighborhood businesses such as coffee shops, service and convenience stores with ATN stations should also help the economy. In addition, the fact that the stations, guideways and vehicles will be under 22/7 CCTV monitoring should create mostly crime-free zones around stations and along guideways – throughout the ½-mile service area. On a local level, crime has the following types of negative economic impact:

- business impact (crime reduces competitiveness of companies and investments)
- tourism impact
- impact on quality of life/social capital
- impact on property value

Crime adds up to an overall negative economic impact which could be significantly reduced.

While it seems clear that an ATN system will bring economic benefits, these are difficult to quantify and monetize (other than the uplift in property values and taxes).

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[13] Federal Transit Administration, TCRP Report 102, Transit-Oriented Development in the United States, 2004

6.8.5.2 Increased safety

ATN systems are extremely safe having completed over 200 million injury-free passenger miles. In this many miles cars would have killed three people and injured 190. To the extent people transfer to the ATN system, safety will be improved – not only for riders but for pedestrians also. While it is possible to quantify the community savings of this improved safety, it is difficult to monetize those savings.

6.8.5.3 Improved resiliency

ATN systems will typically keep operating in inclement weather except severe thunderstorms, wind speeds over 60 mph and severe ice storms. The Morgantown PRT system only shuts down in severe snow storms after all other systems have shut down and people can no longer reach the stations. Once shut down, the infrastructure will withstand the worst weather conditions required by code. Being mostly elevated, the infrastructure will be very resilient to flooding. Typically, power sources will be redundant and can include back-up generators. If the system includes solar generation and battery-powered vehicles, this offers another level of immunity from power failures.

6.8.5.4 Higher sustainability

The ATN system will be far more sustainable than the existing road/automobile system. It will use about one third the energy per passenger mile and the vehicles will be electrically powered (probably using on-board batteries). The potential to incorporate solar panels into stations and guideways is good.

Space needed is minimal and consists of a slender column every sixty to one hundred feet and a small station every quarter to half a mile. Stations can be elevated and served by stairs and elevators or they can be at, or close to, grade.

Noise, vibrations and electro-magnetic interference are all substantially less than for conventional transit.

Visual intrusion of overhead guideways is seen as a problem by some. However, the clear majority of those questioned found this to be outweighed by the transportation benefits provided. Some see small vehicles gliding silently overhead as an appealing art form.

The system should last more than fifty years. The Morgantown PRT system in West Virginia had a design life of twenty-five years. It is still in public service, using upgraded control technology with the original (refurbished) vehicles and infrastructure, after forty-three years.

6.9 NEGATIVE FACTORS

Every transportation mode has negative factors. Cars get caught in traffic, pollute and kill tens of thousands of people in the US every year. Light rail is expensive, and stations are typically a mile or more apart. Streetcars are slow. Buses stop frequently, require transfers and the time between buses can be long. Bicycles don’t work well in bad weather or on steep terrain. Walking is becoming more dangerous and roads and rail lines can be difficult to get across.

ATN typically requires elevated guideways which are seen by some as visual pollution. In addition, these guideways may require trimming or removal of trees. Passengers traveling on elevated guideways may be able to see down into areas previously considered private. Stations take up space and require fixed infrastructure. Guideways and stations are relatively permanent infrastructure that is difficult to move.

While there are positive aspects to some of these issues and mitigation measures can be taken, in the end the community must decide if the benefits outweigh the costs, including the negative factors.

6.10 FEASIBILITY

While this system is significantly larger than commercially-available ATN systems presently in public service, they were all designed to be scaled up and this system is clearly constructible. Systems of this size are presently under procurement/development in the East and Middle East. Issues with rights-of-way and existing utilities, while not addressed here, are not expected to be unduly problematic.

This study indicates this system has the potential financial viability to pay for its own operating and capital costs. This makes it remarkably feasible and helps remove some of the hurdles to implementation.

While this system is unique, the existing system it most closely resembles is light rail. A comparison with light rail projects currently being considered for funding by the Federal Transit Administration (FTA) is therefore appropriate. Those projects are shown in Table 6-2 below.

Table 6-2. Light Rail Projects Listed by FTA for Potential Funding

State	City	Project	Status[1]	Technology[2]	Miles	Stations	Costs (US$ M)			Daily Trips	Annual Trips (M)
							Capital	Local	Ann O&M		
AZ	Phoenix	NW Ext PH II	NSPD	LRT	1.5	3	319	162	2.99	6,400	2.12
AZ	Phoenix	South Central Extensi	NSPD	LRT	4.8	7	704	359	17.75	8,700	2.86
MN	Minneap	METRO Blue Line exte	NSE	LRT	13.5	11	1,563	784	27.50	16,500	5.49
MN	Minneap	Southwest LRT	NSE	LRT	14.5	15	1,857	928	29.40	18,900	6.29
NC	Durham	Durham-Orange LRT	NSE	LRT	17.8	18	2,476	1,238	28.73	14,400	4.05
WA	Seattle	Federal Way Link Ext	NSPD	LRT	7.8	3	2,165	1,665	20.23	22,200	7.09
WA	Seattle	Lynnwood Link Exten	NSE	LRT	8.5	4	3,069	1,897	23.46	44,500	14.33
WA	Tacoma	Tacoma Link Extensio	SSPD	LRT	2.4	6	215	175	6.27	4,000	1.18
LRT Totals					**70.8**	**67**	**12,368**	**7,208**	**156.33**	**135,600**	**43.41**

1. NS = New Starts; SS = Small Starts; PD = Project Development; E = Engineering. NSE = bigger and more advanced than SSPD
2. LRT - Light Rail Transit

These projects average $18.35 capital amortization cost and $3.60 operating cost per trip in contrast to the ATN costs of $2.44 and $1.44 respectively. On this basis, this project is not only feasible, but should compete very well with light rail projects for federal funding.

6.11 PHASING

The problem with phasing is that this project is just large enough to be self-funding. Its financial viability will decrease if it is made any smaller and a small initial phase has almost no chance of being financially self-supporting. Nonetheless, an initial implementation could play a vital role in getting community support for a very large project and helping to prove the ridership model. For these purposes, the initial project must be large enough to perform a real transportation purpose and bring tangible community benefits

Even if the initial phase cannot be financially self-supporting, it can perform a vital role that would justify initial community subsidy. One portion of the ATN network that seems capable of meeting the needs of an initial deployment is the downtown loop. This loop (it is actually two interconnected loops) has thirteen stations and four miles of one-way guideway. Capital costs would be approximately $70 M. Figure 6-6 shows the travel times from the University Ridge Station on the ATN system. All stations can be reached in less than 5 minutes. The entire area within the dark blue outline can be reached in 8 minutes with a combination of riding and walking.

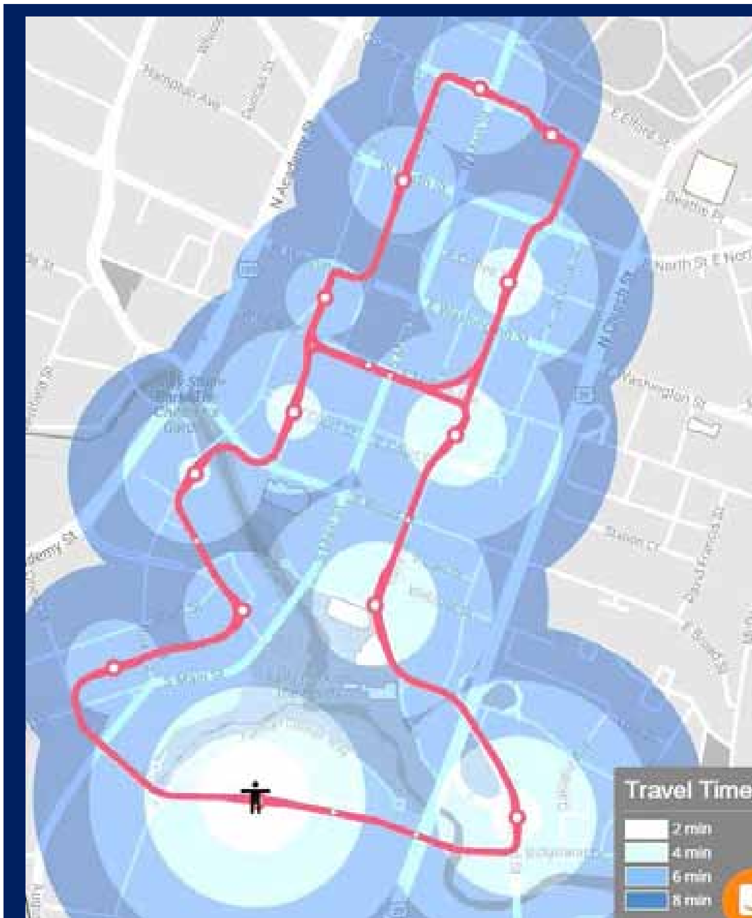

Figure 6-6. ATN Travel Times from University Ridge Station

This downtown loop would allow people to quickly get around the downtown area without using a car. This will reduce both congestion and parking needs. It would give workers more options for parking and more choices at lunch time. The improved accessibility of a fixed guideway system has many economic benefits as discussed previously. The stations are typically less than a quarter mile apart and quickly accessible by walking. A-Taxis/Shuttles could supplement the system providing access for those with limited walking abilities. The potential exists for Main Street to become a pedestrian mall open only to pedestrians and A-Taxis/Shuttles (see Figure 6-7).

Figure 6-7. A Pedestrian Mall Open Only to Pedestrians and A-Taxis/Shuttles

6.12 CONCLUSIONS AND RECOMMENDATIONS

The above results indicate Greenville could have a new, highly effective, transit system that would greatly improve mobility, accessibility and economic prosperity for little or no cost. All the community has to do is confirm that the opportunity is real and, if it so decides, take the necessary steps to implement it in a prudent way. There are some risks involved but it is believed they can be managed in a way that mitigates the risks to a reasonable level.

The potential benefits of the Greenville ATN system are very significant and appear to far outweigh the relatively small amount of funding and risk that could be involved in investigating them further.

6.13 IMPLEMENTATION STEPS

This study has highlighted an alternative to the Greenlink bus service that appears feasible and capable of attracting more than thirty times the ridership, which should in turn alleviate congestion, increase property values and taxes and bring general social and economic advantages. The entire 39 square mile ATN service area will have better transit than most transit-oriented developments.

This study estimates that a Greenville city-wide ATN system will approximately pay for its own operating and capital costs through fare-box revenues. However, the actual costs and revenues will not be known until the system is implemented. One way forward would be to make this report available to suppliers and let them come forward with proposals to build and operate the system. The problem is that it is very unlikely any supplier will be able to raise the necessary financing based on estimates of revenue for a new mode of transportation. Investors will require minimum revenues be guaranteed by the community. Before the community can be comfortable guaranteeing minimum revenues, the following steps (at a minimum) are thought to be necessary

1. Decide if an ATN system is wanted if it will pay for itself
2. Verify the results presented here by undertaking a detailed planning study that includes the following tasks:
    - Community outreach
    - Optimization of station locations and guideway routing
        - Analysis of alternatives (including expansions into adjoining neighborhoods)
    - Station alternatives (elevated/at-grade)
    - Phasing alternatives
    - Permitting requirements
    - Right-of-way needs
    - Utility relocations
    - Maintenance/storage/control facility requirements and location
    - Detailed ridership determination using/adapting the GPATS TDM
    - Cost/revenue study
    - Funding/financing/revenue alternatives and requirements
    - System ownership and governance
    - Procurement alternatives
3. Undertake a risk analysis to project possible revenue shortfalls
4. Identify sufficient revenue sources to cover possible shortfalls
5. Solicit proposals for phased implementation. Strive for an agreement where the supplier designs, builds, finances, maintains and operates the system and the community guarantees minimum revenues up to the amount of funding identified in item 4 above.

Phase I will be used to verify that everything works (particularly the ridership/revenue model). It will therefore need to be big enough to meet a real need. However, it must be understood that it will almost certainly not be able to pay for itself out of fare-box revenues. It will therefore need other revenue sources and/or subsidies until Phase II is built.

a. Phase I
   i. Use the ridership/revenue model to predict ridership and revenue for Phase I
   ii. Implement Phase I
   iii. Measure actual ridership and revenue
   iv. Calibrate the ridership/revenue model
   v. Use the calibrated model to predict ridership/revenue for Phase II
   vi. Go/no-go decision
b. Go
   i. Implement Phase II
c. No go
   i. Continue operating Phase I

It seems possible that the community can raise the capital to build this project without federal assistance. Even if federal assistance is obtained, it will usually only cover 50% of the capital cost or less. If federal funding is used, it will impose additional requirements on the project which will likely include requirements for the previously-mentioned study.

An early step needs to lead to a decision as to how the project is to be funded and whether or not federal funding is to be used. An analysis of the impacts of accepting federal funding may be wise. It would be good to know how requirements such as Buy America may impact the suppliers who can bid, the prices to be paid and the project schedule.

It may be possible to involve federal funding in the early stages such as for the initial study and perhaps even for Phase I. Then the bulk for the project could be completed using private funding/financing only.

6.14 OTHER ADVANCED TRANSIT OPPORTUNITIES

6.14.1 Introduction

The City of Greenville was deliberately chosen for this analysis of an ATN alternative because:

- It has a contiguous area of relatively high density
- It has poor bus service
- It serves a defined area with known populations and automobile travel characteristics

There are a number of areas adjacent to the city limits into which the ATN deployment could probably be expanded with beneficial results. Expansion into Mauldin is briefly examined here.

6.14.2 City of Mauldin

The City of Mauldin is located just southeast of the City of Greenville. It had a population of 25,135 in 2015. The City has a total area of 10.0 square miles and the population density is 2,513 people per square mile – very similar to that of Greenville. For this reason, extending the Greenville ATN layout into Mauldin will likely improve the overall viability of the system. This is because, all things being equal, an area with similar population density should generate a similar proportion of ATN trips. But all things would

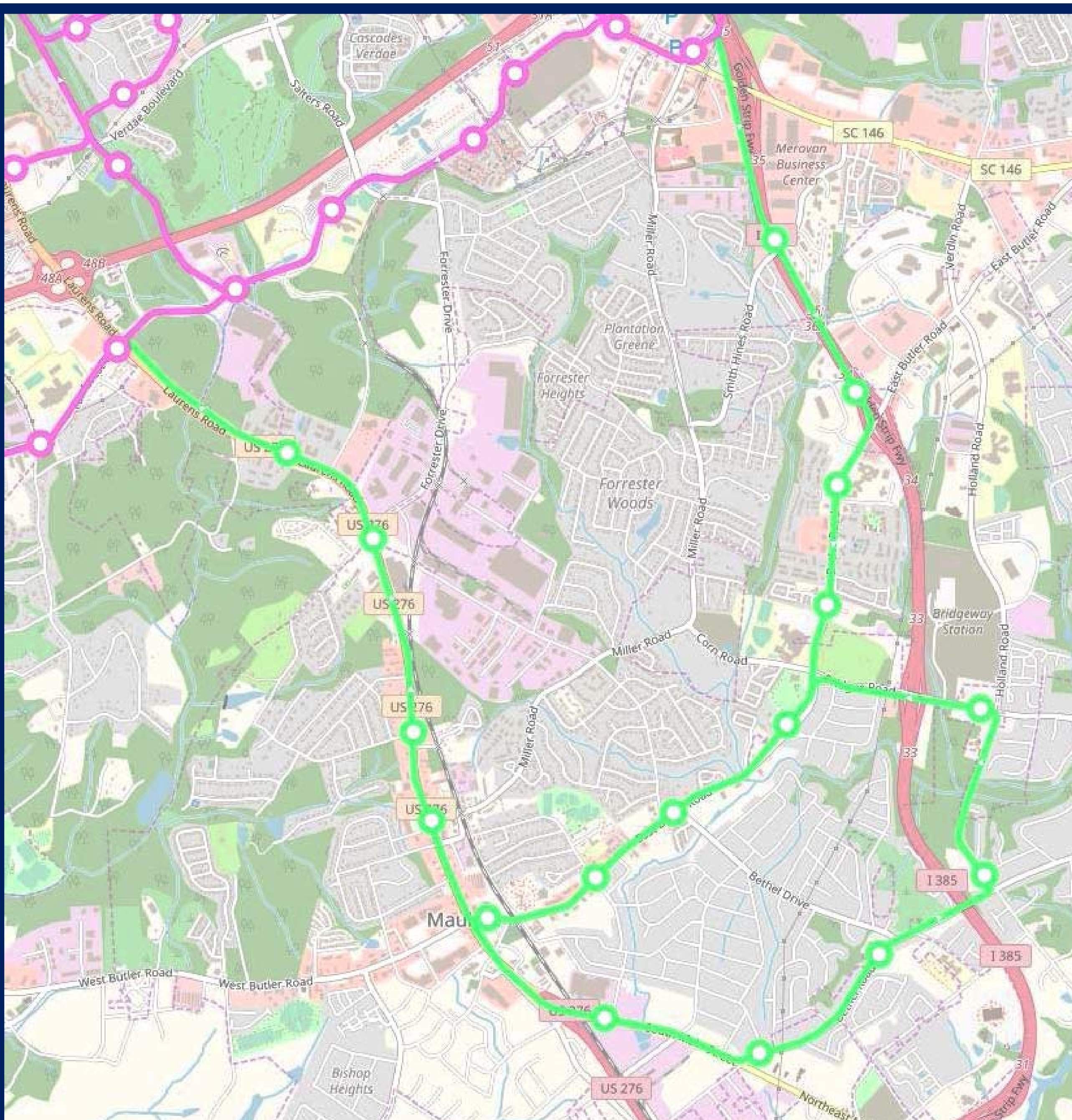

Figure 6-8. City of Mauldin ATN Layout

not be equal since adding Mauldin would increase the number of stations in the system, rendering it more useful and attractive to riders.

A conceptual Mauldin ATN extension is shown in Figure 6-8. It has 11.9 miles of guideway and 17 stations. Estimated capital costs are $200 M.

Figure 6-9 shows the travel times from the City of Mauldin City Hall on the ATN system. All stations can be reached in less than 38 minutes. The entire area within the dark blue outline can be reached in 40 minutes with a combination of riding and walking.

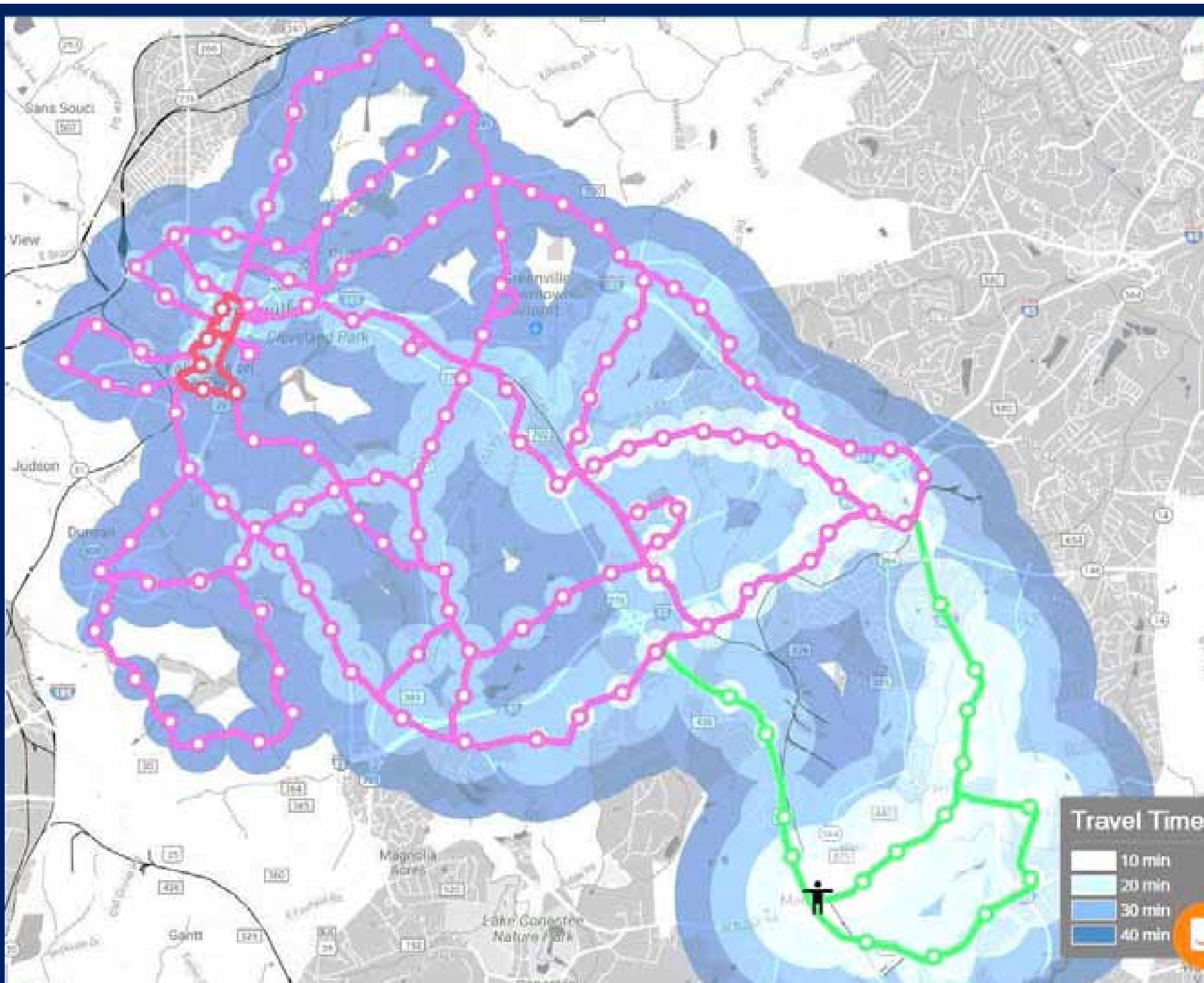

Figure 6-9._ATN Travel Times from City of Mauldin City Hall

7. FUNDING/FINANCING OPPORTUNITIES

Since fare-box revenues will cover the operating costs but probably not all of the capital costs plus contingencies of either the Clemson or Greenville projects, other sources will need to be found to ensure financial stability unless costs turn out to be less than projected. Some potential sources are briefly discussed here but will need more detailed evaluation.

Riders of the system will benefit from it directly and should therefore contribute towards its costs. However, transit can also be seen as a service and the cost should probably be subsidized for some segments of the ridership. The community as a whole will benefit from the improved access to work, education, health care and recreation provided both by the system itself and by any resulting decrease in congestion it brings. The community should therefore contribute to the costs in proportion to the benefits it receives.

7.1 FEDERAL FUNDING

This project should compete well for federal funding of both capital and operating costs. The first step in obtaining funding would be to apply for an FTA planning grant. The planning work completed under the grant would then be used as a basis for competing for funding. Alternatively, this more detailed investigation may show that the project can be made to work without any additional federal funding.

Federal funding programs include:

- FHWA Congestion Management and Air Quality Improvement Program
- USDOT Transportation Investment Generating Economic Recovery (TIGER) Grants
- FTA New/Small Starts Capital Grants
- FTA Section 5307 Urbanized Areas Formula Grants
- National Highway Performance Program
- Surface Transportation Program
- 5305 Planning
- 5307/5336 Urbanized Area Formula
- 5311©(2) Appalachian Development Public Transport
- 5309 Fixed-Guideway Capital Investment

7.2 STATE FUNDING

Most transit funding provided by states comes from general fund appropriations or through traditional taxes and fees, such as motor fuel taxes, sales taxes, and vehicle fees. State funding for transit is generally for both providing operating assistance and capital funds. The State of South Carolina currently funds approximately eight percent of transit operations and one percent of transit capital projects across the state.

7.3 LOCAL FUNDING

To the extent the project is not self-funding, local funding will be required. Any federal and/or state funding will require local matching. The communities that benefit from the project will need to raise these funds. If it is agreed that the benefits of this project outweigh the costs, ways need to be found to raise the money. These could include tax increment financing, sales taxes, etc. There are numerous examples of how communities have raised local funding for fixed guideway projects.

Figure 7-1. Walkable Car-Free Real Estate.

7.4 REAL ESTATE

The property adjacent to some stations is likely to be ideal for transit-oriented development for commercial and/or high-density residential uses. Ways can be found to return this revenue stream, or part of it, to the system that generated the opportunity in the first place.

New real estate developments could reduce the funds spent on roads and parking and direct these towards ATN instead. The overall costs would be reduced and the walkability of the new developments increased

Figure 7-2. Vehicle Advertising Wrap.

7.5 ADVERTISING

Advertising could take many forms. It could involve messaging to passengers about the businesses adjacent to the destination station. It could be wraps of vehicles or station naming rights, etc.

Figure 7-3. Neighborhood Station Incorporating Small Businesses

7.6 STATION REVENUES

Strategically located stations could incorporate local businesses such as coffee or barber shops. Concessions for travel retail, food, ATMs could be incorporated. Naming rights could be sold.

7.7 SPECIAL ASSESSMENT DISTRICTS

The ATN service area could comprise a special assessment district to monetize some of the expected increase in property values. An analysis of a multi-county industrial park designation in a corridor along Laurens Road found signicant potential future growth in property tax values.[14]

7.8 TOURIST AND CONVENTION DEVELOPMENT

There are many ways in which an ATN solution should benefit the tourist/convention business. Ways of monetizing these benefits could be found.

7.9 PARTNER AGENCIES/BUSINESSES

ATN solutions will relieve the accessibility and mobility concerns of many agencies and businesses that could potentially contribute to the costs.

[14] Bookover, Bob, Ph.D., Estimate of Tax Revenue Growth for the Laurens Road Corridor 2015 – 2034, bob@clemson.edu

8. OVERALL CONCLUSIONS

From a transit point of view the results of this study are truly remarkable. The projected ridership is much higher than for conventional transit, yet the model used accurately predicted the existing Clemson Red Route bus ridership and so seems correct. In addition, the results seem in line with those obtained in other studies in the US and around the globe. The system performance factors used in the model have been shown to be regularly achieved by ATN systems in public service. The operating costs used are not out of line with the costs of the antiquated Morgantown PRT system. It seems clear that the proposed ATN solutions will more than cover their own operating costs.

There is more doubt regarding the ability of these systems to also cover their capital costs from fare-box revenues. Is $3.50 a reasonable average fare? Will people be prepared to pay it? Is some sort of tiered fare system feasible whereby people pay more not to share rides or have intermediate stops? Are the estimated capital costs correct? These are some of the questions that need to be more thoroughly investigated.

Nonetheless, it is clear that the proposed ATN solutions are far superior to conventional transit solutions. They bring opportunities of economic and real estate value uplift that are worth paying for. Where fare-box revenues are insufficient there are many options for raising additional funding. These projects should compete very well for federal funding which will, however, add to the cost and complexity. Where fare-box revenues can also cover capital costs, communities should be able to develop public private partnerships and have ATN solutions implemented with very little community funding being required.

ATN appears to be an economical way to increase the capacity of the causeway linking Highpointe and the Pier to Clemson University Campus. This potentially practical way to facilitate development of off-campus student housing could form an ideal initial deployment to demonstrate ATN feasibility.

ATN potentially delivers a real opportunity to increase the overall quality of life in each community involved. Relieving congestion and providing mobility to almost everyone will have a significant impact on personal wellbeing and the overall economy. Installing high-quality transit throughout the community could be likened to providing electricity to each home. We might soon wonder how we managed without it.

APPENDIX A

CLEMSON, GREENVILLE & MAULDIN PUBLIC SURVEY

BACKGROUND

Purpose

To obtain travel preference information sufficient to estimate mode split between car, PRT and gondola as well as time and price elasticity. The results will be used to help support a different methodology for determining mode split. The project budget is insufficient to undertake a rigorous mode split evaluation but it is anticipated the two methodologies used will proved a sufficiently good indication.

Methodology

Develop a set of stated preference questions that can be analyzed to determine the factors being sought.

Ask these questions in survey form to:

- The Mauldin Workshop audience
- The Greenville Workshop audience
- Participants in a web-based survey (the survey will include a description of what it is like to ride a gondola or a GreenPod)

To help prevent the survey itself from biasing the answers, the questions will be presented in the numbered order shown.

INVITATION

(to be posted on various websites in the communities involved)

Can driverless vehicles help increase mobility and reduce congestion in Greenville, Mauldin and Clemson?

This is your opportunity to help us answer this question. Click here [this link will be provided - leading to the SurveyMonkey survey] to:

- Learn about driverless vehicles
- Your transportation preferences and options
- Help shape our transportation future

SURVEYMONKEY SURVEY

Introduction

Thanks for your interest in undertaking this survey. We are investigating the ability of driverless transit systems to increase mobility and reduce congestion and need a better understanding of the travel choices people like you make. Please first take a little time to learn about the options we are considering. Then answer the questions based on what you would really do on a repeated basis for your daily travel needs such as your trip to work, school or daily activities.

What are GreenPods?

GreenPods are small, driverless vehicles operating on dedicated guideways, together forming automated transit network systems. They provide safe, personal, on-demand, direct origin to destination, convenient, comfortable, and cost-effective mobility options. Because the guideways are separated (usually by elevating them) from other traffic and pedestrians, they relieve congestion by removing passengers from roadways and they provide quick trips independent of road congestion. Stations are offline (on sidings) and do not slow mainline traffic. Numerous stations provide improved access for more riders to connect to more attractor locations for daily activities. This clip shows four different GreenPod systems highlighting the passenger experience. This GreenPod video focuses on a potential corridor in Greenville.

Gondolas

A gondola system may be appropriate where terrain or large bodies of water form barriers to transportation. The first two minutes of this clip show typical gondola operations.

More Information

You are now ready to take the survey (it takes about ten to twenty minutes). If you want to learn more you can browse www.advancedtransit.org, www.prtconsulting.com

Survey Questions

First please tell us a little about yourself and your primary travel choices.

1. What city do you live in?
   a. Clemson
   b. Greenville
   c. Mauldin
   d. Other
2. What is your age group?
   a. Under 18
   b. 18 to 24
   c. 25 to 44
   d. 45 to 64
   e. 65 and over
   f. Prefer not to answer
3. What is your gender
   a. Male
   b. Female
   c. Prefer not to answer
4. Are you a full-time student?
   a. Yes
   b. No
5. What was the range of your total household income for 2017?
   a. Under $10,000
   b. $10,000 to $19,999
   c. $20,000 to 49,999
   d. $50,000 to $74,999
   e. $75,000 or more
   f. Prefer not to answer
6. Check all the modes you typically use for your primary daily trip

a. Walk
b. Bike
c. Car
d. Motorized bike/scooter
e. Bus
f. Other

7. How long does this primary daily trip usually take (total travel time one-way)?
    a. Minutes ___
8. What is the longest this trip sometimes takes due to weather and/or congestion?
    a. Minutes ___
9. Approximately how far is it?
    a. Miles ___
10. Where is the origin?
    a. Address, cross roads and/or facility name ___________________________
11. Where is the destination?
    a. Address, cross roads and/or facility name ___________________________

Now let's explore what solutions might work for you. Consider your primary daily trip.

Consider the following trips. Assuming your present circumstances (if you have no daily access to a car ride do not choose the car option). Answer what you think you would actually do on a daily basis. Do not answer what you think you should do or what you think we want to hear.

16. Trip length 10 miles

a) Drive 20 to 35 minutes (depending on traffic) by car, pay $5 to park, walk 5 minutes
b) Walk/wait 6 minutes, pay $2 to ride a GreenPod for 24 minutes

19. Trip length 8 miles

a) Drive 16 to 29 minutes (depending on traffic) by car, pay $0.50 to park, walk 5 minutes
b) Walk/wait 6 minutes, pay $2 to ride a GreenPod for 24 minutes

12. Trip length 10 miles

a) Drive 20 minutes by car, pay $0.50 to park, walk 5 minutes
b) Walk/wait 8 pay $1 to ride a GreenPod for 30 minutes

15. Trip length 2.5 miles

a) Drive 6 to 12 minutes (depending on traffic) by car, pay $7 to park, walk 2 minutes
b) Walk/wait 5 minutes, pay $0 to ride a GreenPod for 6 minutes

18. Trip length 2.5 miles

a) Drive 12 minutes by car, pay $0.50 to park, walk 5 minutes
b) Walk/wait 8 minutes, pay $3 to ride a GreenPod for 6 minutes

20. Trip length 2.5 miles

a) Drive 6 minutes by car, pay $0.5 to park, walk 5 minutes
b) Walk/wait 10 minutes, pay $1 to ride a GreenPod for 8 minutes

21. Trip length 4 miles

a) Drive 8 - 12 minutes by car, pay $0.5 to park, walk 7 minutes

b) Walk/wait 17 minutes, pay $0 to ride a gondola for 14 minutes

13. Trip length 4 miles

a) Walk/wait 8 minutes, pay $0 to ride a GreenPod for 11 minutes
b) Walk/wait 9 minutes, pay $0 to ride a gondola for 11 minutes,

17. Trip length 4 miles

a) Walk/wait 5 minutes, pay $1 to ride a GreenPod for 8 minutes
b) Walk/wait 11 minutes, pay $0 to ride a gondola for 15 minutes

22 Trip length 0.75 miles

a) Walk 15 minutes
b) Walk/wait 4 minutes, pay $0 to ride a GreenPod for 5 minutes

26 Trip length 0.75 miles

a) Walk 18 minutes
b) Walk/wait 5 minutes, pay $0 to ride an autonomous shuttle for 12 minutes

24 Trip length 0.75 miles

a) Walk 13 minutes
b) Walk/wait 3 minutes, pay $0 to ride an autonomous shuttle for 9 minutes

23 Trip to Airport

a) Drive 20 minutes by car, pay $30 to park, walk 5 minutes
b) Walk/wait 6 minutes, pay $10 each way to ride a driverless taxi for 20 minutes

25 Trip to Airport

a) Drive 20 minutes by car, pay $60 to park, walk 5 minutes
b) Walk/wait 6 minutes, pay $10 each way to ride a driverless taxi for 20 minutes

14 Trip to Airport

a) Drive 20 minutes by car, pay $10 to park, walk 5 minutes
b) Walk/wait 6 minutes, pay $10 each way to ride a driverless taxi for 20 minutes

If you would be willing to participate in other follow-up surveys related to Greenpods and automated transit, please provide an email address.

Jacksonville Ultimate Urban Connector (U^2C)

- First proposed US AV guideway
- $12.5M BUILD Project Awarded for design and demonstration
- Repurposed underutilized rail SkyWay for use with Connected Automated Vehicles (CAVs)
- Allows for lower cost flexible extensions to popular destinations

UWB Roadmap Components of U2C

- V2I & V2I over 5G
- UWB Micro-positioning (BSM)
- CV to Traffic Signals
- Precision tracking for independant testing AVs