

Automated Transit Network Feasibility Study

for Clemson, Greenville and Mauldin



FINAL REPORT

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in association with:

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AUTOMATED TRANSIT NETWORK FEASIBILITY STUDY

FOR CLEMSON, GREENVILLE AND MAULDIN

1. EXECUTIVE SUMMARY

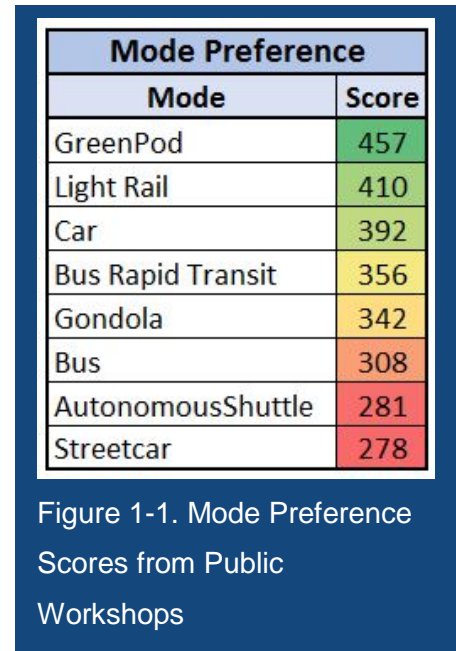
Automated transit network (ATN) systems use small driverless vehicles on dedicated guideways to transport passengers quickly and conveniently to their destinations. Small vehicles require light infrastructure which is relatively unobtrusive and inexpensive. Numerous small stations are offline (on sidings), 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 in the urbanized areas of Greenville and Pickens Counties.

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 Clemson¹ and Greenville² 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.

A 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 that 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



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>

- Improved mobility/accessibility
- 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 Clemson community wishes to move ahead with an ATN solution it should undertake a detailed study which would be a necessary precursor to identifying the funds needed – particularly federal funding.

Other solutions were examined in Clemson including ATN and A-Taxis/Shuttles on the Clemson University 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

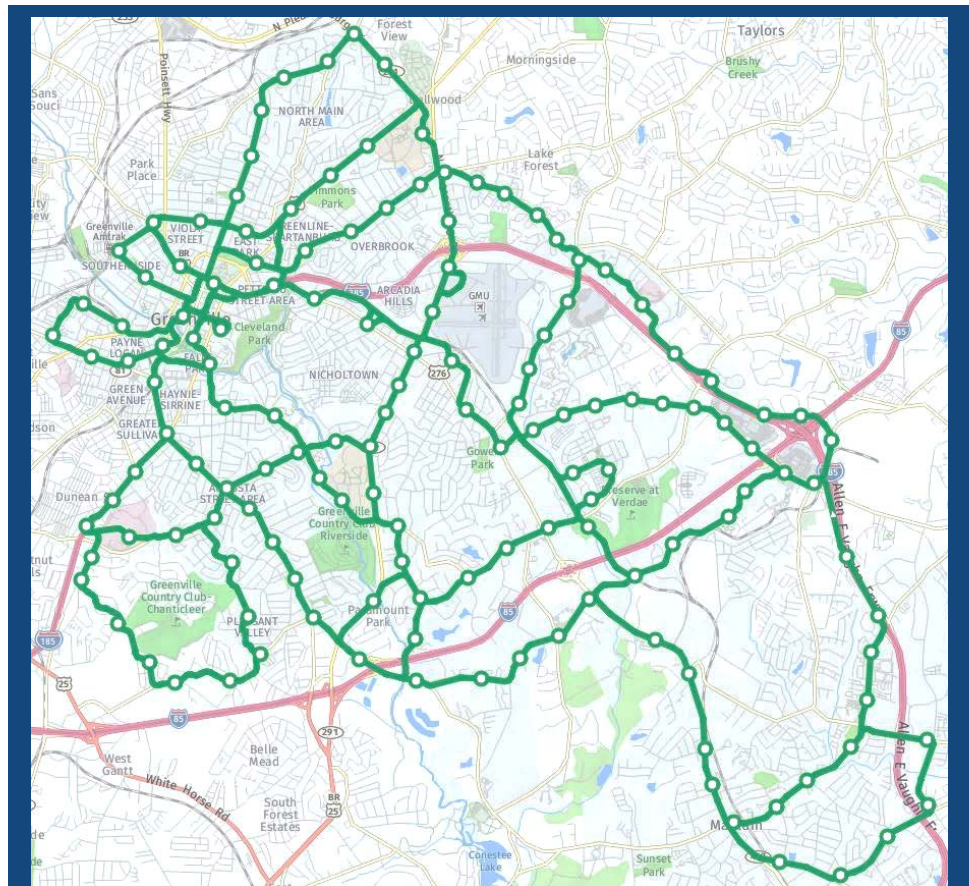


Figure 1-2. Combined Greenville-Mauldin ATN Layout

projects. The more widespread the solution, the more feasible it was found to be. However, 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 Highpoint, 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.

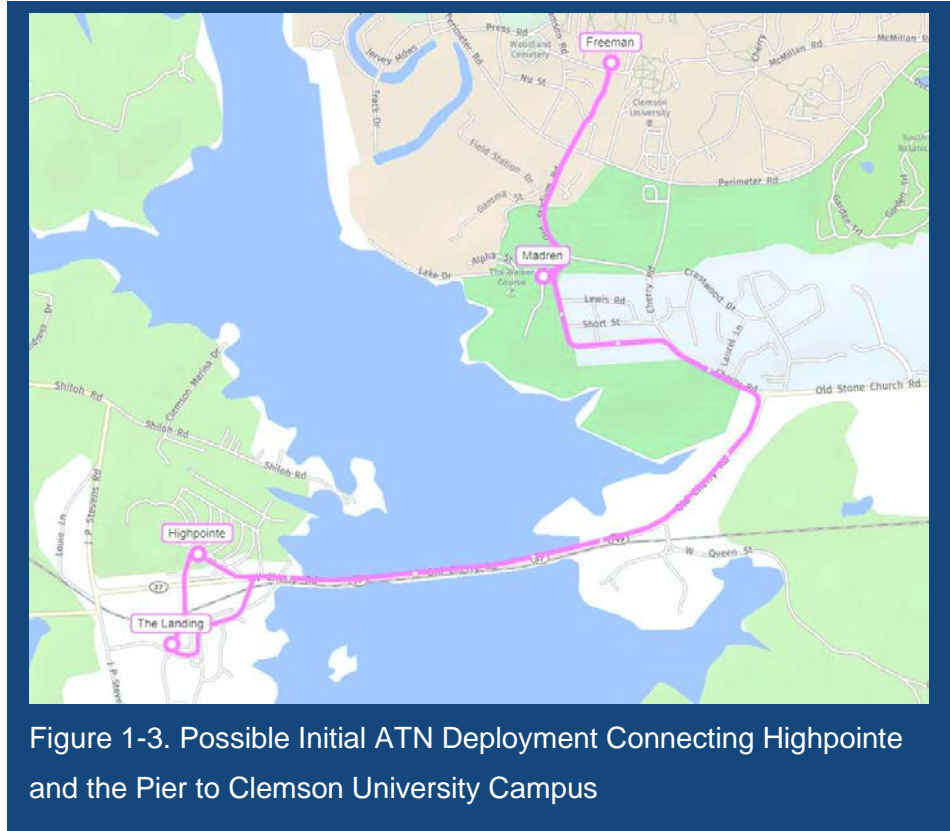


Figure 1-3. Possible Initial ATN Deployment Connecting Highpoint and the Pier to Clemson University Campus

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.

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

3. AUTOMATED TRANSIT NETWORKS (ATN)

3.1 DEFINITION AND DESCRIPTION

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 even 30 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 Transit² 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.

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**

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

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.



Figure 3-1. Ultra PRT Vehicle on Elevated Guideway

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.

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

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 3-2. 2getthere PRT Vehicles in Station



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	Attribute	Votes
Safe	18	Minimal Transfers	4
Reliable	17	ADA Compliant	4
Cost-effective	13	Multi-Modal	3
Convenient	13	Fun entertaining attractive	2
Frequency	9	Quiet	2
Comfortable	6	Respect for privacy	2
Sustainable	6	Secure	2
Effective	5	Facilitates Sponsorship	1
County-wide	5	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.

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

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

Figure 4-2. Mode Preference Scores

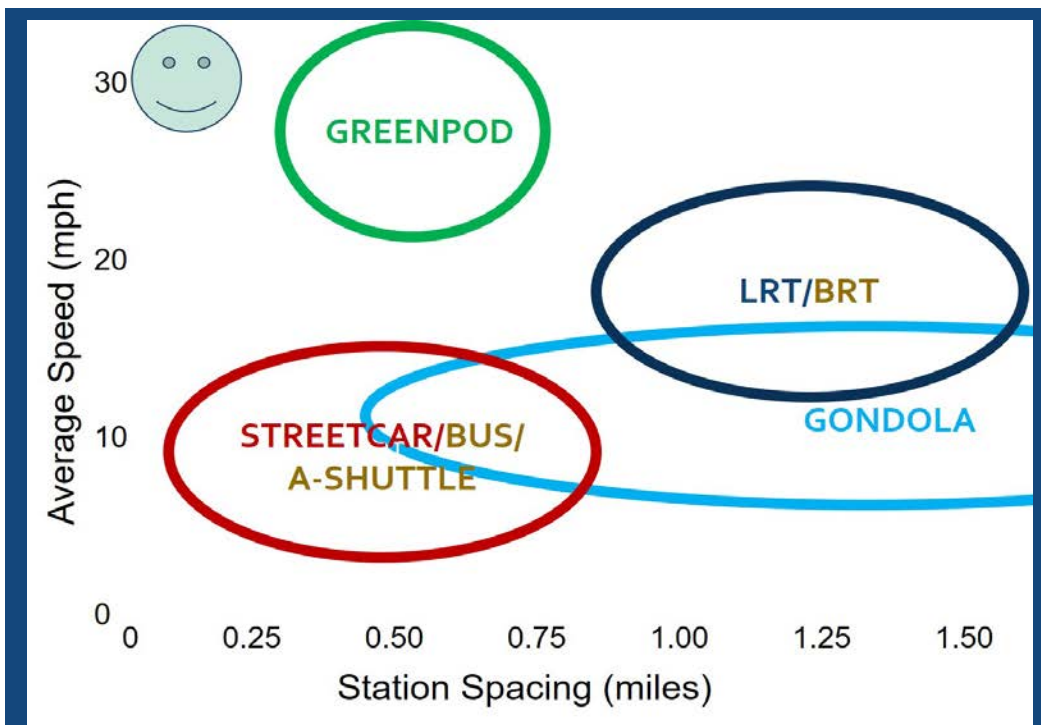


Figure 4-3. Average Speed vs Station Spacing

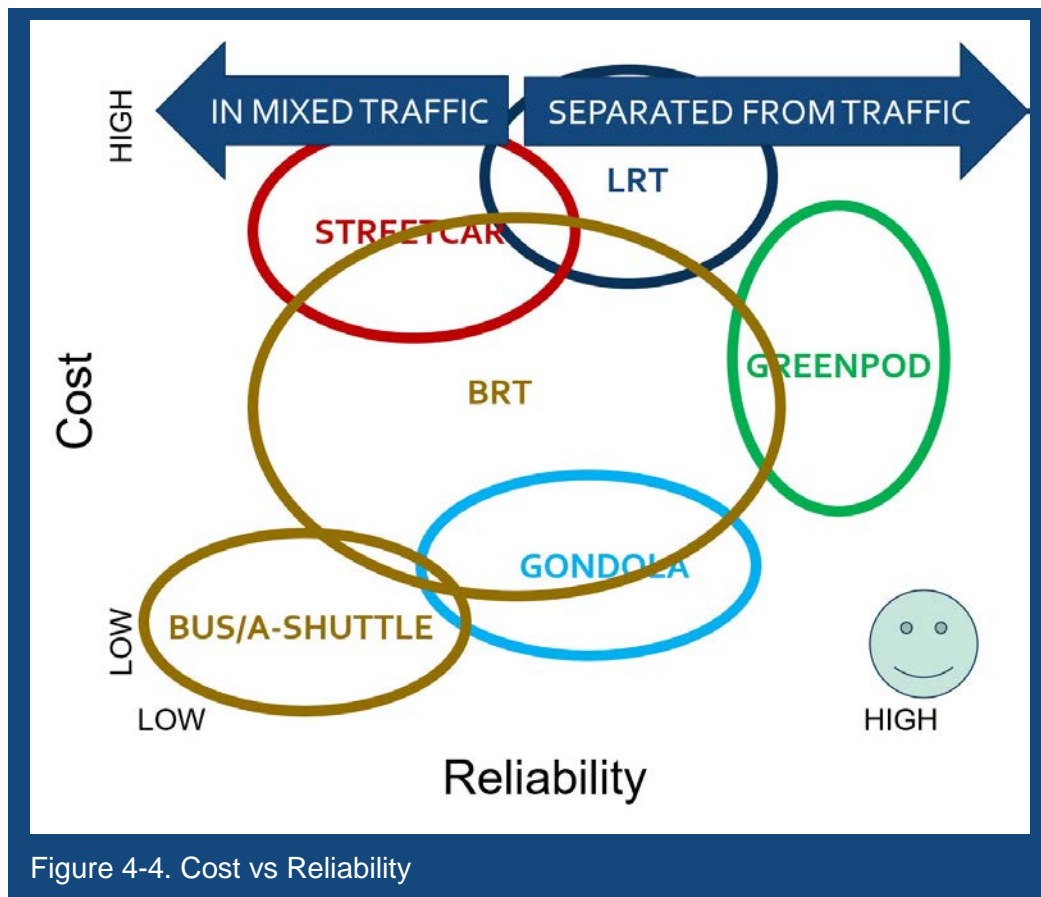


Figure 4-4. Cost vs Reliability

5. CLEMSON

5.1 BACKGROUND

The Clemson Area Transit System (CATbus) recently took a 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

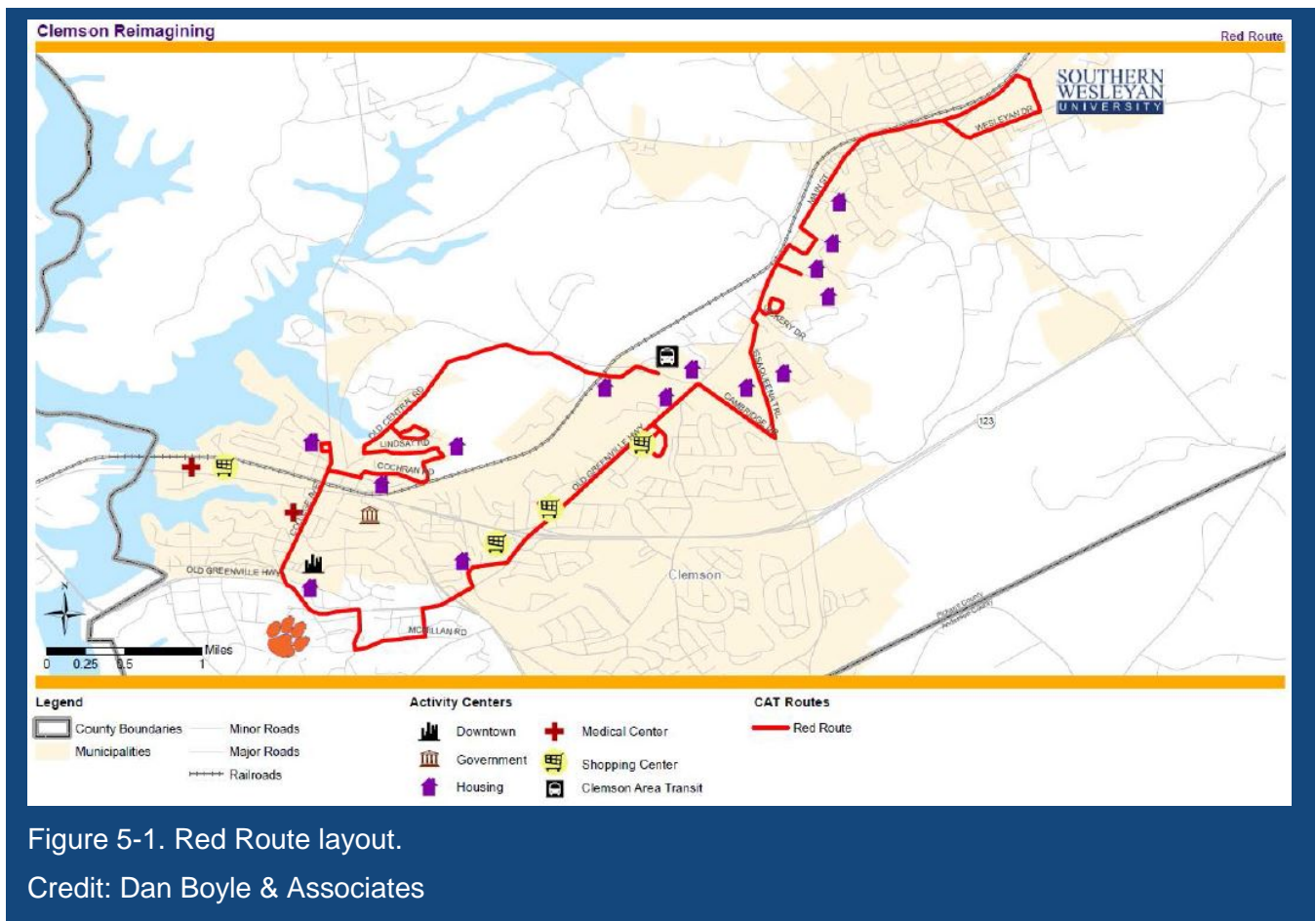


Figure 5-1. Red Route layout.

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

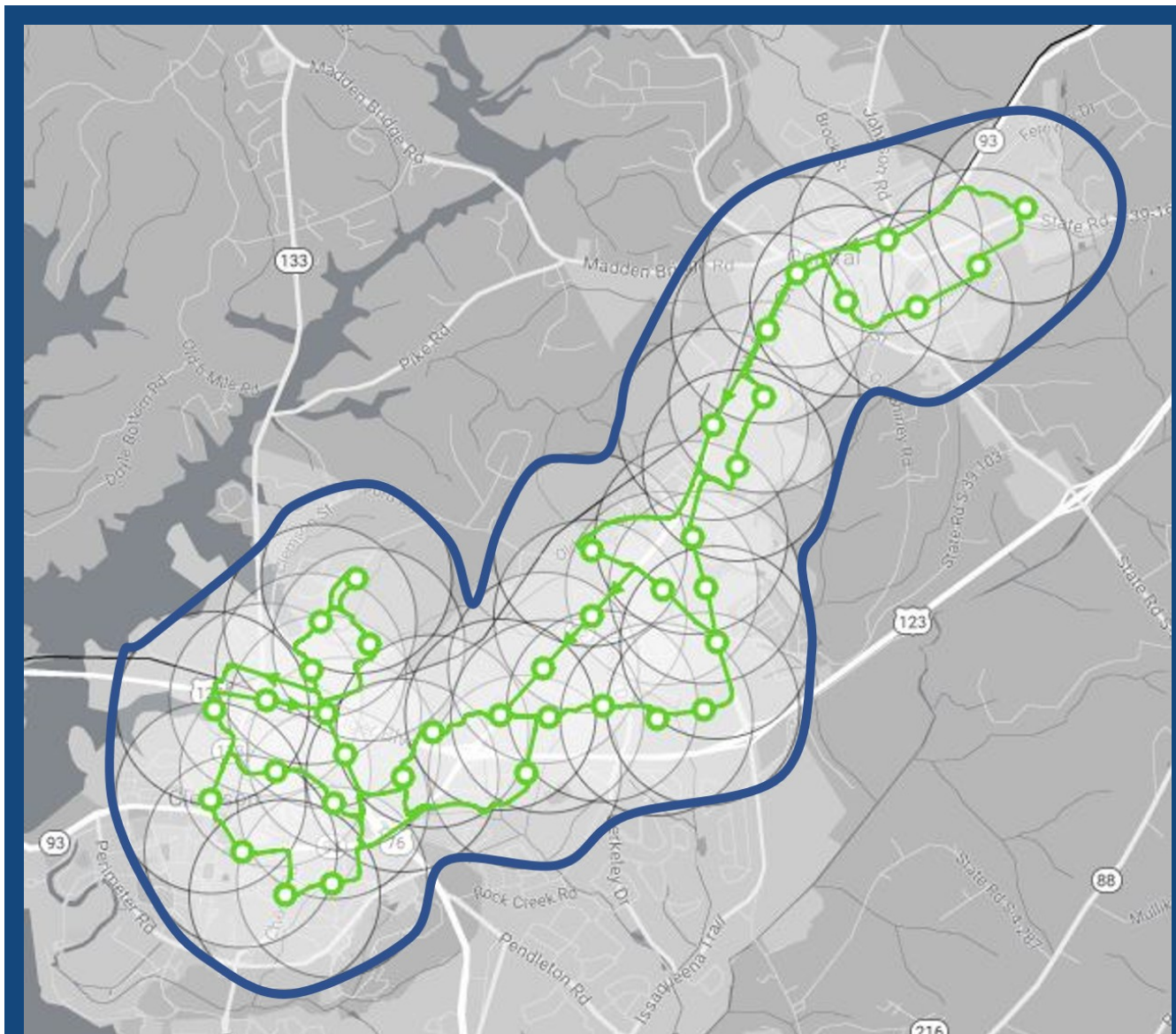


Figure 5-2. Red Route ATN Alternative Showing the Service Area Within One-Half Mile.

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.

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).

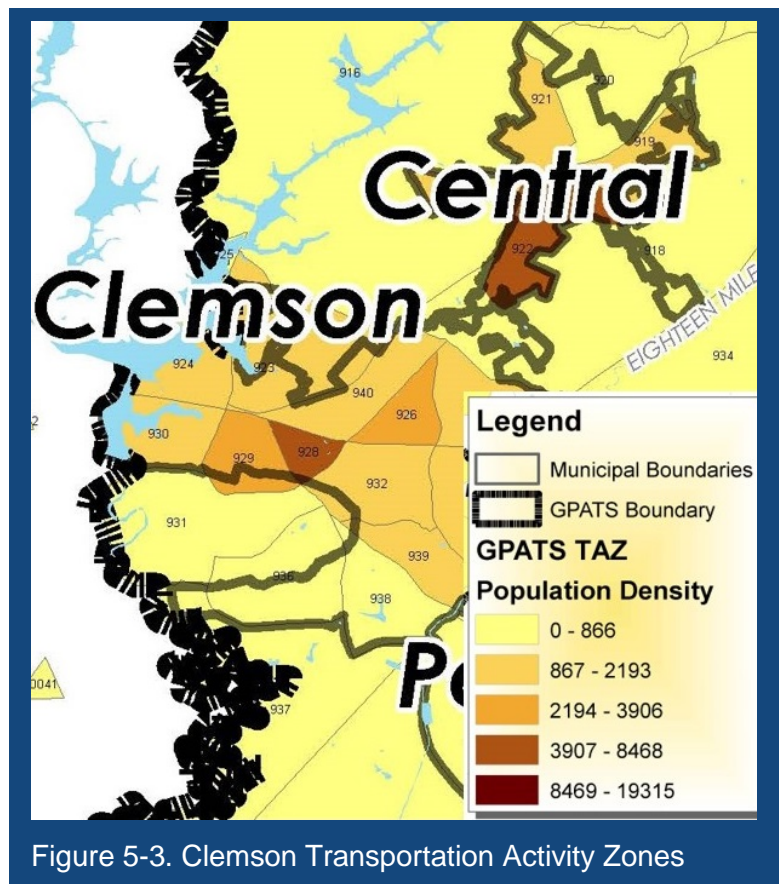


Figure 5-3. Clemson Transportation Activity Zones

5.3.1.2 Bus

The CATbus schedule shows the bus time from Southern Wesleyan 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 al⁵ 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.

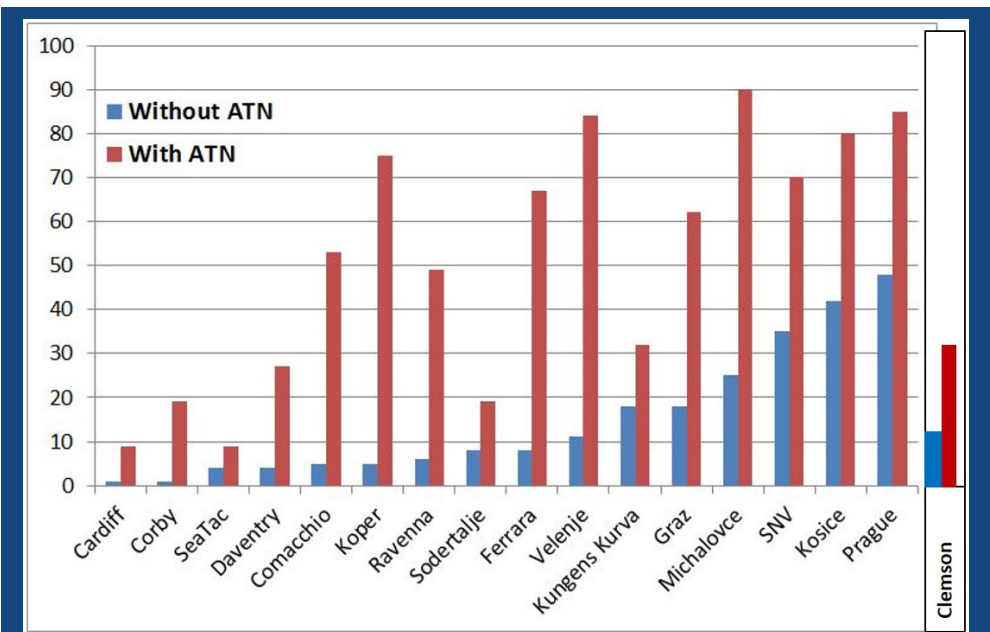


Figure 5-4. Transit Mode Share With and Without ATN

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 time⁶. 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 used 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.

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.

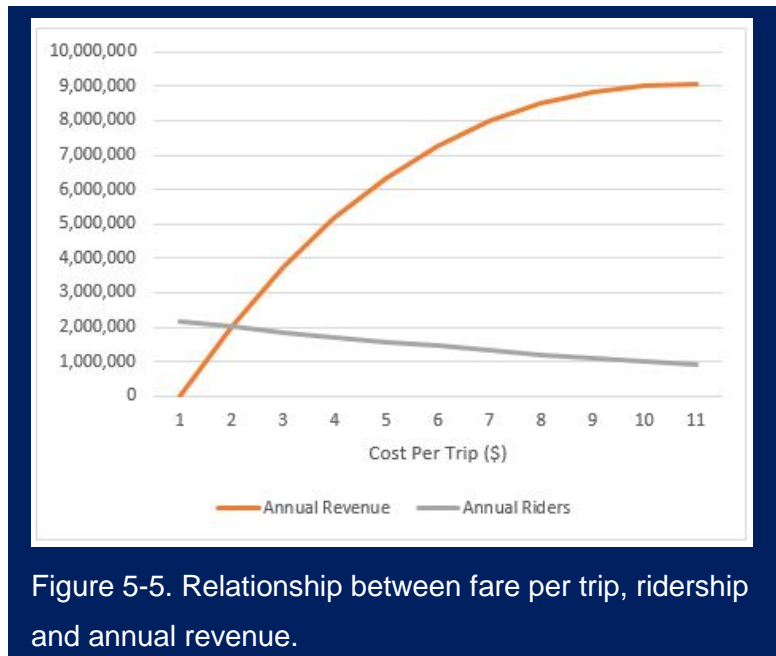


Figure 5-5. Relationship between fare per trip, ridership and annual revenue.

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.



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 system⁷
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 (= $8,423 - 3,239 / \text{car occupancy of } 1.5$) 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%.

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

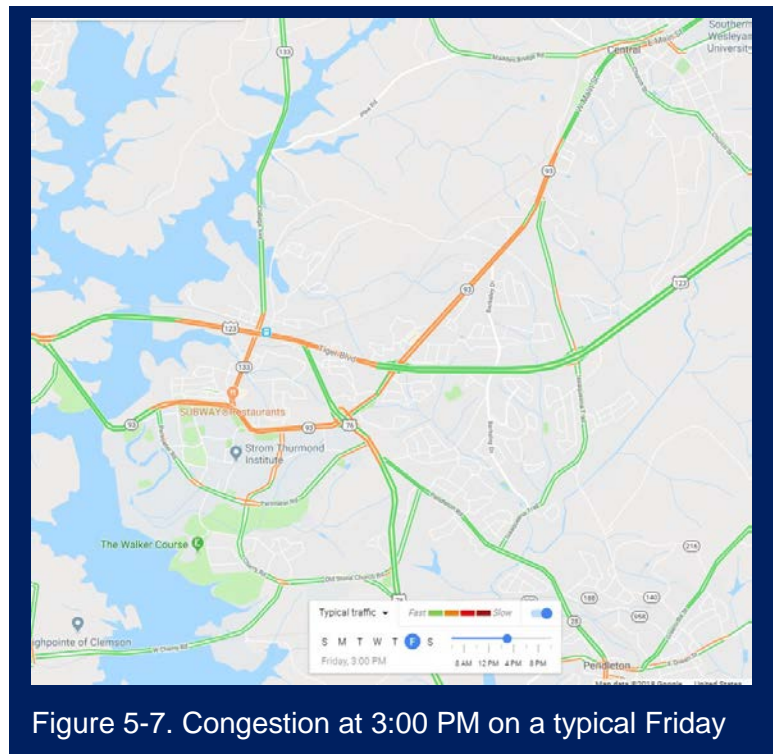


Figure 5-7. Congestion at 3:00 PM on a typical Friday

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 heavy 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.

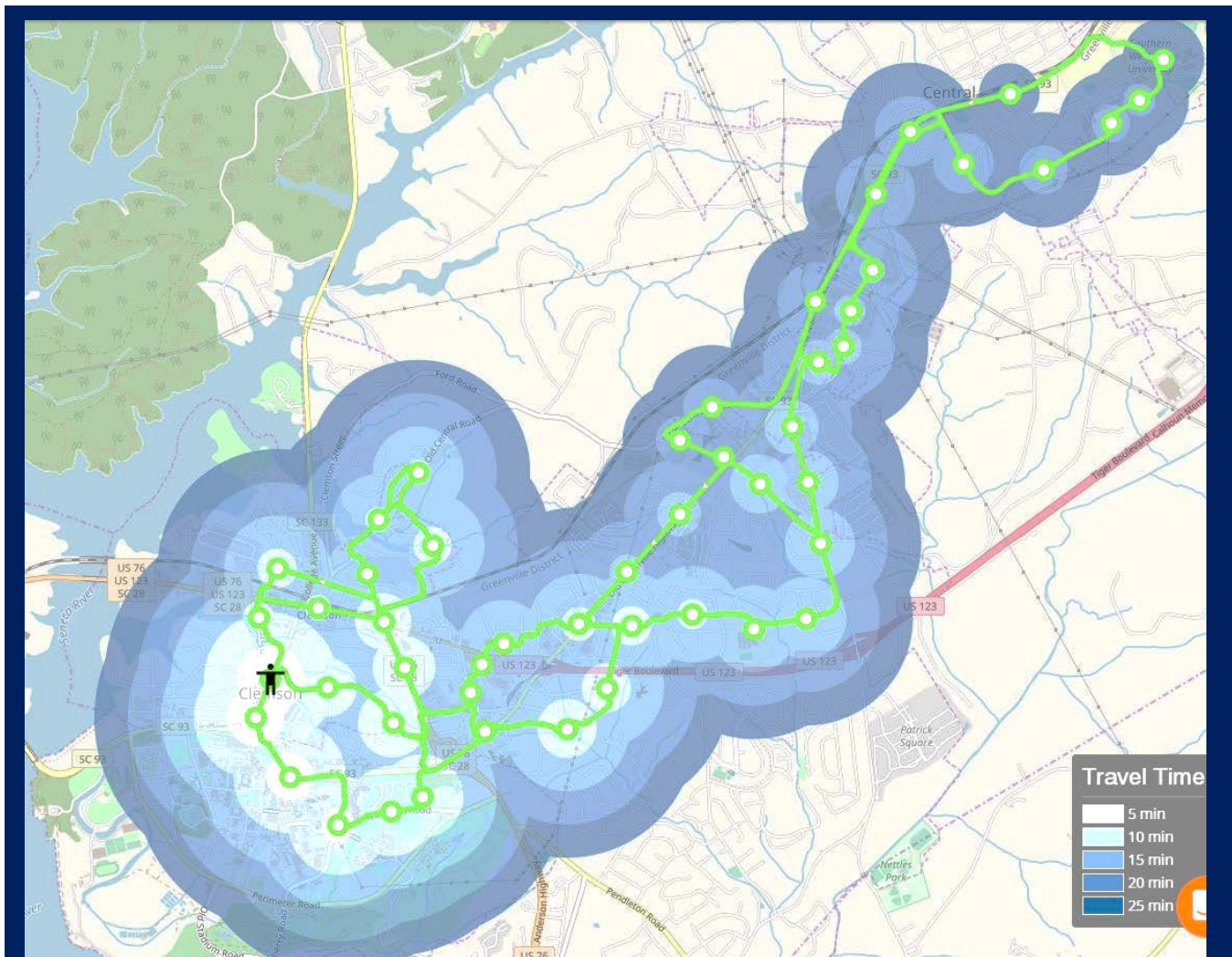


Figure 5-8. ATN Travel Times From Downtown Clemson

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 102⁹) 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 \$7.87¹⁰. 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 Extens	NSPD	LRT	4.8	7	704	359	17.75	8,700	2.86
MN	Minneapolis	METRO Blue Line exte	NSE	LRT	13.5	11	1,563	784	27.50	16,500	5.49
MN	Minneapolis	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 Extens	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 light rail 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 Clemson University 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:

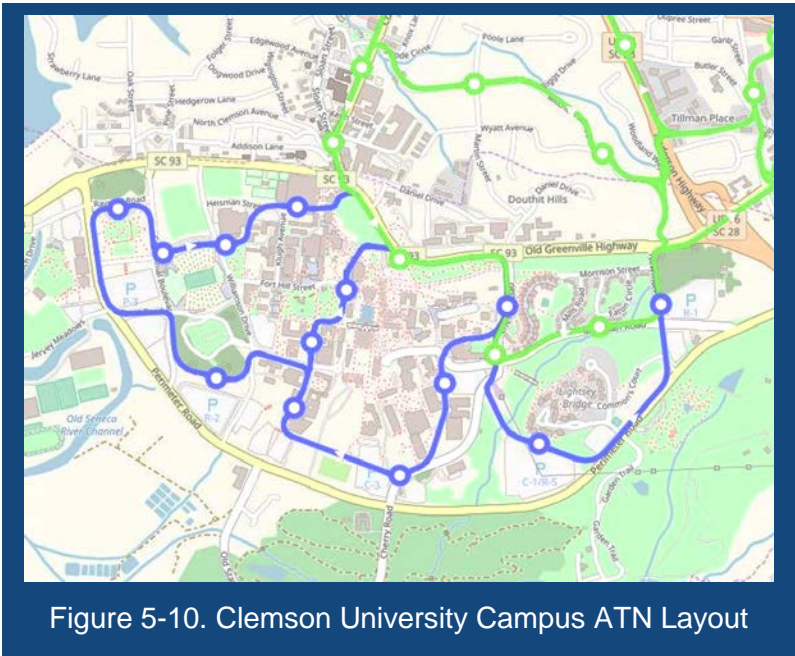
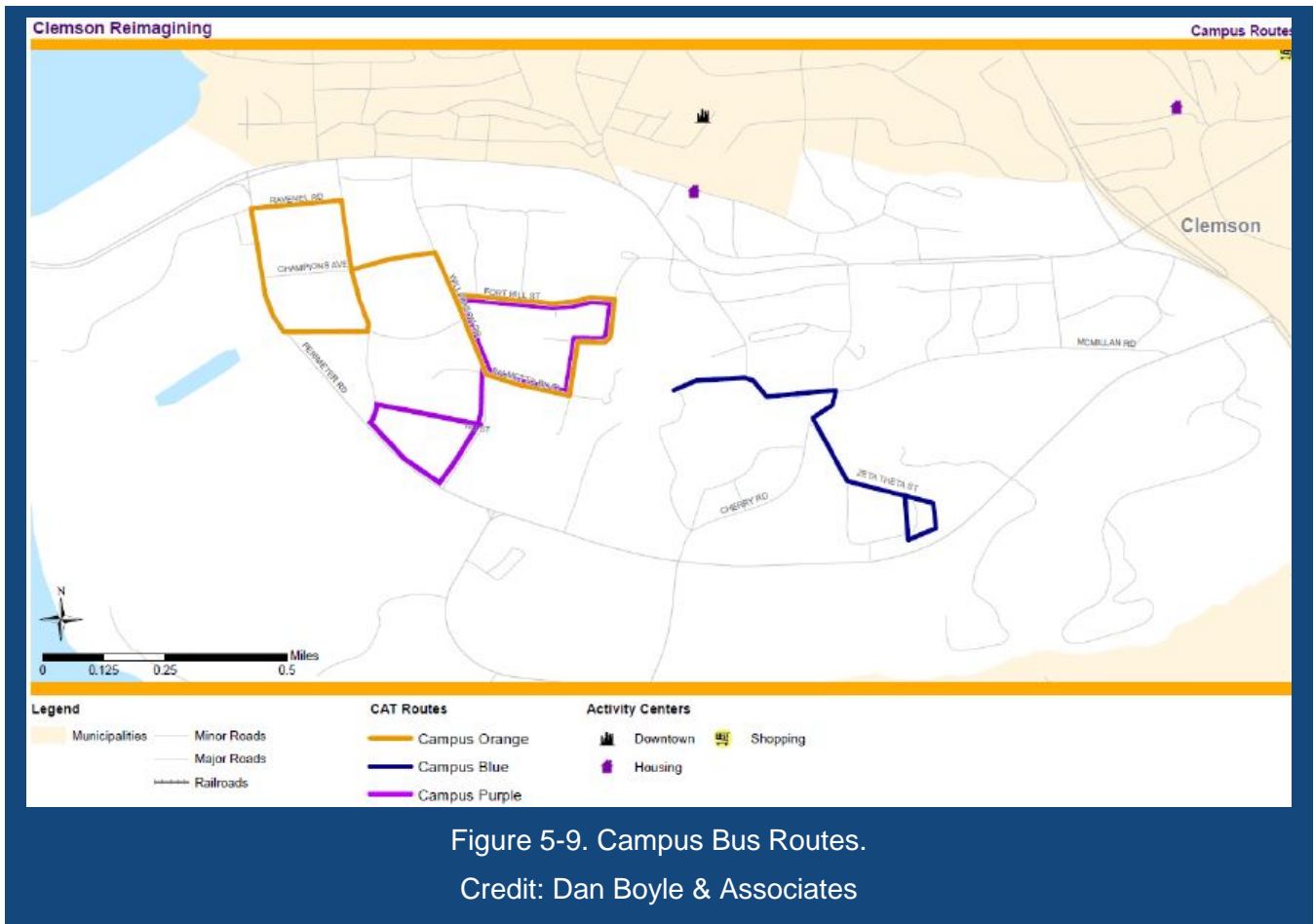
- It is struggling to meet demand and difficult to expand since adding more busses without additional infrastructure improvements could exacerbate existing congestion
- There is a good set of data regarding its operating characteristics and passenger demand
- It serves a defined area with known populations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



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.

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/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.

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.



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

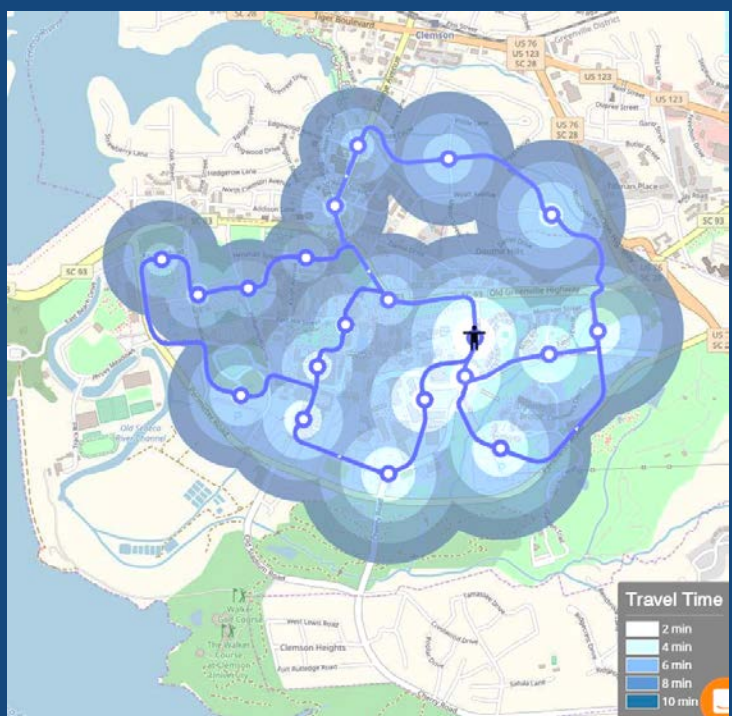


Figure 5-12. Clemson University Campus and Downtown ATN Travel Times

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 Naveya

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.

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



Figure 5-14. Causeway and Bridge Over Lake Hartwell

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

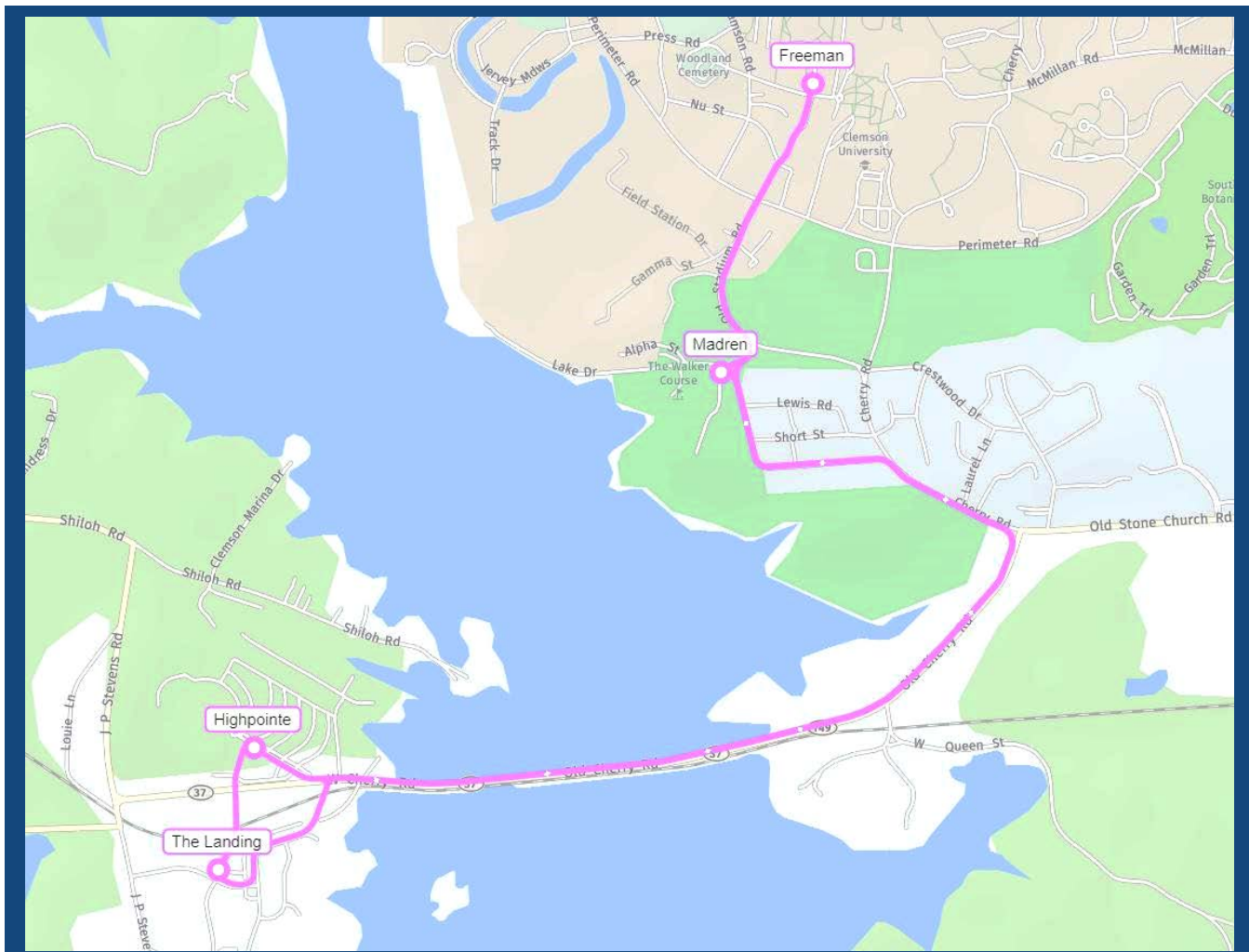


Figure 5-15. ATN Connection between Highpoint and the Pier and Clemson University Campus

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).

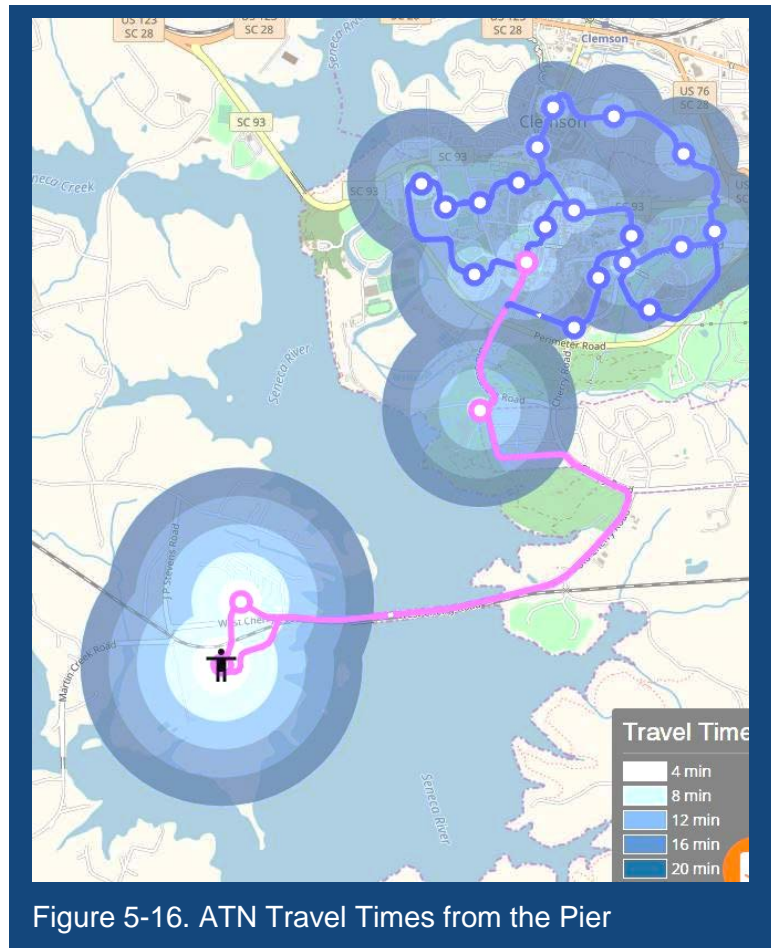
The detailed study outlined in Section 5.12 will still need to be undertaken but, with this initial project, some aspects could be turned over to the private partner. This is to say that the decision to proceed with the project could be based largely on the results of this report plus only those aspects 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.

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 (*monocable*) 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.

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

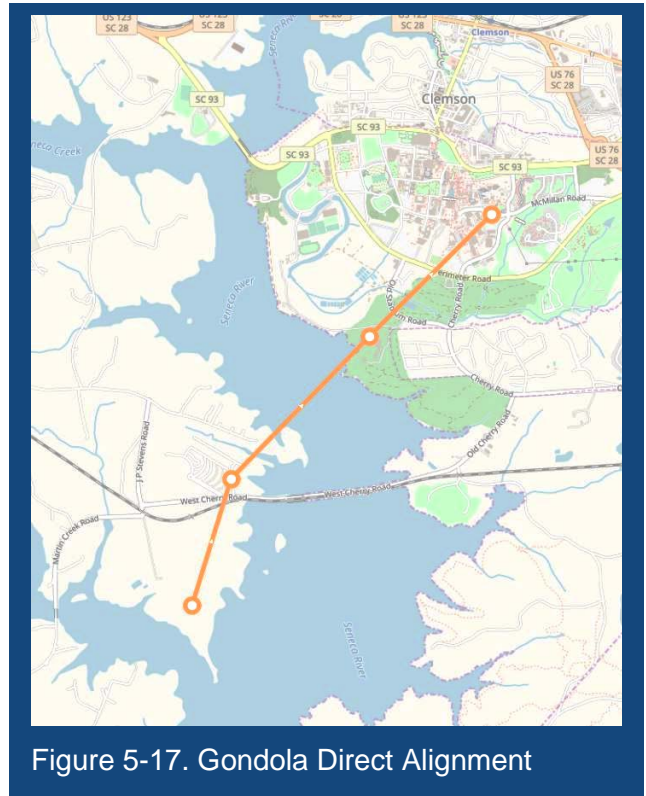


Figure 5-17. Gondola Direct Alignment

portion of the lake would not be a significant implementation issue, a monicable 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.

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.

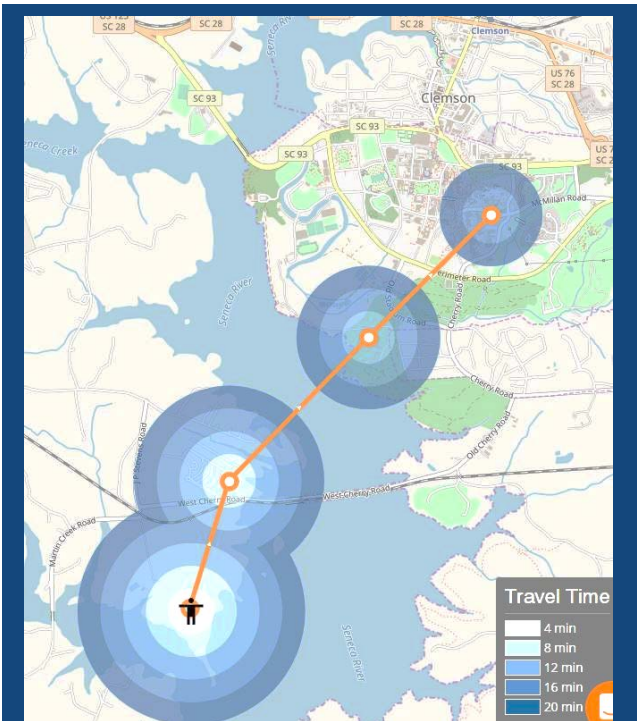


Figure 5-18. Gondola Direct Route Travel Times from the Pier

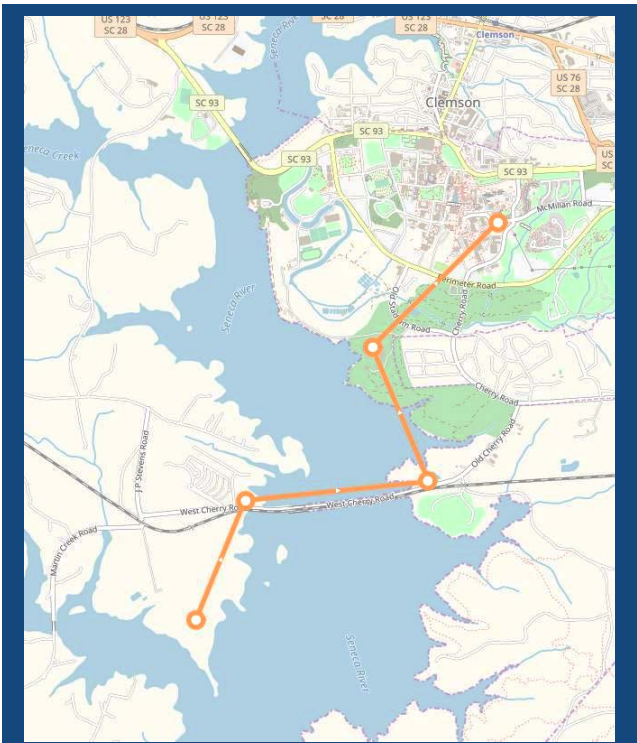
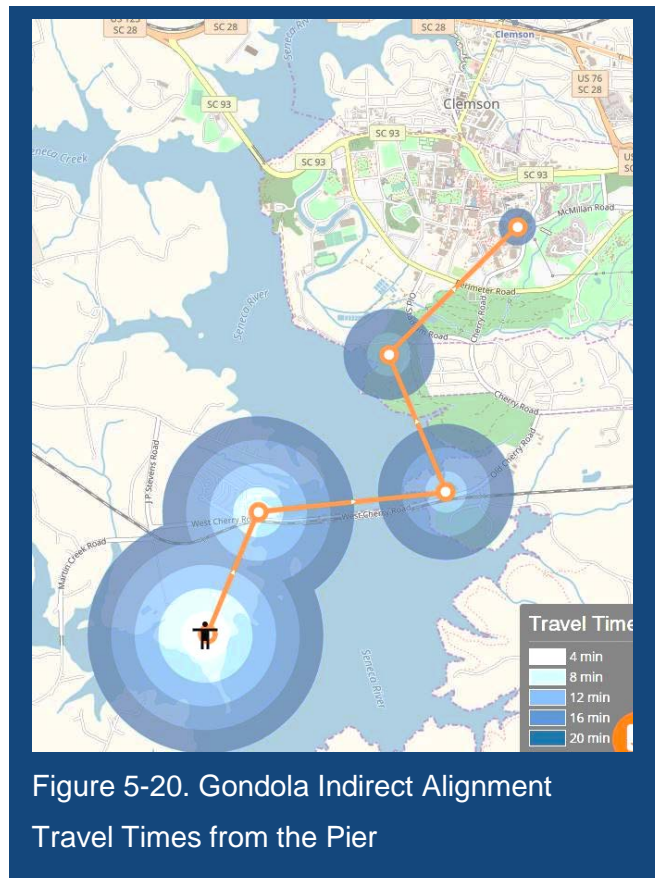


Figure 5-19. Gondola Indirect Alignment

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.



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.

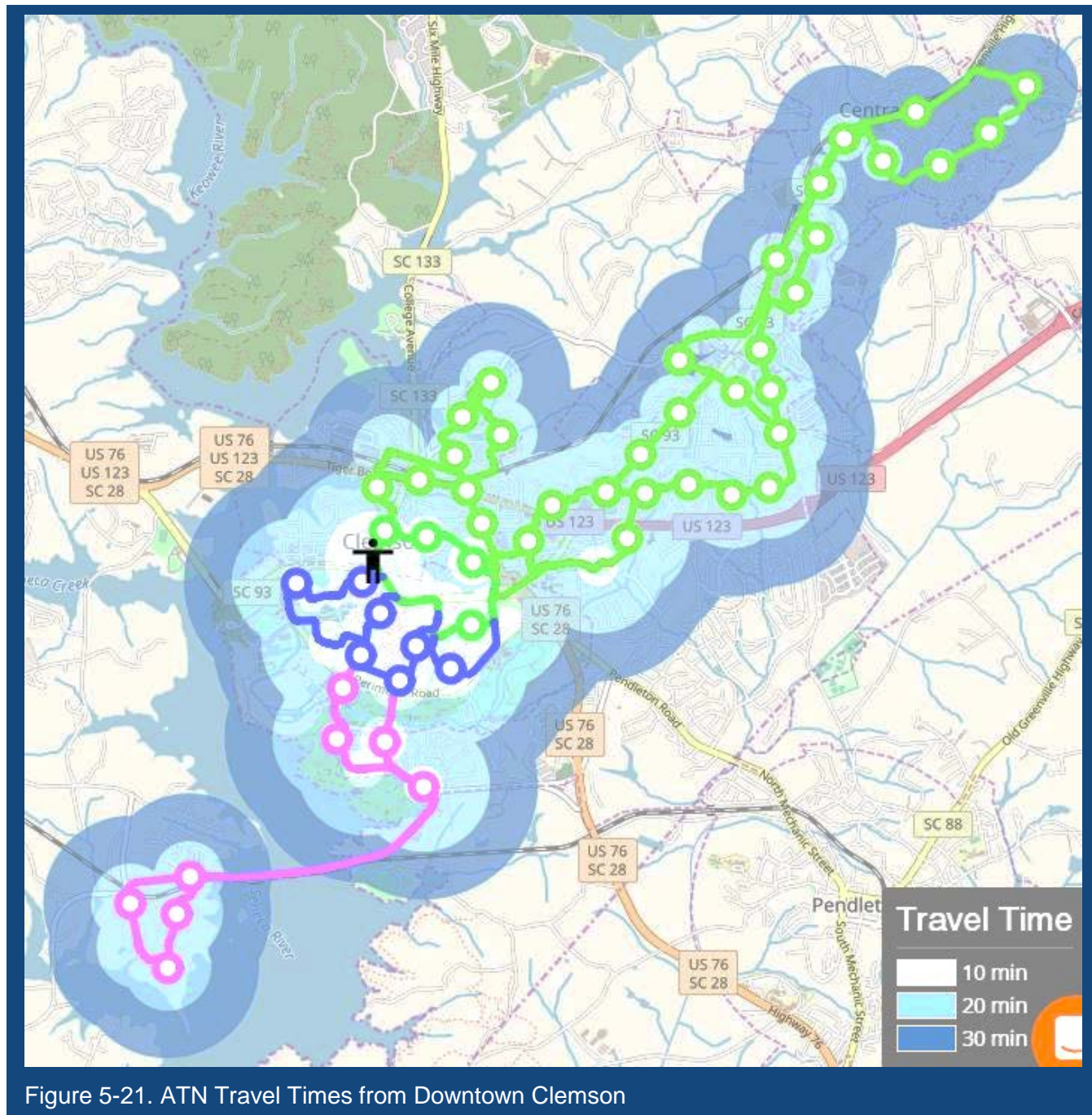


Figure 5-21. ATN Travel Times from Downtown Clemson

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.

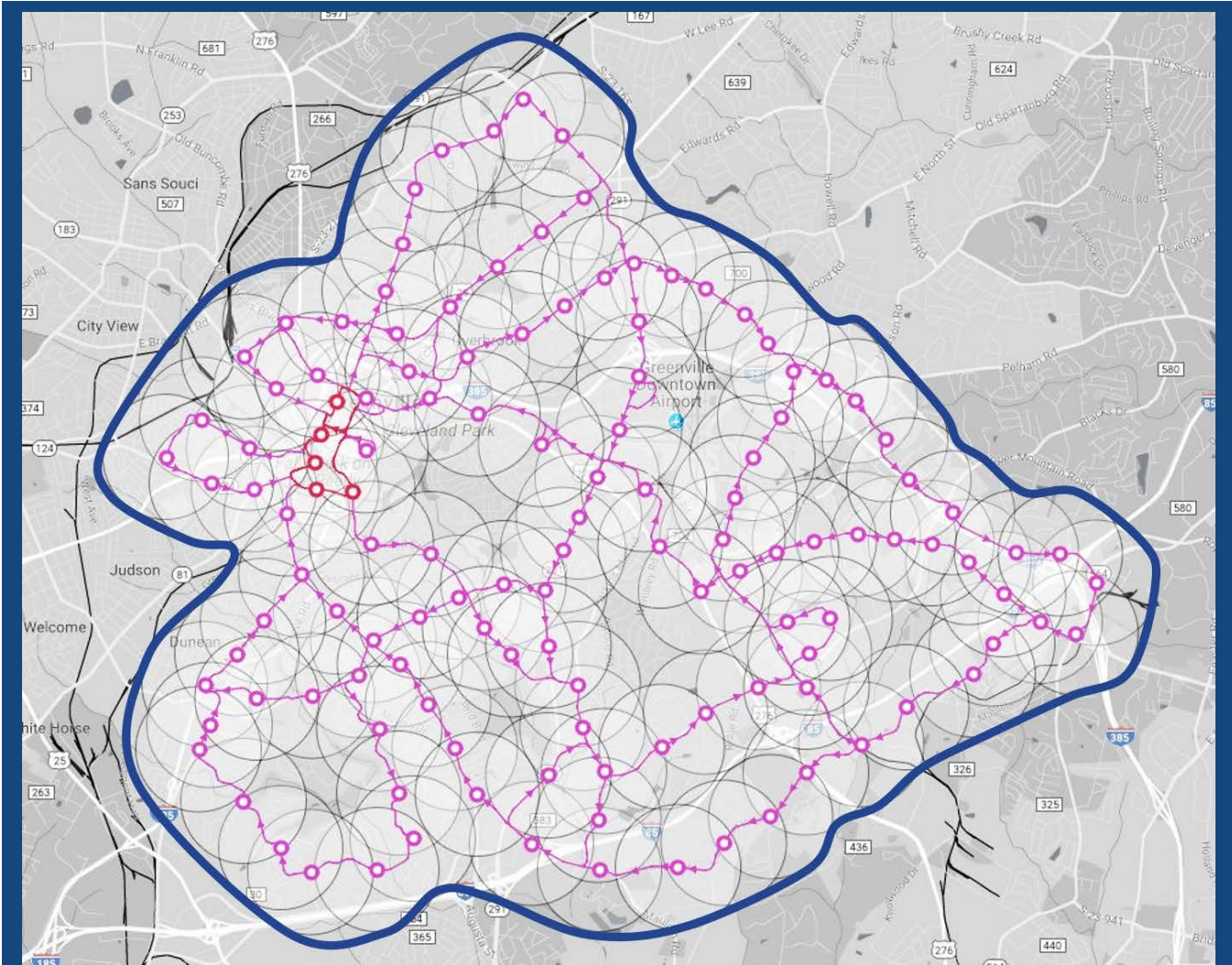


Figure 6-1. Greenville ATN Alternative Showing the Service Area Within One-Half Mile.

6.4 METHODOLOGY TO DETERMINE ATN RIDERSHIP

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

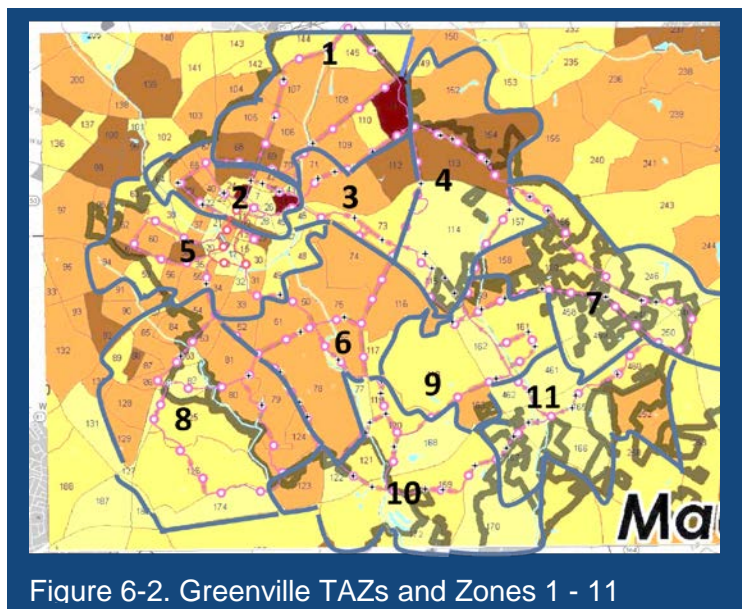


Figure 6-2. Greenville TAZs and Zones 1 - 11

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.

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.

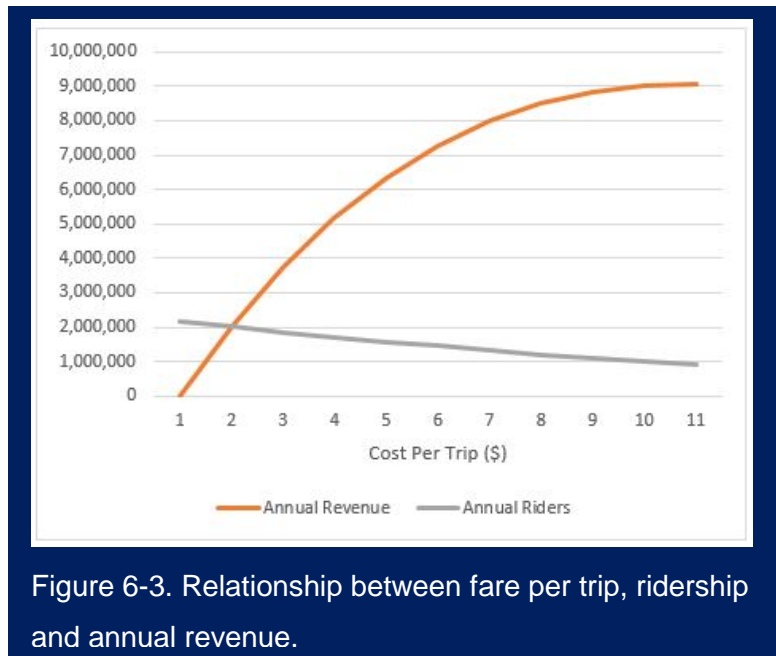


Figure 6-3. Relationship between fare per trip, ridership and annual revenue.

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 system¹¹
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)¹² 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

¹² This relatively high cost per mile is attributable to the high number of pods required per mile.

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.

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

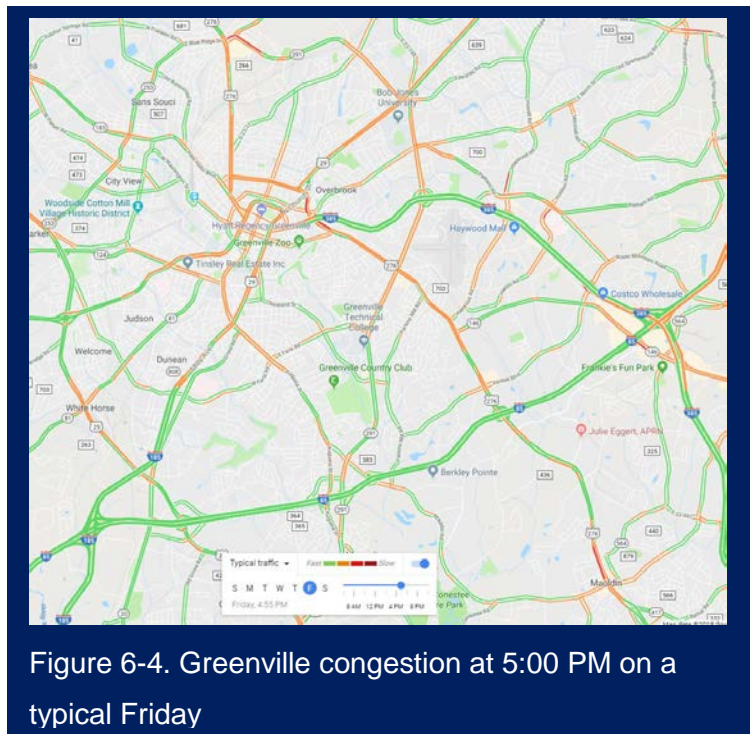


Figure 6-4. Greenville congestion at 5:00 PM on a typical Friday

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.

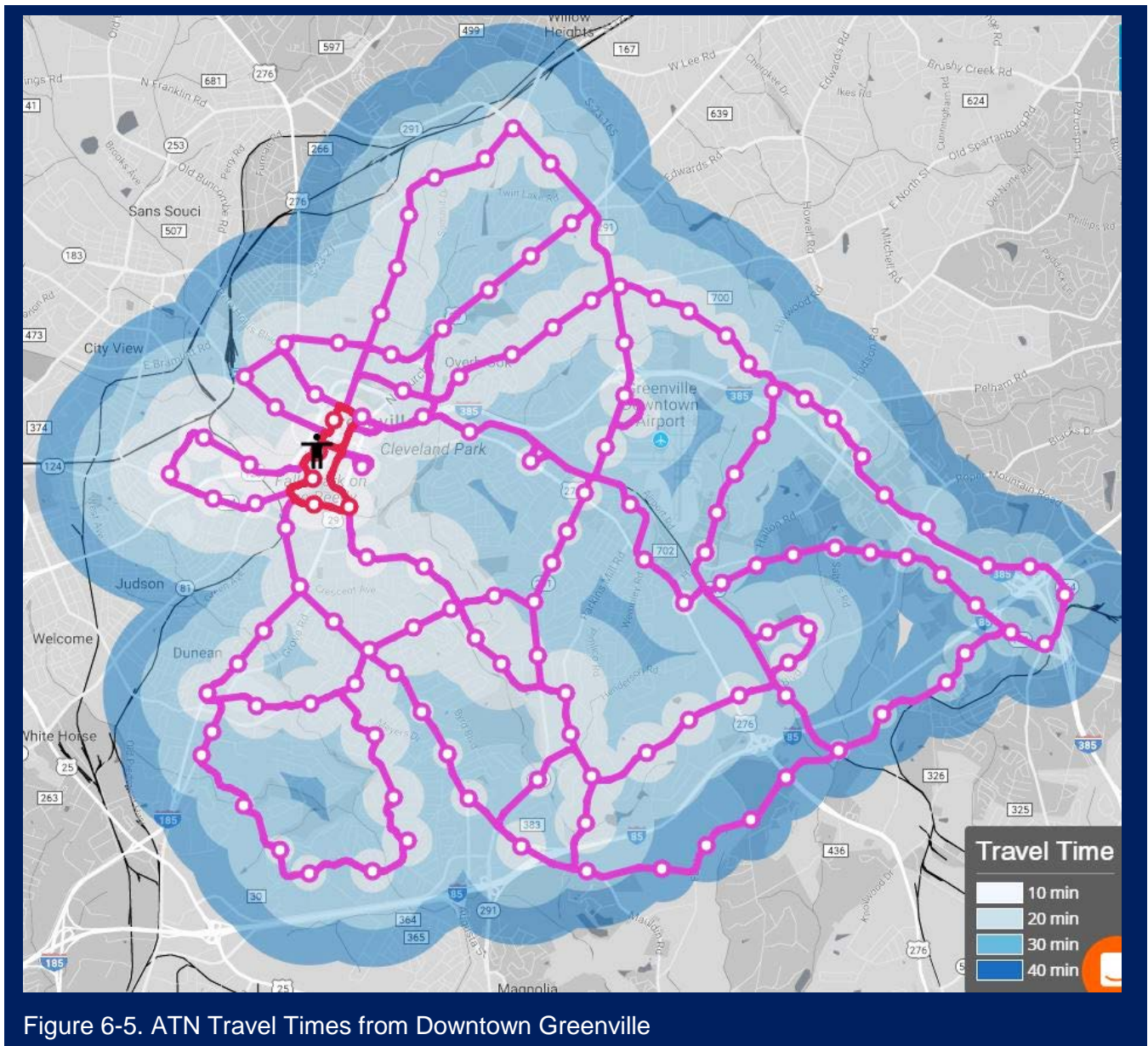
6.8.3 Improved mobility/accessibility

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 trips¹³. 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.

¹³ 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.



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 102¹⁴) 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).

¹⁴ 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.

Surface 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 Extens	NSPD	LRT	4.8	7	704	359	17.75	8,700	2.86
MN	Minneapolis	METRO Blue Line exte	NSE	LRT	13.5	11	1,563	784	27.50	16,500	5.49
MN	Minneapolis	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 Extens	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.

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).

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

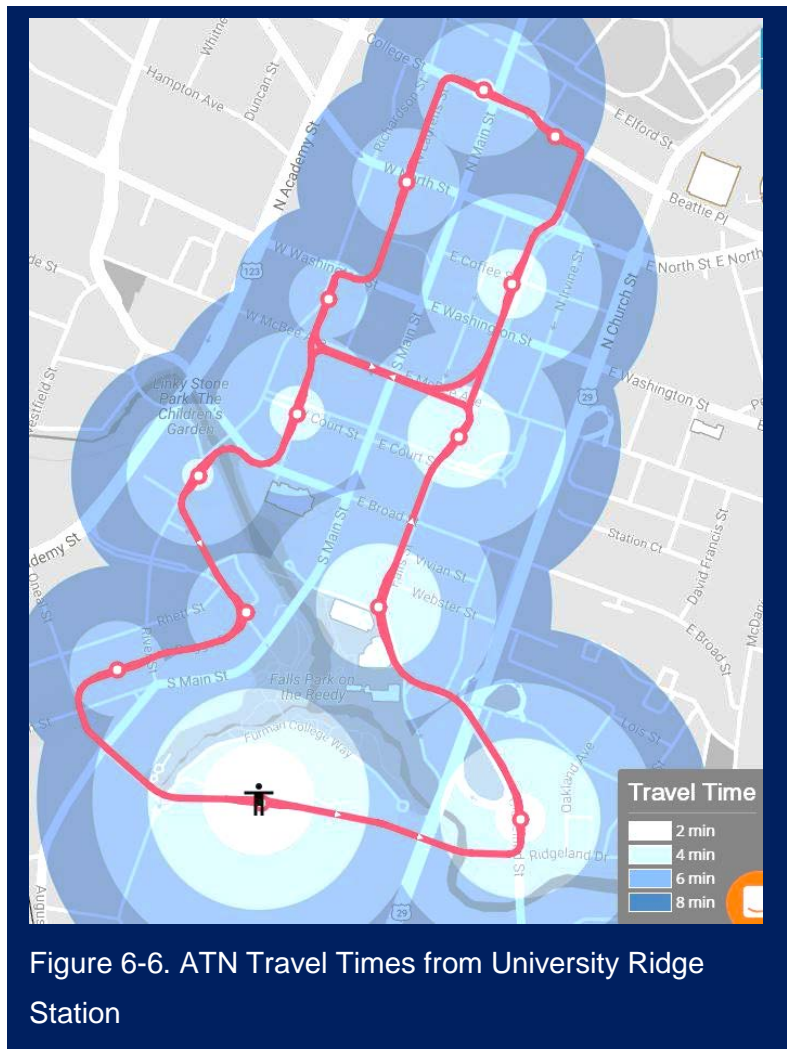


Figure 6-6. ATN Travel Times from University Ridge Station



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

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

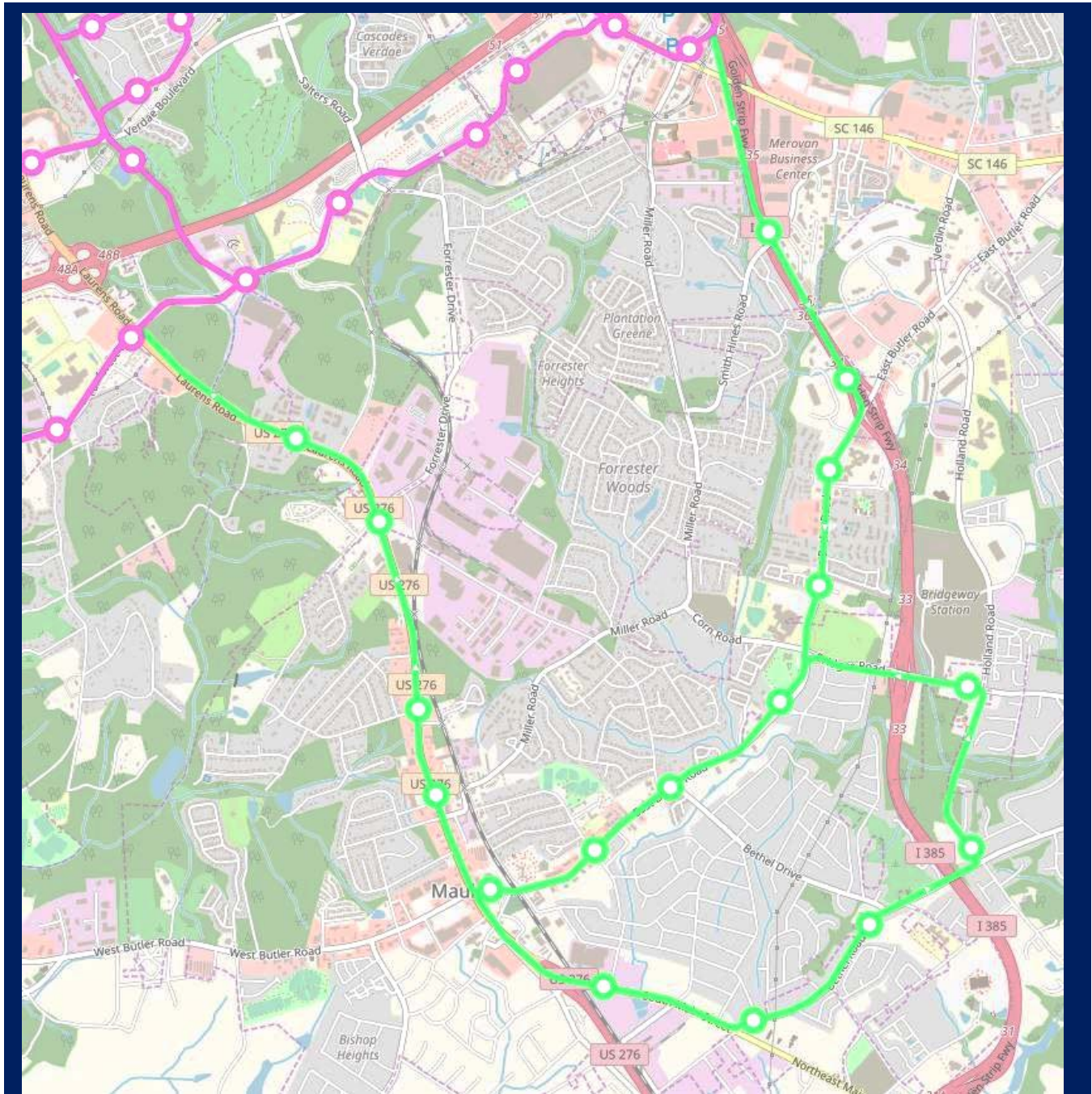
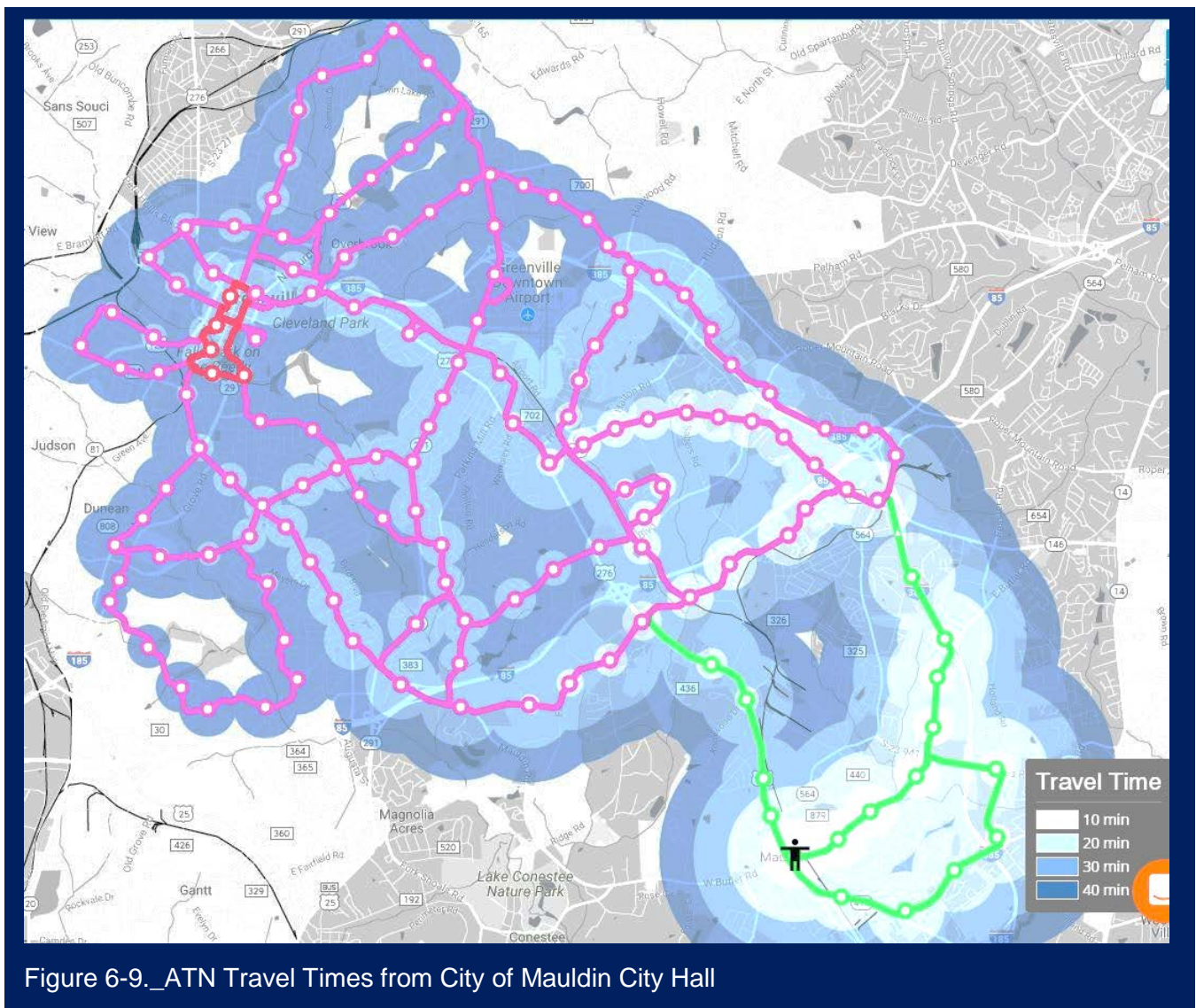


Figure 6-8. City of Mauldin ATN Layout

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.



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.

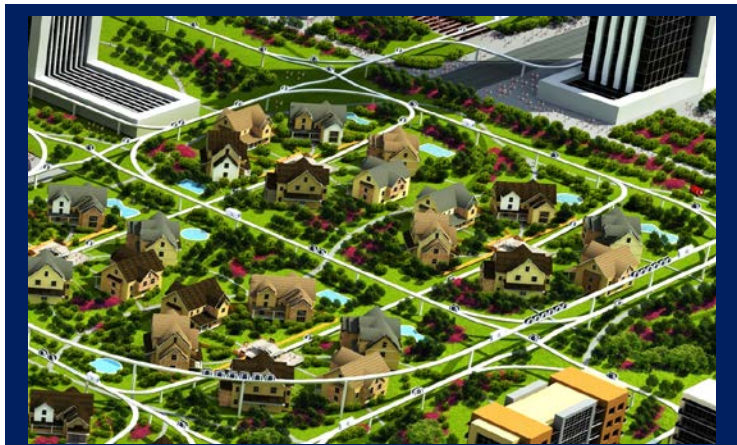


Figure 7-1. Walkable Car-Free Real Estate.

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.

7.6 STATION REVENUES

Strategically located stations could incorporate local businesses such as coffee



Figure 7-3. Neighborhood Station Incorporating Small Businesses

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 significant potential future growth in property tax values.¹⁵

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.

¹⁵ 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 provide 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.