Greenville County Economic Development Corporation

PERSONAL RAPID TRANSIT EVALUATION

An addendum to

The 2010 Multimodal Transit Corridor Alternatives Feasibility Study

FINAL REPORT

June, 2014

1. Executive Summary

Personal rapid transit (PRT) is a form of driverless transit that offers a very high level of service characterized by frequent stations, short waiting times, and nonstop seated trips. Now that PRT is commercially available from three different suppliers, the Greenville County Economic Development Corporation (GCEDC) commissioned this report as an addendum to the 2010 Multimodal Transit Corridor Alternatives Feasibility Study that found bus rapid transit (BRT) to be the preferred transit solution for the GCEDC transportation corridor. The purpose of this report is to act as an addendum to the Feasibility Study adding PRT to the modes considered for the GCEDC corridor.

The three suppliers with commercially-available PRT systems are Ultra, with a system at Heathrow Airport, UK; 2getthere, with a system in Masdar City, UAE; and Vectus, with a system in Suncheon, Korea. Other suppliers with systems approaching readiness include Modutram in Guadalajara, Mexico and Taxi 2000 in Fridley, Minnesota. The Morgantown PRT system in West Virginia has been in operation since 1975 but the supplier, Boeing, is no longer in the PRT business.

When compared with cars and conventional transit, PRT is found to be a transit system that is more like cars than transit. This conclusion is verified by the finding that, between downtown Greenville and CU-ICAR, a PRT system will attract more than three times the ridership of a BRT system. While the capital costs for the PRT solution will be slightly higher than those for the BRT solution, the operating costs are projected to be slightly lower and the total annual costs are thus anticipated to be similar. Three times the ridership for the same cost is a remarkable difference. While the BRT system along Laurens Road is projected to only cover about 17% of its operating costs through farebox revenues, the PRT solution is expected to cover up to 96%. This means, once the capital costs are covered (approximately $59 M), the system will be mostly self-supporting which is very unusual for a US transit system.

The PRT solution was found to be superior to the BRT solution in most aspects except for capital costs (which were higher but offset by lower operating costs) and the feasibility of an extension to Mauldin. PRT connectivity with the proposed Southeast High Speed Rail was found to be feasible. Connectivity with local bus service and proposed regional BRT systems was found to be good. Bus service along the adjoining portion of Laurens Road could be reduced since the PRT system would provide better connectivity.

Covering the capital costs of a transit system can be challenging. Federal assistance is available but competition is fierce, and the ridership (even though much higher than the BRT ridership) is probably not high enough to qualify. In addition, Federal requirements could significantly increase the project costs. Monetizing the benefits of the new transit system through some type of incremental property tax combined with other innovative funding sources and traditional financing mechanisms, such as private sponsorships, advertising, park & ride agreements, will probably be required.

A wider network of PRT guideways beyond the GCEDC corridor is anticipated to have greater utility. For example, a downtown Greenville loop could connect the GCEDC corridor system, to existing parking decks and major attractor locations, and be the beginning of an even larger network. Such a loop could make the downtown area even more attractive than it already is. Bold possibilities could include turning part of Main Street into a pedestrian mall served by nearby PRT stations and supplemented by automated shuttles. Once expanded into the more densely populated areas, the network could help improve mobility and decrease congestion while being fed by bus transit systems serving less dense areas. The resulting combined high-quality transit network would make businesses, shops, hospitals, and schools more accessible while reducing congestion and energy use and increasing safety and sustainability – all leading to economic vitality, increased property values, and improved quality of life for all Greenvillians.

The Greenville-Spartanburg (GSP) International Airport is another niche PRT location that was investigated. Passengers using its 1,506 stall economy parking lot have to walk over 1,000 feet to the terminal~~s~~. Five automated transit alternatives were investigated to transport people between the lot and the new terminal expansion which is presently under construction. These included three PRT alternatives, a group rapid transit (GRT) alternative and an alternative utilizing a driverless shuttle vehicle (such as Navia). While the capital costs varied from $5 M to $19 M, the operating costs also varied considerably, with the result that the total annual costs of each alternative did not vary greatly. When compared to the revenue generated by the parking lot, the total annual costs were found to vary from about 49% to 65%. The PRT solutions were found to provide the lowest trip times and two of the PRT solutions did not interfere with surface traffic making them likely candidates for the preferred solution.

2. Introduction

In March, 2010 the Greenville County Economic Development Corporation (GCEDC) completed its Multimodal Transit Corridor Alternatives Feasibility Study which examined transit alternatives for a 3.42 mile rail corridor it owns (see figure below) and beyond. The Feasibility Study area extended from downtown Greenville going south on the corridor. Research completed in 2009 compared bus rapid transit, diesel light rail transit, light rail transit, commuter rail, and streetcar options and found bus rapid transit (BRT) to be the preferred solution.

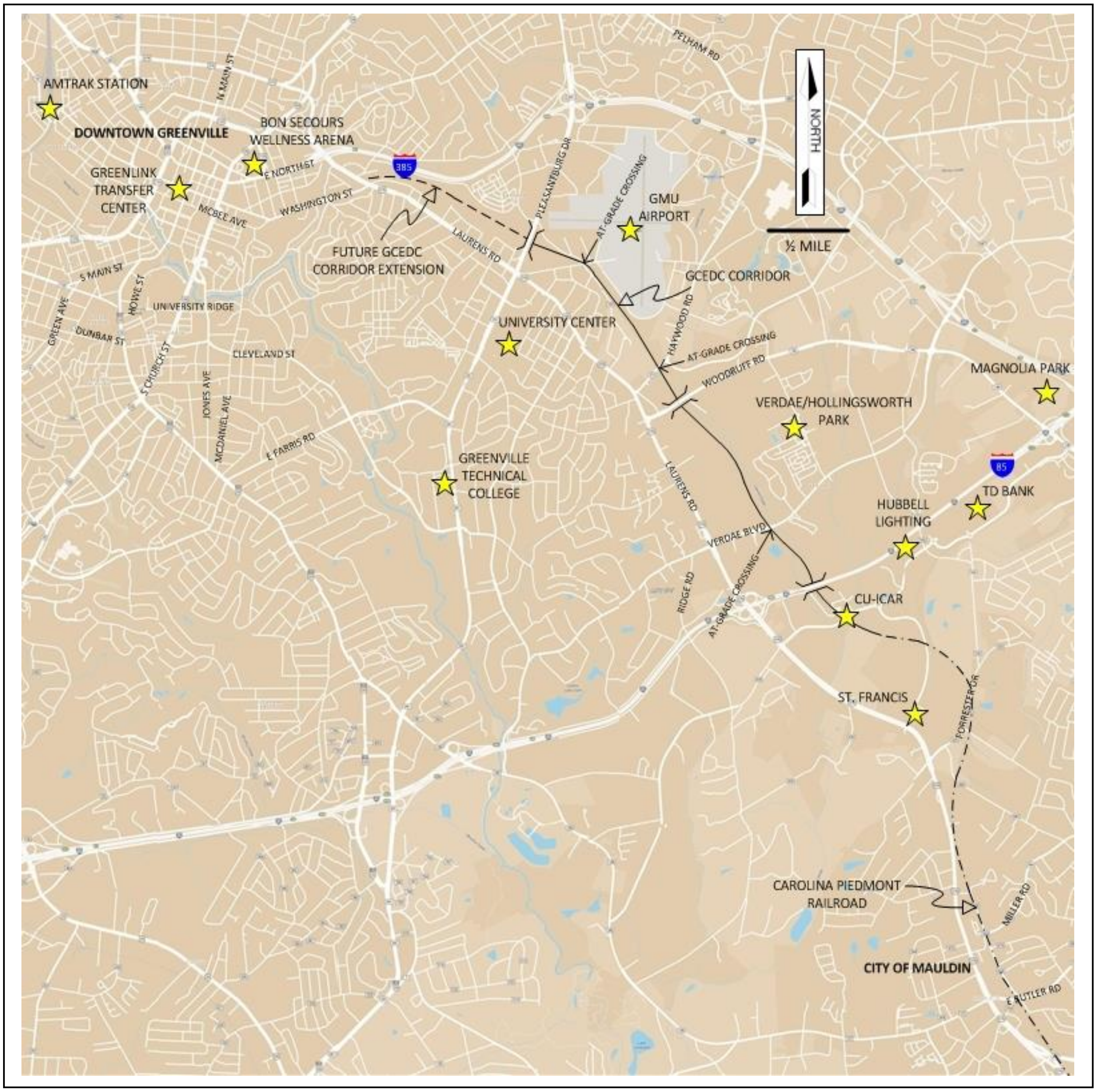

Figure 1 – GCEDC Corridor

At the time of the report, personal rapid transit (PRT) was not considered since it was not commercially available. Since then three modern PRT systems, by three different suppliers, have entered public service. GCEDC therefore commissioned this investigation to add consideration of PRT as an additional alternative and compare it to the preferred BRT solution. The subject area of this study is from downtown Greenville in the north to CU-ICAR in the south. Additionally this study includes investigating an extension to Mauldin and the potential for possible niche PRT applications in the Greenville area.

This study is based on projected conditions in the year 2020 using 2010 Census data. It focuses on commercially-available PRT systems that are in public service while giving some consideration to emerging systems.

The report commences with a description of the public outreach undertaken followed by a description of PRT which includes a comparison with transit and cars. Quite detailed case studies of operational systems are provided. The study then investigates alternative GCEDC corridor applications as well as potential niche applications. Corridor ridership is estimated and implementation and funding is discussed after which conclusions and recommendations are offered.

Greenville is a community that values many transportation options: cars, buses, bicycles, walking – and the new PRT alternatives that are emerging as a 21st century option for choice riders. The GCEDC wants to develop a true multi-modal corridor in the former railroad right-of-way that it owns parallel to Laurens Road between Downtown Greenville and CU-ICAR. Improved connectivity will help create GreenVillages development – places where people love to live, work, shop, dine and play.

3. Public Involvement

Public involvement for this project commenced in May 2013 following an April article that asked: "Is Greenville Ready for Podcars?" and in tandem with an InnoVenture2013 Conference which featured some presentations on PRT and potential mobility improvements. A presentation on "GreenVillages" suggested that improved multi-modal connectivity, including PRT, between mobility centers would create developments in which people love to live, work, shop, dine, and play. A separate workshop was held to inform interested parties about PRT and gain their input regarding its ability to contribute to transportation solutions in Greenville. Over 35 people were involved over a six hour period, and a brief summary was produced (see Appendix A).

In conjunction with the above workshop, a website questionnaire was published and used to obtain public preferences regarding transit. When the answers were analyzed, it was found that the resulting coefficients for elasticity regarding trip cost, in-vehicle time and out-of-vehicle time were similar to those in Transit Cooperative Research Program (TCRP) Report #118[1]. Since the website questionnaire respondents did not comprise a statistically valid sample, the TCRP coefficients have been used in this study. However, the website results did serve to confirm that Greenvillians value these factors similarly to transit users in other communities. In other words, Greenville transit users adjust their use of transit in response to changes in trip cost, in-vehicle time, and out-of-vehicle time similarly to the way other US transit users do.

Media articles associated with InnoVenture2013 created a growing awareness of PRT potential. A group of GCEDC Advisors was identified to provide perspectives and feedback from the companies or interests they represented. A GreenvillePRT.org website was created to model the Austin PRT site. A November InnoMobility2013 Conference in the Greenville community brought additional publicity to PRT. A public workshop held at the Greenville Chamber as a part of InnoMobility2013 attracted about 60 individuals discussing business opportunities in designing and building PRT systems with leaders of two PRT companies: Taxi 2000 and Ultra Global PRT.

On February 3rd and 4th, 2014, at the commencement of this addendum project, two stakeholder/public meetings were held. Attendance was open to the public by public notice and by direct invitation. A total of over 40 people attended these two meetings. The meetings educated the attendees about PRT technology and presented three alternatives to be examined during the study:

1. Replicate the 2010 Feasibility Study route and station locations from the downtown Transit Center to CU-ICAR
2. Leverage the flexibility of PRT to improve Alternative 1 by adding stations, optimizing station locations, and reducing costs while also considering an extension to Mauldin
3. Investigate a niche PRT application at the Greenville/Spartanburg Airport (GSP).

Attendees provided input to assist in optimizing the station locations. They were also asked to suggest any other suitable location to be considered under Alternative 3 and none were suggested.

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[1] TCRP Report #118 Bus Rapid Transit Practitioner's Guide

A final stakeholder/public meeting was held on May 22, 2014, to present the findings of this study and obtain any additional input.

4. Attributes of Personal Rapid Transit

4.1 Attributes and Characteristics

The Advanced Transit Association (ATRA)[2] defines personal rapid transit (PRT) as having *all* of the following characteristics:

- Direct origin-to-destination service with no need to transfer or stop at intermediate stations
- Small vehicles available for the exclusive use of an individual or small group traveling together by choice
- Service available on demand by the user rather than on fixed schedules
- Fully automated vehicles (no human drivers) which can be available 24 hours a day, 7 days a week
- Vehicles captive to a guideway that is reserved for their exclusive use
- Small (narrow and light) guideways, usually elevated but also can be at or near ground level or underground
- Vehicles able to use all guideways and stations on a fully-connected network.

Any transportation system meeting all of the above characteristics will provide an exceptional level of service that, many studies indicate, will attract a high ridership level. However, such a system may prove to be considerably more expensive than the BRT solution recommended by the 2010 Feasibility Study and could, thus, be quickly eliminated from further consideration. For this reason, the above PRT definition will not be strictly applied in this study in the hopes of developing a solution that provides most of the advantages of PRT at considerably lower costs. The following are the primary modifications to the above definition that will be considered in this report:

- Occasional stops at intermediate stations may be allowed (particularly during peak hours)
- Ridesharing may be required (particularly during peak periods)
- Controlled crossing of guideways by pedestrians and vehicles may be permitted.

4.2 Comparison with Cars and Conventional Transit

In the discussion which follows, PRT is compared with car and transit (light rail or bus) for a number of different attributes. For each attribute, each mode is rated Poor (red), Acceptable (yellow), or Good (green), on the summary (Table 1) overleaf. Note that this is a generic discussion and is not adapted to be installation-specific.

[2] ATRA, *Personal Automated Transportation: Status and Potential of Personal Rapid Transit*, 2003

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** ✔

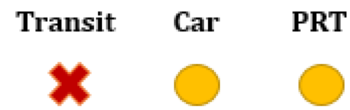
Table 1 - Benefits Comparison Table

Technology Level (or Maturity)

Transit	Car	PRT
✔	✔	●

Transit systems and autos are both mature industries. PRT has been operating since the early 1970s, in the form of the Morgantown, WV, system. Modern PRT has been in public operation since 2010, and there are now three suppliers with commercially-available systems as described later in this section. Thus, while not yet mature, PRT has advanced beyond the conceptual phase.

Trip Time



Automobile trips in urban areas do not typically result in low travel times, because of the numerous stop signs, traffic lights, and often congested roadways that have to be negotiated. This is true even for trips that are undertaken at high speeds on freeways, since low speed segments at each end of the trip invariably offset these high-speed trip segments. Analysis of trips at all times of the day - in the Denver Metropolitan area - reveals that trips shorter than about twelve miles are undertaken at average speeds of less than 30 mph. Bus speeds over a 12 mile route average approximately 16mph.

Light rail (LRT) seems fast with its 55 mph maximum speed, but this is impacted by the numerous stops that must be made. The 12.5 mile light rail trip from Mineral Station to Downtown Denver is scheduled for an average speed of 26 mph.

A PRT system, with a maximum speed of 35mph, will average about 30 mph over a 12 mile trip. This takes account of acceleration and deceleration at the origin and destination, as well as the fact that there will be no intermediate stops. It also takes into account the extra travel distance of approximately one half mile, due to a one-way guideway system, with guideways and stations at half mile intervals.

Thus, a PRT system with a maximum speed of 35mph can be expected to have better travel times than buses and similar travel times to LRT, or car, over a distance of less than about 12 miles in an urban setting.

However, travel time is only part of the total trip time. Buses and LRT almost never pick up their passengers at their homes and deposit them at their workplaces. Even cars have to sometimes be remotely parked. Almost all public transit trips involve walking segments, at the beginning and end, and many also require transfers. PRT networks should be built on a spacing of approximately one half mile, so that stations are located throughout the service area. If this is accomplished, the maximum walking distance should be about one quarter of a mile, and this portion of the trip should take less time than on other forms of transit.

Another aspect of total trip time is the time spent waiting for transit. Few transit systems have times between vehicles of less than 5 minutes during peak periods. Off peak, this can increase to half an hour or more. PRT systems are designed such that vehicles are usually already waiting at stations during off-peak periods, and so the average wait times should be less than one minute, at any time of the day or night.

When all of the above factors are considered, total trip times for PRT in urban settings are much closer to total trip times for cars than transit. These PRT trip times are still not considered “good” relative to what people want from urban transportation systems. Good city-wide trip times will become available when a one half-mile PRT guideway grid covers a metropolitan area, and PRT maximum speeds exceed 40mph.

Operating Cost per Passenger

Transit costs have two basic components – capital cost for the initial vehicles and infrastructure, and operating and maintenance costs for running the system. Operating costs are somewhat less complex and will be dealt with first.

The current cost of operating and maintaining the Morgantown people mover system is $1.50 per passenger. This includes both the vehicles and the infrastructure. It compares with $4.63 per passenger for the Denver Regional Transportation District (RTD) - note that ticket prices are subsidized below cost by tax revenues. While this RTD figure includes buses and the light rail trains and infrastructure, it does not include maintaining the streets the buses run on, whereas the PRT costs do include PRT infrastructure maintenance.

The IRS automobile rate is .56¢ per mile. This exceeds the Morgantown costs for trip lengths exceeding 2.8 miles. It also excludes the cost of maintaining the road system used by automobiles; though it includes gasoline taxes that partially cover those expenses.

Because a typical pod will undertake 50 or more trips per day, the total number of vehicles needed will be much less than the number of automobiles needed to meet a similar travel demand (it is estimated that automobiles are unused more than 90% of their lifetimes – making them a huge underutilized capital cost for individual owners – costs that only make sense to bear if alternatives, like PRT and user-friendly pedestrian and low-impact vehicles systems, are unavailable.) Thus, PRT will result in a savings in vehicle costs (for individuals and fleets) and related savings in parking facilities needed.

The per-ride operating costs of some transit systems are provided below:

Morgantown PRT	$1.50
Denver International Airport (DIA) Automated People Mover	$0.61
DIA shuttle bus	$3.50
Denver Regional Transportation District (Bus & Light Rail)	$4.63

Since modern PRT systems are expected to function at least as efficiently as Morgantown, it seems clear that operating costs should be very competitive with other forms of transit and with automobiles. Carnegie[3] estimated PRT operating and maintenance costs ranging from $0.30 to $0.80 per passenger mile.

[3] Carnegie, John and Paul Hoffman. *Viability of Personal Rapid Transit In New Jersey*, New Jersey, 2007

Personally owned vehicles (POV) are relatively expensive to own and operate. Studies show that owners pay an average of between $5,000/year and $10,000/year to purchase, insure, maintain and operate their car. Most personal vehicles are parked more than 20 hours per day. However, people appreciate the convenience, freedom, and flexibility of personal vehicles, and have been willing to pay for those values.

Bus transit and PRT vehicles are more expensive to purchase. Buses have larger capacity. PRT has expensive guidance equipment. Both buses and PRTs can be shared by many riders during the day, and generally are in service many more hours per day than POV. Thus, the average operating costs per rider are much lower. However, because PRT vehicles do not operate on a schedule but on demand from riders, their operating costs tend to be lowest per passenger mile.

Infrastructure Capital Costs per Passenger

Infrastructure is very expensive for all forms of transportation. Roads are typically seen as a service of government and are heavily subsidized. Transit infrastructure is also heavily subsidized. Costs of PRT systems are not currently seen as a public obligation, thus, capital costs are somewhat more complicated to compare. First, one has to prove that one PRT guideway can carry approximately the same number of passengers as one light rail line, under the same conditions of waiting and travel times. If one guideway has similar capacity to one rail line, then it is easy to see that the small pods (compared to the heavy “light” rail cars) will require much less infrastructure and, therefore, less capital cost. In addition, although there are many more pods than rail cars required, their total weight is less than the total weight of rail cars. This, combined with the economies of mass-producing many small vehicles, should result in lesser capital cost too.

When compared with the infrastructure required for automobiles, pods require much less width, because they are automatically, and therefore, much more accurately controlled. A PRT guideway only needs to be about seven feet wide, compared to the 11 to 12 feet width of a typical highway lane. The cost savings of the narrower guideway will be somewhat offset by the extra cost of other appurtenances required to support automation. If the guideway needs to be elevated, then the costs may well exceed those of a highway lane. A subterranean PRT tunnel (like an underground subway) will probably be even more expensive than an elevated guideway (and for this reason, none are presently proposed.)

On the other hand, a PRT tunnel or elevated guideway should be much less expensive than an automobile tunnel or elevated roadway, because of the narrower width, the reduced need for ventilation, and the restricted height and weight of the vehicles.

PRT installations often have the ability to reduce the money that needs to be expended on other systems. Examples include in-town parking structures being replaced by less expensive remote surface lots, and expensive intermodal facilities being replaced by PRT systems connecting existing stations and stops that no longer need to be co-located.

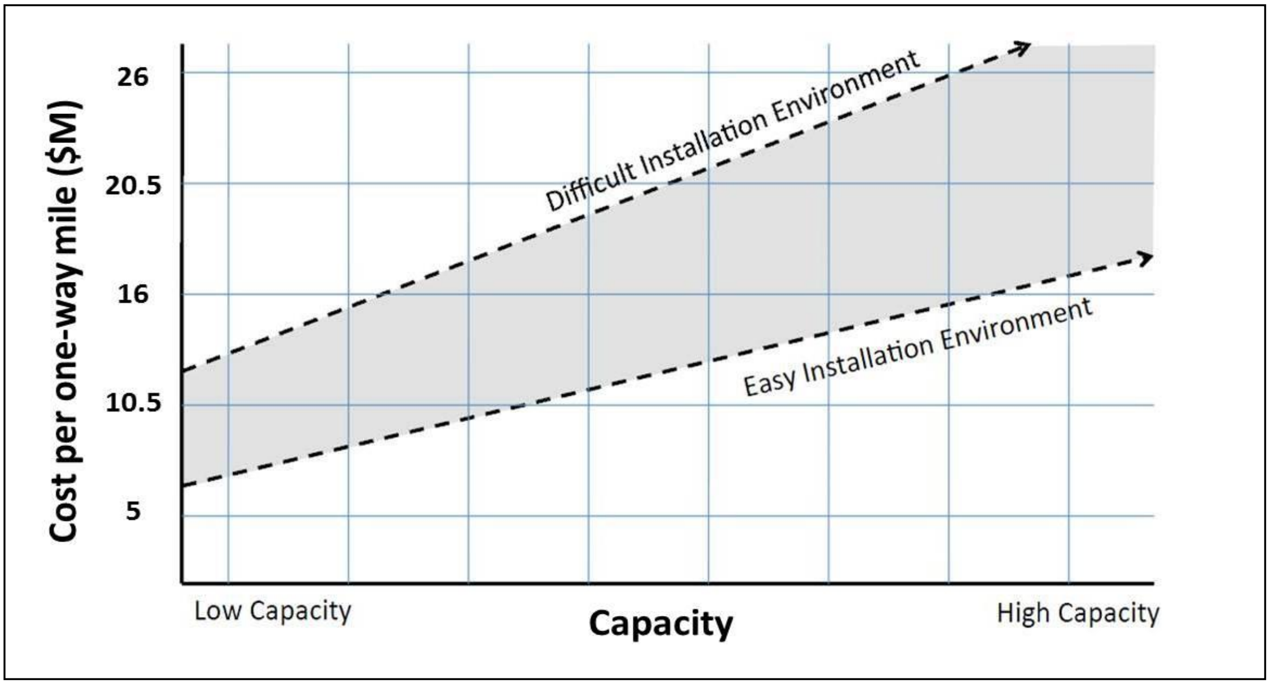
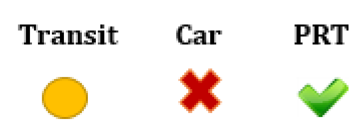


Figure 2 – PRT capital costs chart provided by Ultra; conversion to US units by PRT Consulting, Inc.

The figure above shows the range of capital costs to be expected. Costs increase with higher capacity and more vehicles as well as in more rugged terrain and/or with greater construction challenges such as swelling soils or adverse weather/seismic conditions. It includes all system costs except for right-of-way acquisition and utility relocations.

Accident Potential and Cost Savings



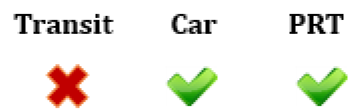
PRT systems are inherently safe because there is no crossing traffic – only merges and diverges. This is borne out by the Morgantown PRT system, which has completed over 140 million injury-free passenger miles. By contrast, other forms of surface transportation, with cars being the worst, would have injured over a 100 and likely killed somebody in that many passenger miles. Accidents involving transit vehicles or automobiles are extremely costly in terms of both property damages and personal injuries and loss of limbs and lives. Grade separated PRT is more expensive to build, but the reality of accident avoidance is huge savings to the traveling public and to society.

On-Demand 24/7

Transit systems usually provide frequent (5 minutes or less) service during peak periods. The service typically gets less frequent away from peak periods and is often totally non-existent in the early hours of the morning. On the other hand, automobiles are available all of the time. PRT systems are designed and operated in such a way that empty pods are automatically routed to empty stations where they will wait for passengers. Except during heavy peak periods, passengers arriving at a station should be able to immediately board a waiting pod. During off-peak periods, empty pods will be stored at stations, waiting for passengers, in a maintenance facility and/or in a storage area. There will be no need for a large system to ever shut down (except for segments requiring maintenance).

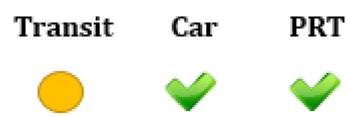
In a network layout guideway segments can be shut down with little impact on the remaining system (especially off peak). Only the stations associated with that particular guideway segment would be put out of service.

Transfers



Unlike transit, cars and fully developed PRT systems should seldom require transfers. Transfers from other systems to PRT, or even among different PRT systems, should be relatively convenient, because the close station spacing will provide numerous options, and the minimal waiting time will reduce disruption to travel.

Seated Travel



Both cars and PRT systems are designed for seated travel only. This allows vehicles to accelerate and decelerate more rapidly. Transit provides seated travel, much of the time, except during peak periods when most travel actually occurs.

Privacy and Personal Safety

Small PRT vehicles allow an individual or a few family or friends to travel to a destination and talk privately, and driverless pods allow riders to text or talk on the phone without distractions. Except for systems specifically designed to operate differently (in airports, for example), PRT systems will be operated on the basis of people traveling together only if they know each other and/or have the same destination. While this does mean that pod occupancies will be low, it also ensures privacy and a non-stop trip.

All vehicles will have alarm buttons and, possibly, video surveillance. Pods subject to alarms could possibly be directed to stations where emergency personnel are waiting. The Morgantown experience, with the PRT system often used by college students, has shown an exemplary personal safety record over 30 years, with only two incidents, each limited to verbal harassment.

Non-stop Travel

Transit has been rated more negatively than cars, because much transit travel is done in buses, which stop more frequently than cars. However, light rail may stop less frequently than cars. PRT pods are designed never to stop from origin to destination.

PRT systems are usually designed with all stations “offline” (see Figure. 3). This means each station is like a rest stop on a freeway with its own off- and on-ramps. Thus, pods in a station are bypassed by others not needing to stop at that station. Some systems can even allow each station bay to be offline from the others (see Fig. 4). In this way, someone taking a long time to board does not delay others using the station.

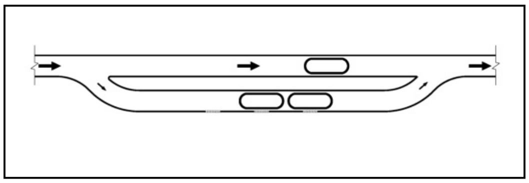


Figure 3 – Off-line station with in-line bays

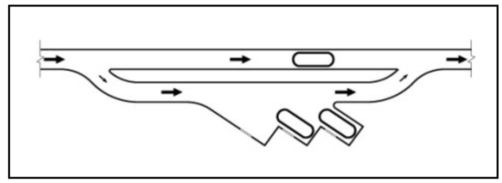
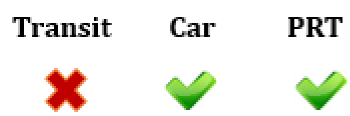


Figure 4 -Off-line station with off-line bays

Vehicle Waits for Passenger



Except for end-of-line situations, transit vehicles almost never wait for the passenger. On the other hand, automobiles always wait for their passengers unless they represent a shared vehicle. PRT manages to have pods waiting for passengers most of the time, while also avoiding the very low passenger to vehicle ratio exhibited by automobiles. During any one day, a pod will carry many tens of passengers – possibly more than a hundred for short systems.

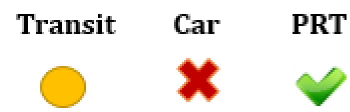
ADA Compliant

Transit systems comply with the Americans with Disabilities Act (ADA), but at large expense. Light rail stations require special ramps, buses require special lifts and service must be augmented with special buses.

Automobiles do not accommodate handicapped people very well – the blind cannot drive and wheelchairs usually require special vehicles. In addition, cars often require special modifications for the handicapped to drive them.

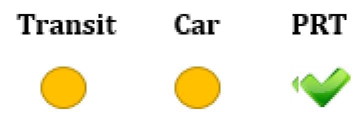
On the other hand, PRT stations will allow wheelchairs (pushchairs and luggage on wheels) to easily roll on board. Ultra has demonstrated the ability for Pods to park at stations with less than ½” tolerance, thus, ensuring the narrowest of gaps between platform and vehicle. The ½ mile spacing between most PRT stations will also facilitate handicapped access.

Security



By eliminating crowds at stations and in transit vehicles, PRT reduces transportation-related terrorist targets. In addition, it facilitates passenger processing by delivering a steady stream of passengers, as opposed to intermittent large groups.

User Friendly



Transit is somewhat user friendly for non-transfer trips, but the user is required to understand routes and timetables, have exact change or a monthly pass, must often climb stairs, and has little to no storage area for bags or luggage (aside from specially designated airport vehicles).

Cars require ownership and a driver's license (which requires the ability to drive), in addition to an understanding of routes. Drivers are also frequently challenged by distractions and poor visibility due to sunshine, night blindness, etc.

PRT only requires knowledge of the origin and destination stations. People simply need to know which origin and destination stations to use, how to use a station kiosk to request a T-pod, and which button to push to begin pod operation when they are ready.

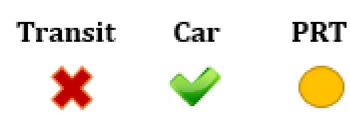
Snow And Ice

Transit systems vary in their resistance to snow and ice – steel wheel on steel rail systems typically have little trouble, provided grades are relatively flat, while buses will be stuck in slow traffic along with automobiles.

Inclement weather can be a major problem for autos, depending on the vehicle, the confidence and skill of the driver, and the abilities of all other drivers, some of whom can be quite inexperienced with poor weather driving conditions.

Rubber-tired PRT systems tend to be less tolerant of adverse weather conditions than steel rail-based systems, but more than cars and buses. The Morgantown system has operated successfully with a heated guideway system, though this is an energy-intensive solution that goes against sustainability principles of maximizing life-cycle energy efficiency. Some PRT systems use linear induction motors in combination with steel rails and operate with relative disregard to snow and ice.

Minimal Walking



Transit typically involves quite a lot of walking. Light rail stations are typically about a mile apart. Bus stops are often within a quarter of a mile of each other, but bus routes are often more than a mile apart. Most people are located beyond reasonable walking distance (1/4 mile) from a stop or station. For example, even once FasTracks is complete, 96% of the City of Denver (by area) will still be more than ¼ mile from a rail station. Many are forced to park and ride.

While automobiles typically involve little walking, remote parking is sometimes required.

A good PRT system will have guideways and stations spaced at about ½ mile intervals. This should keep almost all walking down to less than ¼ mile at each trip end. However, some passengers could experience total walking distances exceeding ½ mile.

Environmentally Friendly

Transit	Car	PRT
●	✖	✔

Transit is generally considered more environmentally friendly than automobiles. This is more likely for well-patronized rail, and possibly natural gas powered buses, than for diesel powered buses that spend large portions of the day driving around, mostly empty. A transit bus with less than 11 passengers is probably achieving less fuel efficiency per passenger than an auto with an average occupancy of 1.6 people.

The dramatic environmental impacts of automobiles are well-documented to include hazardous air emissions (from fossil fuel combustion), emissions of greenhouse gases (approximately 20 pounds of carbon dioxide per mile), and the life-cycle impacts of producing and disposing of the vehicles. More efficient vehicles are expected to become increasingly popular, including electric vehicles (powered by batteries, compressed air or hydrogen) and plug-in electric hybrids that run on electricity for all trips less than the battery range of 40-100 miles. Roads, freeways and parking lots devour a large amount of real estate, and contribute to storm water runoff problems, wildlife/pet safety problems, and frequent maintenance, costs of which have been increasing dramatically faster than costs of living and tax revenues for maintenance purposes.

In corridor or line-haul (as opposed to network) mode, PRT should be as environmentally friendly as light rail, or more so, because of the low energy use due to non-stop trips. In network mode, PRT has the potential to return some of the real estate used by roads. This is particularly true in downtown situations where one lane can only carry about 500 automobiles per hour, whereas one elevated PRT guideway has the capacity to replace a four-lane downtown road, freeing up the land for development, pedestrian malls or greenways.

Transit buses and PRT vehicles require maintenance and storage facilities, but not large parking lots. Cars create a high demand for downtown parking spaces and expensive parking decks as well as large parking lots in malls and other attractor locations. PRT can help maximize the effectiveness and income from existing parking facilities, reduce the need for new parking decks, and allow highest and best use of downtown space. Parking can be moved to fringe locations where park & ride lots can be located on inexpensive land. Urban transit corridors allow planning for trails, parks, and greenways as well as PRT systems that connect higher density communities.

Small electrically powered pods make little noise and vibration. Any pollution caused by the generation of electricity will be off site and subject to being reduced when the grid power source is upgraded for sustainability performance; e.g., renewable energy, carbon-sequestered fossil-fuel electricity generation, etc.

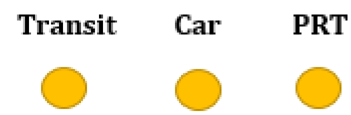
Energy Efficient

Transit	Car	PRT
●	●	✔

Bus-based transit is generally considered to be more energy efficient than automobiles, but as noted previously, it depends on ridership. Buses would be more energy efficient if they did not have to operate mostly empty most of the day. Even during peak periods, transit vehicles generally start fairly empty in the neighborhoods and arrive downtown fairly full. They then have to return to the neighborhoods fairly empty again. Thus, even in peak periods, they are only operating half full at best.

PRT, on the other hand, is much more energy efficient for three reasons: (1) PRT travel is non-stop and so little energy is expended accelerating, and energy is generated through regenerative braking – a feature available only on electric vehicles; (2) At 25-35 MPH, PRT travel is relatively slow compared to LRT and autos on uncongested roadways, and so little energy is expended combating wind resistance (the same auto will typically get 16% more miles per gallon at 40 miles per hour than at 70 miles per hour, (3) PRT systems should have less need to move empty vehicles around in off-peak periods.

Visually Appealing

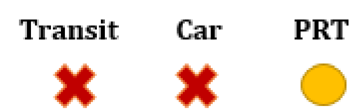


Visual appeal is in the eye of the beholder. It is such a subjective factor that the same rating has been given to each system.

Many PRT systems will largely consist of elevated guideways. Even though these guideways will be much smaller than elevated guideways for light rail or monorail systems, they will still create a visual impact. The impact caused by curvilinear elevated guideways, snaking through a facility, may be very desirable for a theme park or possibly an airport – maybe even for a downtown area. Some urban residents may view a “taxi on a monorail” as an iconic symbol of cutting-edge technology. However, it may be negatively perceived in a suburban neighborhood.

Each PRT system needs to be carefully planned so that it fits in and complements the existing setting to the extent possible. New developments can be planned to unobtrusively accommodate guideways. This might mean planning for substantial lengths of guideways at ground level, which would also save money. On the other hand, it may mean going to the extra expense of underground guideways in sensitive areas.

Operates Inside Buildings



Transit systems are typically too big to operate inside buildings, although it would be possible to incorporate a light rail station inside an airport terminal building, for example. Unless they are electrically powered, buses and cars cannot readily operate inside buildings because of exhaust gas issues.

PRT systems are small and electrically powered and can relatively easily be accommodated inside buildings. Studies have shown that PRT systems could operate inside airport concourses, replacing moving sidewalks. PRT vehicles parked end to end only provide a floor load of about 41 pounds per square foot, which is less than the design loading for most building floors.

4.3 Suppliers with Commercially-Available PRT Systems

The Ultra PRT System

Figure 5 - Ultra vehicles operating at Heathrow

Offered by Ultra Global PRT of Bristol, United Kingdom, the Ultra system[5] is rubber-tired, battery-powered, and runs on an open guideway. The front wheels are steerable, and the vehicle keeps itself on the guideway without any physical lateral guidance (using lasers), simplifying switching, which is accomplished by steering. This system has been in operation at London's Heathrow International Airport since April, 2011. The commitment to using off-the-shelf technology, wherever possible, coupled with a rigorous testing and development program, has allowed the Ultra system to be the first modern PRT system to win a commercial contract. Heathrow Airport has expressed its satisfaction with the system by including significant expansion in its budget[6].

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.

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.

The 2getthere PRT System

Figure 6 - 2getthere Pod

2getthere[7], a Dutch company, has been operating an automated PRT-like shuttle bus system, in cooperation with Frog Navigation Systems in Rotterdam, Holland, since 1999. Their true PRT system went into operation in Masdar City in the United Arab Emirates in November 2010. An expansion to this system to serve the city center has recently been announced.[8]

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

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[5] http://www.ultraglobalprt.com/

[6] http://www.ultraglobalprt.com/heathrow-announces-plans-additional-personal-rapid-transit-prt-system-heathrow/#

[7] http://www.2getthere.eu/

[8] http://www.triplepundit.com/2014/01/interview-steve-severance-makes-business-case-masdar-city/

The Vectus PRT System

Vectus[9] 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 now appear to have accomplished both of these goals.

Figure 7 - The Vectus T-Pod

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, Korea, uses conventional rotary motors which obtain wayside (third rail) power. Propulsion batteries are not required, allowing the vehicles to be lighter-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.

4.4 Other Suppliers

The business and technical capabilities of suppliers that do not yet have commercially available systems are examined, highlighting the strengths and weaknesses. Only those suppliers that have, at a minimum, a full-scale guideway and a vehicle capable of carrying passengers under control of a fully functional operating system are discussed.

Modutram

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 and gasoline motors, and function in a manner similar to hybrid automobiles.

Figure 8 - Modutram Podcar on Guideway

The Modutram system has been designed specifically for the Mexican climate and is not 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 and, more recently, a demonstration system that has carried passengers in four-passenger vehicles.

9 http://www.vectusprt.com/EN/

Modutram appears best suited for campus type operations such as universities and hospital centers. The system is designed for speeds up to 40 mph with minimum headways of 3 to 4 seconds. Its costs are unknown, but from the appearance of this system, will likely be in line with or lower than the costs of the father of modern PRT systems the previously discussed PRT systems.

Taxi 2000

Taxi 2000 was originally developed by Dr. Ed Anderson, thought by many to be the "father" of modern PRT. Despite numerous papers and much engineering and design work, the system has not progressed beyond the short test track and single demonstration vehicle that were built over 10 years ago. The design is very carefully thought out and appears to offer a system that will offer both high capacity and all weather capabilities.

Figure 9 - Taxi2000 on Track

Taxi 2000's SkyWeb Express system was originally implemented and tested via a joint venture with Raytheon in Marlborough, MA where a 1 mile, multi-vehicle system operated for technology demonstration purposes on the Raytheon Campus. Taxi 2000 maintains a fully functional electronic vehicle on an indoor track which is operated by the echoTM controls at its office in Fridley, MN.

Third party evaluation of SkyWeb's echoTM control system has been conducted by Honeywell Aerospace. This independent report substantiates the development of an operational (commercial) system that meets the requirements and replicates the current performance and operating parameters as intended and found nothing to "…preclude the ability to achieve a headway as low as 0.5 seconds."

Taxi 2000 has expressed considerable interest in a PRT application in Greenville and the potential for PRT development capabilities in the area.

5. Case Studies of Operational Systems

5.1 Morgantown/WVU PRT[10]

Summary

West Virginia University Personal Rapid Transit (WVU PRT) is an Automated People Mover located in Morgantown, West Virginia, a community of approximately 30,000 residents. The enrollment at the University is approximately 19,000 students, with 7,500 university staff. The system connects the three campuses of West Virginia University and was built by the U.S. Department of Transportation and Boeing Vertol in the 1970s. It is the first of its kind in the world.

To many who work in the field, it is actually considered a *quasi*-PRT system because it lacks some basic features of PRT, such as 100% on-demand service. Therefore, to help distinguish it from other systems in progress, it is often referred to as automated Group Rapid Transit (GRT).

An experiment in energy efficient public transportation at the time, it has now been in operation with first-rate reliability for over thirty years. The cost to ride the Morgantown/WVU PRT is nominal, to say the least. Included in undergraduate tuition and fees, students simply swipe their IDs at the station, while visitors and citizens only pay $0.50 to enjoy the bypass of parking and traffic hassles, earning it a reputation as the easiest, fastest, and least expensive mode of transportation in town.

History

In the 1960's, WVU expanded to a second campus two miles away that was served only by two hilly roads, causing major difficulties in mobility. At the time, buses shuttled students and staff back and forth between campuses, but they would soon experience severe traffic congestion. At one point, to reduce daily student travel, the university was forced to require students to take classes at only one of the two campuses.

To address the rising concerns over the escalating costs and losses in efficiency of public transit, the Morgantown/WVU PRT project was proposed in 1969 and was backed by U.S. President Richard Nixon as a demonstration project for modern rapid transportation. To fully understand the greater context, however, let us keep in mind the U.S. was also amid the first major OPEC oil crisis.

What started out as a demonstration project estimated to cost between $15 to $20 million dollars quickly turned into a political chess piece in the presidential election campaign of 1972. Pressure applied by the administration to complete the project before the next election combined with the uncertainty of this new technology resulted in an approximately $130M system which took nearly a decade to complete and is much more awkward and cumbersome than many had anticipated. Although not exactly what was initially designed, the system is regarded as a great success, having achieved world "firsts" for innovations being put into public service that include:

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[10] Extracted from: C&S Companies, Feasibility of PRT in Ithaca, New York, September, 2010

● First fixed guideway transit switching via in-vehicle switching, rather than track switch.
● First "demand mode" fixed guideway transit service.
● First transit control system whereby central control communicates to vehicles, providing automated vehicle control, via inductive wire loops embedded in the guideway.
● First "moving slot" control system.
● First automated re-distribution of empty vehicles to match predicted demand

Operations

Morgantown/WVU PRT operates at between 98% and 99% availability (transit level of service A is 97.5%). Currently, the total staff is 48 and includes a manager, four supervisors and five operators. The maintenance staff includes a manager, two supervisors and 26 technicians. Support personnel include three engineers, three stores personnel and two business people.

Vehicles

The original fleet of vehicles is still operating. Each of the 73 vehicles used on the system weighs 8,760 pounds (3.97 t) and can reach 30 miles per hour (48 km/h). The network serves about 16,000 riders per day. The record for most riders in a day is 31,280, set on August 21, 2006.

Figure 10 - Fiberglass-bodied vehicles are well-lighted, climate-controlled and carpeted.

The cabs contain eight fixed seats; four in a 'U' shape at the front of each vehicle and a matching four at the rear. In the center of the cars is standing room designed for twelve passengers, who are provided with four poles to grasp, giving each car a maximum capacity of twenty.

Vehicle features include automatic pneumatic leveling, a cabin heating/cooling system, welded steel frame, emergency exit rear window, impact collapsible front bumper, rigid rear bumper, emergency braking deceleration, and passive power collection from guideway power rails.

Vehicles steer by means of side guide wheels that sense the location of the left or right guide-rail. Although the vehicles are built upon a steer-able rubber-tired platform, they do not navigate autonomously. The vehicles are controlled via communications from the station control center through the communication loops in the guideway. The vehicles are directed either left or right at the appropriate speed and four-wheel steering is used to achieve a 30 foot turning radius.

The vehicles are maintained on a predetermined scheduled maintenance basis with 3,000-mile intervals. Additional tasks are accomplished at 6,000, 9,000 and 12,000-mile intervals. The propulsion motor is rebuilt every 90,000 miles; a schedule that essentially rebuilds the vehicle continuously.

Operating Modes

The system has three modes of operation: Demand, Schedule, and Circulation. Demand and Schedule modes are designed to operate during times of peak demand and Circulation mode is used during off-peak service. The Demand mode attempts to capture the on-demand aspect of PRT, the other two modes are prescheduled vehicle operation patterns intended either to optimize throughput during peak demand or to limit operating expenses during off-peak hours.

Demand mode reacts dynamically to passengers' request for service. The algorithm governing the Demand mode balances two parameters, passenger wait-time and vehicle occupancy. Once a passenger enters a station and requests service to a destination, a timer starts. If the timer reaches a re-determined limit, typically 5 minutes, a vehicle is activated to service the request even if no other passengers have requested the same destination. Also, if the number of passengers waiting to travel to the same destination exceeds a predetermined limit, usually 15 people, another vehicle is activated to lend support.

Once activated, a vehicle opens its doors and an electronic display prompts passengers to board. The vehicle doors remain open for 20 seconds allowing passengers to board. The doors close automatically, and the vehicle departs to its final destination, avoiding any intermediate stations. The two parameters that govern the algorithm, maximum passenger wait time and vehicle occupancy, can be varied by central control.

In Schedule mode vehicles travel direct from origin to destination based on predetermined schedules. For high demand periods with well-known travel-demand patterns, Schedule mode operates slightly more efficiently than Demand mode. During peak demand periods, operating in either Demand or Schedule mode, the system transports approximately 1,500 passengers per hour. Historically 80% of travel demand is between the Beechurst and Towers Stations. Periods of peak demand coincide with the 20-minute period between scheduled classes.

The average wait for passengers traveling between Beechurst and Towers stations during peak demand is about 1 minute. If the system is in Demand mode, the 15-person rule is usually triggered after about 60 seconds. During the 20 seconds in which the vehicle doors are open, more passengers may arrive and board, often filling the vehicle to capacity. Wait time is higher at less busy stations.

During off-hours, Demand mode would result in many nearly empty vehicles traveling about the system. During periods of low demand the system switches to Circulation mode which operates like a local bus, stopping at each station along the route on a preset schedule. Passenger travel time to destination lengthens while the system operates more cost-effectively.

Performance

In the 2006 fiscal year, the PRT system broke down a total of 259 times for a total of 65 hours and 42 minutes, out of a total of 3,640 hours and 15 minutes scheduled running time, which equates to about 98% availability. Of those 259 breakdowns, 159 were caused by vehicle-related problems. Operators are working to improve efficiency by reducing this vehicle downtime.

Since the system's completion in 1975, technology for such systems has advanced considerably, while the control equipment for the Morgantown/WVUPRT has changed very little. The control room is said to resemble a NASA mission control room from the 1970s, though the underlying electronics are more modern. Despite these factors, the overall availability of service (98%) exceeds the original design specification of 96.5% availability.

On April 4, 2014, the West Virginia University Board of governors approved improvements to the PRT system. [11] The PRT upgrade authorized up to $60 million in bond funding from WVU fees and federal grants for the second phase of a modernization plan. The work includes tunnel repair and control system electronics that operate the track, stations, pay booths and other items. The control system improvements are expected to improve overall reliability.

Guideways

In contrast to many other automated people mover systems, the Morgantown/WVU PRT relies on rubber tires rather than rail for movement. Due to Morgantown's snowy winter climate, the concrete pathways feature embedded piping containing a glycol solution used to melt snow and ice. Several stations along the track help to heat the glycol solution.

Figure 11 - Guideway view.

The guideway also houses inductive communication loops through which signals travel between vehicles and the control and communications equipment. These messages include a stop signal that generates a signal to decelerate and stop the vehicle ±6 inches from the loading/unloading platform gate. The loops also include a switch tone transmitter which signals vehicles to steer right or left. Calibration loops generate a signal to provide measured distance reference. This signal is used to calibrate each vehicle’s odometer.

Additional embedded loops facilitate communication with the vehicles to send performance level, braking command, door command, and identification request signals. Presence detectors are embedded into the guideway and are used in the collision avoidance system. Power is distributed to the vehicles via high-voltage passive channel conductors. Although the guideway was built using conventional standards, materials, and techniques, it comprised the majority of the cost of the system.

While portions of the PRT track are at or below ground level (35%), much of the system is built on elevated bridges and viaducts (65%). The viaduct spans are approximately 30 feet (9.1 m) in length. There are two distinct styles of viaduct in use on the system, with those constructed for the first phase being noticeably heavier-duty than those built for the second phase extension.

In order to enable the direct origin-to-destination service, each of the three middle stations, (Beechurst, Engineering, and Towers) have by-pass lanes and turnaround channels. These features allow each of the three middle stations to operate as offline stations. Having by-pass lanes alleviates the need to stop at any stations between origination and destination.

[11] sfgate.com/sports/article/WVU-board-approves-facilities-PRT-upgrades

This was a major advancement in mass transit concepts at the time, and still remains atypical of rail and bus service even today. Since the system is linear, the two end stations do not require by-pass lanes. Any vehicle utilizing these stations will, by nature, have passengers needing to disembark.

Control System

The Morgantown/WVU PRT was originally controlled by DEC PDP computers installed in 1971. Due to difficulty in procuring replacement parts, these older computers were replaced in 1997-1998 with Intel Pentium computers. The entire control system is divided into four parts: *central, station, vehicle, and guideway.*

Central Control collects destination service requests and distributes commands to the stations via 2400 bps modems links that connect central control with stations. The system features a large control room with 32 surveillance monitors, multiple computer consoles, and a mimic display that depicts the guideway, tracking vehicles relative to each presence detector. A three-person crew operates the control system and a flexible voice communication system assists the crew.

The basic control concept is based on the moving slot scheme. Imaginary numbered slots, 15 seconds apart, travel around the main guideway. Vehicles may only travel within one of these moving slots. In practice, expected vehicle position is checked against actual position at presence detectors.

Once a loaded vehicle's doors close, central control allocates a numbered slot to the vehicle. Acceleration from the station to the merge point with the main guideway is timed precisely so that the vehicle enters the main guideway at cruising speed within its designated moving slot. An occupied slot may be allocated to a waiting vehicle if the current vehicle plans to exit the main guideway before the loaded, in-station vehicle merges onto the main guideway. System operators are alerted when any vehicle positions are out of tolerance. Because portions of the main guideway speed vary, the distance between moving slots varies while the time remains constant.

Empty vehicle management is also an important aspect of the control system. In demand mode, vehicle demand at each station is estimated based on current passenger requests and past travel patterns. When a station shortfall is detected, empty vehicles are routed to the deficit station from surplus stations. At surplus stations, vehicles are first filled with any waiting passengers before departing for the deficit station. The minimum vehicle demand for each station platform is two, representing a policy of always having two available vehicles per platform.

Station Control processes rider destination requests, manages passenger displays, tracks vehicle status including door closing, and controls vehicle movement (speed, smooth stop in channel berth, switching – steer left or steer right, position calibration).

Vehicle Control responds to station commands to operate motor, brakes, steering, and doors.

Guideway Control monitors inductive loops for the vehicle control unit antennae. Vehicles have one send antenna and one receive antenna. Inductive communication message types include: switching, stopping, and door operations.

Stations

The system connects the University's disjointed campuses with five stations (Walnut, Beechurst, Engineering, Towers, and Medical) and an 8.65 mile (13.9 kilometer) track. All stations are designed as a two-level building. Passengers enter on the lower level and either climb stairs or ride an elevator to the boarding areas. The middle three stations have two boarding areas. At these stations passengers are directed to the appropriate platform by an electronic display. All stations are constructed so that pedestrians are prohibited from crossing the guideway.

Figure 12 - Morgantown Station

There are 108 berths for vehicles in the Morgantown/WVU PRT system, 22 each at the three middle stations, eight each at the end stations, and 10 and 16 respectively at the two maintenance facilities. During off-peak periods, many of the 71 vehicles will reside in the station berths. During periods of peak demand a large percentage of the fleet will be en-route between stations.

The three middle stations of the Morgantown/WVU PRT are of relatively complex design. Towers Station, which was constructed to meet significantly higher demand, has six switch points, six merge points, and six channels. Each channel or docking area has three or four vehicle berths.

The Engineering and Beechurst Stations are similar in design to the Towers Station. The layout differences reflect the differences in the expected volume and distribution of trips. Also, bypass lanes at the Engineering and Beechurst Stations are routed underneath the station. Engineering Station also encompasses one of the two maintenance facilities.

The physical dimensions of the middle stations are roughly 200 feet x 120 feet including platforms and channel guideway. The size is dictated by the need to accommodate the various channel movement and expected capacity. These dimensions do not include deceleration/acceleration lanes of the guideway.

Safety Systems

Morgantown/WVU PRT is designed for failsafe operation. A major component failure results in a graceful system stop, whereby all vehicles immediately slow down until they stop, and this stop occurs without vehicles crashing. Additional redundant systems include:

● Control/communications power uninterruptible power supply (UPS)
● Station lighting/surveillance power
● Standby generator
●Central computer Backup PC with automatic switchover
● Station computers Backup PCs with automatic switchover
● Central control system human monitors can override
● "Moving point" control system
●Collision Avoidance System Safe block system independently verifies safe distance between vehicles, using a second set of presence detectors.
● Brakes: Redundant 4 wheel disc brakes. Tandem piston actuators w/ independent hydraulics per caliper
● Brakes: Parking brakes actuate when normal brake hydraulic pressure drops
● Presence detectors: Redundant presence detectors
● Successful switching detection: Vehicle validates guideways' check

● Vehicle speed control: "High speed enable" guideway magnets. Only in special guideway segments can vehicles go fast.
● Tires: Second air chamber prevents punctures
● On-board vehicle control hardware, redundant hardware and safety checks (2)

Power Subsystem
A 23kV, three-phase, 60-Hertz power supply comes from the utility company and is distributed to the guideway and stations. For the guideway power rails, incoming power is converted to 575 VAC, three phase, delta power at three points on the guideway. Passenger stations received 480/277 VAC, three-phase power for heating, lighting, etc.

5.2 Heathrow Pod[12]

Ultra is a modern PRT system that became reality when it was implemented by BAA as a pilot network at Heathrow International Airport to help shuttle passengers to and from a distant car parking lot to Airport Terminal 5. The system was implemented at a capital cost of $50 M. Passengers pay for parking and ride for free. There have been no know incidents or accidents and the availability is reported to be over 99%.

With a nod to the history and success of other efforts in Automated People Movers (APM), GRT, and PRT design around the world, this BAA/Ultra mobility initiative proudly claims itself as the first traditional, super light-weight, personal rapid transit system designed to be commercialized for passenger use. It entered limited passenger service in late 2010 and full service on April 11, 2011. Since then, it has achieved over 99% reliability to rave passenger reviews. Today, the system provides 900 passengers a day with a link between Terminal 5 (T5) and the remote parking lots.

Figure 13 –Aerial view of the Heathrow track from the parking lots on the left to Terminal 5 on the right.

The Heathrow track from T5 to the parking lots exits the airport below the access road, tracks above the roadways, back under the runway approach, up again over the access road, river, wetlands, and then back down to the parking lots.

The Ultra system uses a fleet of low power, electrically driven vehicles on a dedicated guideway. The operation of the system and movement of the vehicles on the network is managed by software and systems developed by Ultra Global, the maker of Ultra, which work to direct and distribute the independent vehicles on a network of direct routes and offline stations to help provide non-stop travel.

The track is passive and switching is achieved by in-vehicle steering using an electronic guidance system. Stations can have spacing similar to bus stops and the basic network form allows the guideway to be one-way, providing important benefits in cost and visual intrusion.

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[12] http://www.ultraglobalprt.com/wheres-it-used/heathrow-t5/

Ultra can operate at-grade or elevated either within or external to buildings, offering the opportunity for more convenience to the passenger. Low loading footprint means that the system can be carried by conventional building structure with no need for structural strengthening. The vehicle has a small (16 foot (5 m)) turning radius and readily copes with grades of 20%, yet operating routes are limited to 10% to ensure passenger comfort.

Figure 14 - Vehicle running under Access Road.

Most Reports commenting on Ultra's overall performance have suggested that the design, engineering and technology have indeed proven viable. Because the Ultra model mostly utilizes modern, yet mature, off-the-shelf, computing and information technologies from the automotive industry, they provide their product with a foundation of reliable systems and components.

Some basic features of the Ultra PRT:

- Principal parameters - scale overhead or at-grade:
    - Width: 6.5 feet

    Overhead
    - Depth: 1.5 feet
    - Height above roadway: 18.7 feet
    - Column spacing: 59 feet

- Basic vehicle characteristics:
    - 4 - 6 seats
    - 1,000 lbs. payload
    - 25 mph

- Simplified analysis of theoretical capacity:
    - 50 seat bus every 5 minutes provides 600 seats/hour
    - 200 seat light-rail every 10 minutes provides 1200 seats/hour
    - 4 seat Ultra every 3 seconds provides 4800 seats/hour

Vehicles

The vehicles are controlled autonomously. Once the vehicle has received its instructions from central control it will continue to its destination without any need for further input.

Figure 15 - Inclement weather operations.

Extensive tests have been done on various forms of vehicle control. Ultra Global has performed full scale system evaluations tests to examine control methods based on wire guidance, optical and radar sensing, embedded guideway magnets and local sensors based on Ultrasonics or lasers. They found the last two of these approaches to be significantly more reliable and robust, so a combination of these is used in the final system.

Each pod is electrically powered with four rubber wheels. Battery pack weight is 64 kg and is only 8% of the vehicle's gross weight, compared to many electric cars which require up to 50% of gross weight for batteries. In testing, it has shown that it can recharge a 5 minute trip in 1 minute.

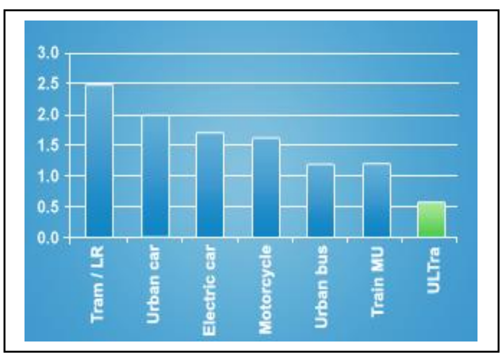
The vehicle is equipped with two bench seats facing each other and has a level entry from the station, allowing plenty of barrier-free access for wheelchairs, shopping or pushchairs. Individual vehicles feature heating and air conditioning for hot or cold climates, as well.

Ultra vehicle - Principal parameters:

Gross weight	800 kg
Empty weight	400 kg
Maximum speed	40 km/h
Length	3.7m
Width	1.45 m
Height	1.6 m
Passengers	4
Payload (kg.)	450
Minimum Turn Radius to center-line of front track (m.)	5
Maximum Climb Gradient	20
Maximum Planned Climb Gradient	10
Maximum Planned Decline Gradient	6.25
Maximum Vehicle Speed on level (m/s.)	11

Emissions and Energy Use

Because Ultra is electrically powered, zero emissions are released at the point of use, while it also boasts significantly reduced energy usage overall; over 70% more efficient when compared with cars, rising to 90% in peak periods when cars are restricted by congestion. The average system energy usage is 0.55 megajoules (MJ) per passenger kilometer. This can be compared with figures between 1.2 and 2.4 shown for conventional forms of transport in the table below.



This energy saving translates directly into reduced CO2 emissions. Documentation shows that Ultra meets the recommendation of the Royal Commission on Environmental Pollution (RCEP), following the Intergovernmental Panel on Climate Change, that CO2 emission should be reduced by at least 60%. The RCEP target is set for 2050, and Ultra is able to exceed this target in the present decade - 35 years early.

Figure 16 - Average System Energy Usage (MJ per passenger km)

Ultra also boasts an emission saving of a factor of 3 or 4 over current car or public transport, meeting Kyoto sustainability targets, providing the required 60% reduction in carbon emissions over the car today, rather than in 2050, which is the target date set by the Kyoto agreement.

Guideway

Like traditional PRT, Ultra runs on its own guideway network with offline stations. Typically, the pods are guided electronically with sensors embedded in the vehicle and the guideway network is arranged in a series of loops, combined by merge/diverge sections, serving key locations in the city. However, most of the Heathrow track consists of two-way guideways in a more conventional corridor alignment. The total length of one-way track is 2.4 miles.

The vehicles run at ground level or on elevated guideways in the form of a concrete trough, supported on a lightweight steel structure; columns are designed to be truck impact proof.

Control Systems

Technically, the operating system is managed by software developed by Ultra Global. It utilizes synchronous controls, similar to that used at Morgantown, and ensures that vehicles are only launched from their berth when it is known that there is a safe free route to their destination. This allows the central control system to respond to the passenger's request by allocating a vehicle for the journey and instructing the vehicle on the required path and precise timing.

Figure 17 - Heathrow Control Room.

Basically, the system manages fixed 'slots' for each vehicle at the prescribed headways and requires free routes to be identified from start to destination, including all merges before the launch of a trip from the station. Each slot is unique, ensuring there is no interaction between vehicles and includes empty vehicle management, which sends available vehicles to where they are needed, when needed, including to maintenance. Ultra Global suggests that this reduces overall waiting times and ensures lower environmental impact due to not having to take unnecessary journeys.

The central control function, including development of effective empty vehicle-management algorithms, has been the subject of extensive simulations by Ultra Global since the start of the project, and the functionality has been well developed and tested. Average waiting times at Heathrow are under 30 seconds and 75% of passengers immediately board a vehicle with no wait at all.

Stations[13]

The Ultra pod system station at T5 Heathrow Airport comprises the following main elements:

1. Berth – vehicle docking point, interfaces, buffer and charging equipment
2. Passenger interface – each berth features a destination selection console, communications, and automatic doors
3. Plinth – a raised floor for passenger-level access to vehicles
4. Envelope – the overall station building
5. Canopy – passenger area roof and vehicle solar shading

Figure 18 - Station with Canopy

The two remote stations (parking lots) at Heathrow comprise a 200 square feet passenger weather-protected concourse and two berths.

[13] http://www.Ultraglobalprt.com/wp-content/uploads/2011/09/PDF_Infastructure.pdf

Approved by disability groups, the stations always offer at least minimal shelter above the bays.

Maintenance

Ultra's system is highly reliable and minimizes the possibility of breakdown. Each pod has an on-board computer that automatically detects maintenance issues so that the unit can be taken out of service before a problem develops. The Heathrow maintenance facility is similar to an automobile repair shop.

Figure 19 - Maintenance Facility at Heathrow

Figure 20 - Service Vehicle

In the extremely unlikely event that a vehicle does break down, a service vehicle can be sent to retrieve it. The vehicles also have emergency exits, the guideway does have escape routes; however, passengers should stay in the pods at all times where possible.

5.3 Masdar City PRT System[14]

On November 28, 2010, the Masdar City PRT application was the world's first podcar system to open to the general public. 2getthere was selected as the supplier for the first phase of Masdar City, providing the link to the Masdar Institute of Science and Technology (MIST) by means of eight PRT, two VIP (leather interior) and three freight vehicles. In this phase, the network is approximately 1.2 kilometers long and features five stations (two for passengers, three for freight). The installation costs are unknown and passengers travel for free.

Figure 21 - FRT for delivery of small goods and removal of waste (not yet in service).

Figure 22 - Undercroft view with visible tracks

The PRT vehicles travel at speeds up to 40 kmh, with the longest routes in the city taking around 10 minutes. The system was planned for 3,000 PRT vehicles serving 130,000 trips/day over the 85 stations. The dedicated guideway in the undercroft, an artificial basement

[14] http://www.2getthere.eu/

created by raising the pedestrian level, will also accommodate the Freight Rapid Transit system (FRT). The FRT system will be capable of making 5,000 trips per day carrying the loads and deliveries for residents, stores and hotels. The flatbed vehicles can carry two pallets, with a maximum total payload of 1,600kg.

As viewable in the Undercroft figure, the vehicle tires have marked the precise track where they follow magnets embedded within the pavement.

2getthere PRT System Summary:

System Capacity (4 second headway):	3,200 – 4,800 passengers per hour
Economically viable from:	Approx. 300 pax/hour or 1500 pax/day
Supervisory System (Network Controls):	TOMS (Transit Operations Monitoring and Supervision)
Vehicles:	6 passenger CyberCab
Infrastructure:	Asphalt, at grade or elevated
Status:	2nd generation
Configuration:	Network
Operations:	On-demand / On-schedule
Connections:	Direct / Ride-sharing (Single Origin, Multiple Destinations)
Stations:	Off-line
Propulsion:	Central AC motor, differential rear axle
Energy supply:	Electric or Hybrid
Maximum speed:	40 km/hour [25m/hour]
Guidance:	FROG-technology
Track Length:	1200 meters (one-way)
Number of Stations:	2 offline (+3 freight stations)
Berths per station:	6
Crossings for Traffic/Pedestrians:	On podium level

History

2getthere was established in 2001. Formerly it was a business unit within Frog Navigation Systems. It was established as an independent company to capitalize on the people mover market opportunity and split off in 2007.

Masdar City itself was established in 2006 to be the world's first carbon neutral, zero-waste to landfill, car-free city powered entirely by alternative energy sources. Masdar City is being built on six and a half square kilometers and will eventually grow to house 1,500 businesses, 40,000 residents and 50,000 commuters. There will be no fossil fuel cars within Masdar City. The city will be a pedestrian-friendly environment, with a Personal Rapid Transit system available for longer journeys. The PRT vehicles will travel at speeds up to 40km/h, with the longest routes in the city taking around

Figure 23 - Masdar station level platform with 4 passenger vehicles, seated across.

10 minutes. Ultimately there will be 3,000 PRT vehicles serving 130,000 trips/day over the 85 stations.

Vehicles

2getthere's personal rapid transit system features a number of automated taxis (CyberCabs). The CyberCab accommodates a 6-person family (4 adults, 2 children) and additionally has space available for either a wheelchair or luggage. The vehicle features an automated sliding door, optionally a second door can be installed allowing (dis)embarking on both sides of the vehicle.

Performance

In 2013, the Masdar City system celebrated the completion of its third year of operation, having transported over 819,000 passengers during that time. Since its opening, the system has carried more than three times the expected number of passengers and operates consistently with a system availability exceeding 99.4%.[15]. In May, 2014 the system carried its millionth rider after being in operation for three and a half years.

Benefits include:[16]

- Passenger transfer time between the car park and MIST is reduced to approximately two minutes.
- There is a minimal waiting time as the vehicles are generally waiting in the stations for passengers and only travel on demand. If no vehicles are present the distributor function ensures empty vehicles are on their way.
- Each vehicle has 4 seats and enough room for accompanying luggage. Passengers travel in their own passenger groups or on their own.
- There are no emissions at the point of use. The system uses lithium ion batteries which provide a 60+km range.
- The vehicle features a flat floor which aligns accurately with stations to allow safe and easy access for push chairs, wheelchairs, luggage and people, meeting the access requirements for disabled passengers.

Control

2getthere's ability to provide a PRT system is based on the well-proven (20+ years) FROG network and vehicle controls, fully customized for Automated People Mover requirements. 2getthere's personal rapid transit system features the supervisory control system TOMS (Transit Operations Monitoring and Supervision). The guideway can be constructed at grade, but also elevated, embedded in buildings or underground. The system is configurable as 'true' PRT – providing direct

Figure 24 - Masdar Control Room.

[15] http://electricvehicle.ieee.org/vehicles/masdar-podcar-2getthere/

[16] http://www.advancedtransit.org/advanced-transit/applications/masdar-prt/

connections, on-demand operations and personal transportation – but alternatively 'ride sharing' (single origin, multiple destinations) and scheduled operations (to optimize capacity) can also be implemented.

Safety

2getthere was granted certification by the Abu Dhabi Department of Transportation for the Masdar PRT System on November 23, 2010, based on the Letters of No Objection as issued by the Independent Safety Assessor (Lloyd's Rail Register) and Independent Health Assessor (Bureau Veritas).

Figure 25 - Rescue Vehicle

One distinct feature of 2getthere's systems is the advanced obstacle detection sensors applied on the vehicles. The sensors are capable of scanning up to 200 meters in front of the vehicle -- the actual area taken into account being dependent on the speed of the vehicle. The area is always scanned empty, a failsafe approach.

5.4 Suncheon Bay PRT System[17]

Figure 26- Suncheon Bay Layout - following the river.

Following a successful four year period of testing and demonstration at the test track, Vectus has now moved forward very rapidly with building its first fully commercial system in South Korea. This is essentially a visitor transit between a park-and-ride location on the outskirts of Suncheon city, in the southernmost part of the country, linking to a world famous wetlands and bird reserve in the Suncheon bay estuary. The main station, 'Station One', is located at the entrance to the 2013 International Garden Exposition. From here, Vectus will be operating 40 vehicles initially (and one maintenance vehicle) running down to a second station, along 3 miles (end to end) of elevated, double track. The track has a full loop at either end with four on-line berths at each. The capital costs are uncertain.

An average of three million visitors per year are expected to visit the Suncheon Wetland Park, and daily ridership is forecast at around 5,000 passengers per day. The system entered limited service in August 2013 and full service on April 19, 2014. Passengers travel for free.

Guideway

The guideway itself is predominately concrete using site-cast columns and pre-fabricated, pre-stressed beams of typically 30 meter spans – although there is also one 50 meter steel box-girder section over a river. Because the entire area is an earthquake zone and is also prone to occasional cyclones, the construction has been very carefully engineered, with most of the

Figure 27 - Pre-cast concrete to withstand earthquakes and severe weather, and secured over marshland; hence, structure is larger than normal.

[17] http://www.vectusprt.com/EN/media/documents/

column piling buried some 30 meters into the marshy terrain. Since, in most cases, the foundations are laid far under the top soil on top of the pilings, this has the effect of placing the bending moment from wind loading deep underground.

Track

The track-work itself is manufactured from rolled steel profiles, mounted along the concrete structure and the entire railway is powered through a 500VDC system of continuous current collection located on both sides of the guideway. For this application, where there is no issue of track adhesion (in comparison with Uppsala, for example, which is prone to very icy winters), there is no necessity for using in-track linear motors at all.

Vehicles

The 4.6 km line runs parallel to the Suncheon-dong Stream, mud flats and reed fields of the bay. Twelve hundred people an hour will be able to use the system which consists of 40 vehicles — each vehicle capable of transporting a maximum of nine persons. The vehicles or “podcars” can travel at a maximum speed of 50 km/hour and are fully automated. One major difference with the PRT system is that vehicles only operate when there are passengers, the opposite to the other transport systems where the passenger usually has to wait for the service to arrive.

Figure 28 – Inside bench seating with grab bars for standees.

Control

Where Vectus starts to add value beyond the notion of simply running point-to-point, is the way that each vehicle controls its speed, position and direction, relative to all other vehicles on the system, as a method of optimizing overall system capacity and efficiency. The methodology behind the Vectus control system, which is being deployed at Suncheon, can be divided into four key components: distributed and scalable control, asynchronous control, dynamic moving block and optimal control.

A distributed system means that the control is carried out locally, in pre-designated zones. If there is a fault, it only effects a small part of the system. The rest of the system will continue to work. With the distributed system there is no increase in the load for each individual control segment when the system is expanded.

With asynchronous control the flow of vehicles is handled as they each travel along their paths to their respective destinations. Merging of vehicles is managed as required on a local basis. Occasionally there may be a need to slow down to facilitate merging in switches; there may even be short queues along the route at times. Travel time may be prolonged by a few seconds, but the overall capacity of the system is maintained, which is essential to the overall ability to transport passengers during periods of high system loads.

A dynamic, moving-block vehicle protection system is superior to any fixed-block system, even if the fixed blocks are very short. It continuously updates each vehicle with information on the position of the one in front of it. With this information, each car can run, by varying its speed relative to the others, with the shortest allowed spacing based on the worst case braking performance. At lower speeds the vehicles run closer to each other; at higher speeds the distance is increased. These systems, in combination, are the building blocks in providing both safety and capacity within the Vectus system.

Stations

Currently, there are only two stations. Station One includes passenger facilities such as the elevators, turnstiles, platform screen doors, information displays and waiting areas. Station Two is similar to Station One and houses the same facilities.

Figure 29 - Four-bay Station

Figures 30 and 31 - Turnstile entry and level platform with station doors

Maintenance

Adjacent to Station One (the Suncheon City end) is located the Operations and Maintenance building. This houses the control room, vehicle storage (on the lower levels) a five berth daily maintenance area and a five berth, off-line, heavy maintenance facility. The maintenance building houses the control room, all vehicle lifts, garaging facilities and maintenance bays within the depot facility below.

Figure 32 - Maintenance Facility

5.5 System Comparisons

The following table shows statistical comparisons between the three systems:

	Masdar	Heathrow	Suncheon
In service date	11/28/2010	4/18/2011	4/20/2014
Number of vehicles	13	21	20-40
Miles of one-way track	.75	2.4	5.8
Number of stations	2(+3 freight)	3	2
Maximum speed (mph)	25	25	40
Availability (%)	99.5	99.5	N/A
Vehicle power principle	Battery	Battery	Wayside Electric
Range (miles)	37	12	Unlimited
Vehicle/guideway interface	Rubber tires	Rubber tires	Polymer on steel
Lateral guidance	Magnets in pavement	Laser sensing of sidewalls	Side rails
Switching	Steered	Steered	On-board side wheels
Vehicle capacity	4 + 2 children	4 + 2 children	6 seated, 3 standing
Minimum headway (sec)	5	6	3-4
Max theoretical capacity	2,880	2,400	8,100
Max track gradient (5)	10	10	10
Min centerline radius (feet)	18	16.5	16.5
Clearance envelope (feet wxh)	6.1 x 7.5	6.9 x 6.6	6.9 x 8.2
Max berth throughput per hour	120	120	160-200
Emergency recovery	Manual + tow vehicle	Reduced speed + tow vehicle	Reverse operation + push/tow with other vehicles
CCTV/Intercom/Operator	Yes	Yes	Yes
Energy consumption (kWh/mile)	0.30	0.21	0.38

Table 2 –Systems Comparisons

6. Potential PRT Corridors or Networks

This section investigates different ways of implementing a PRT system along the GCEDC corridor. All alternatives are compared to the BRT solution chosen by the 2010 Feasibility Study. To the extent possible, the factors taken into account here match those considered in the Feasibility Study.

6.1 Alternative 1, BRT Route and Station Locations

The six stations identified in the 2010 study are considered as alternative 1. They have been used to make a direct comparison between a PRT solution and the previously identified BRT solution. The PRT solution is comprised of a two-direction PRT system installed along the same alignment and with the same station locations as the BRT solution. It extends from an at-grade station at CU-ICAR on Millennium Boulevard, for 5.57 miles to an elevated station at the Greenville Transit Authority Transit Center on Richardson Street. All of the intermediate stations, except the one at Bell Plaza/Spinx Shopping Center (#5) are at grade. The guideway is at grade along the rail corridor, but is elevated where the corridor presently has at-grade crossings with Verdae Boulevard, Haywood Road and Airport Road. It makes use of existing railroad tunnels under I-85 and Pleasantburg Drive, and a grade-separated crossing at Woodruff Road. It is elevated for the entire portion that is not in the corridor extending from Laurens Road to Richardson Street (station 6). The overall length of the system is 5.57 miles with approximately 1.50 miles being elevated as shown in the figure below.

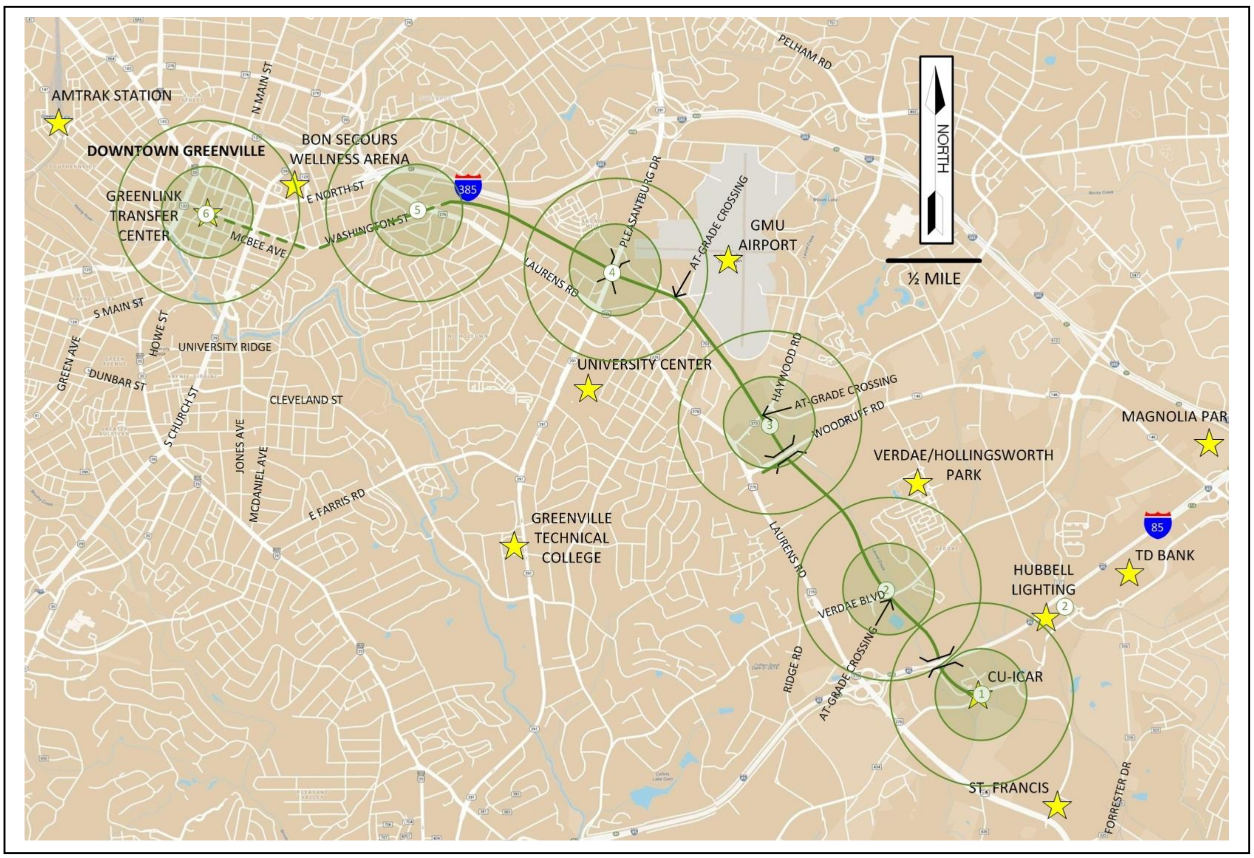


Figure 33 – PRT Alternative 1

Pedestrians and animals using the corridor would be prevented from crossing the at-grade guideway by fences. However, crossing opportunities would exist at each of the six roads that cross the portion in the GCEDC ROW.

This solution is entirely conventional and any supplier with a commercially-available PRT system should be able to build and operate it. The capital costs are estimated at $54.9 M while the annual operating costs are estimated at $1.0 M. The average wait time (equivalent to the frequency of service) has been conservatively assumed at 2.5 minutes. The service area within walking distance (assumed to be a ½ mile radius around each station) is 4.7 square miles. The average travel time (end to end) would be about 16 minutes. The daily ridership is projected to be approximately 1,500 riders (Alternative 2 ridership adjusted by the relative service area).

This PRT solution has been compared to the BRT solutions proposed in the GCEDC Feasibility Study and the City of Greenville BRT/TOeD study. The results of the previous studies have been adjusted to reflect the route and station locations shown in Figure 33. While the comparison shows the PRT solution increases the anticipated ridership because of reduced waiting times, construction is more expensive than the BRT option. However, on a cost-per-rider basis it is three times less costly. A second alternative is investigated next in order to see if adding many more stations will improve the cost-effectiveness of a PRT solution.

6.2 Alternative 2, Additional Stations On and Off the Corridor

In PRT Alternative 2, every effort has been made to eliminate elevated guideways and reduce capital costs. Because the ridership is relatively low, it has been found that the elevated portions of the guideway, from station 13 to station 15, can be built as a single guideway with double sections at stations only. Thus each portion of guideway between each station pair will operate in one direction only at any given time. The direction will switch on demand according to the direction of travel of the next vehicle to arrive. Vehicles going in the opposite direction will wait in stations until the guideway becomes available for them. Even in rush hour, only one or two vehicles are expected to be waiting at any one time and the wait will be less than two minutes. Note that, when ridership demand increases sufficiently to justify the cost, the guideway can be doubled up to allow two-way travel or return loops could be constructed to also serve a wider area.

Instead of elevating the guideway at places where the ROW crosses roads at grade, the existing traffic signals will be used to stop vehicular and pedestrian traffic and allow the PRT vehicle to cross at grade. In addition, where appropriate, stations will be placed closer to activity centers by allowing vehicles to leave the rail ROW and travel short distances along existing crossing roads. Since this type of operation is conducive to economically adding stations, more stations will be provided with minimal expense. Finally, the system will be operated in a way that encourages ride sharing and peak period trips may sometimes require an intermediate stop.

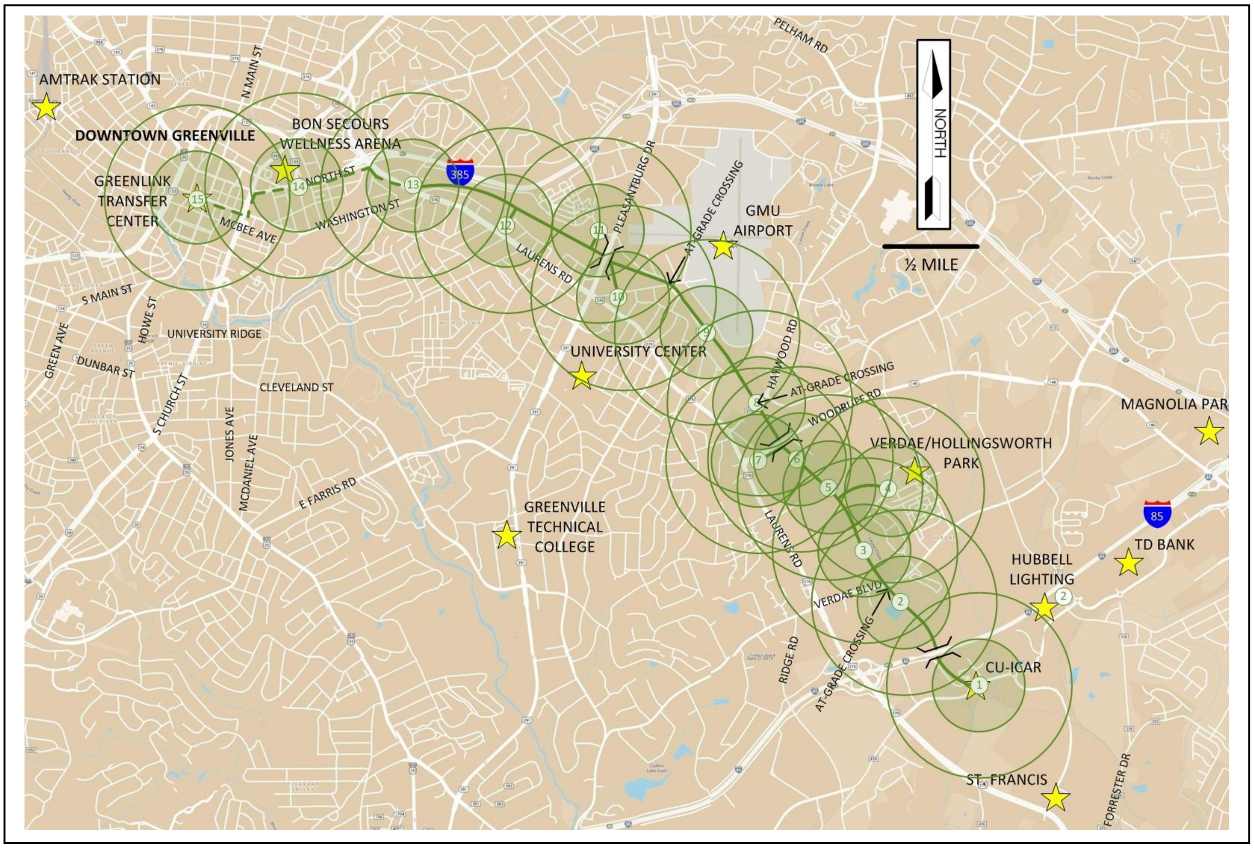
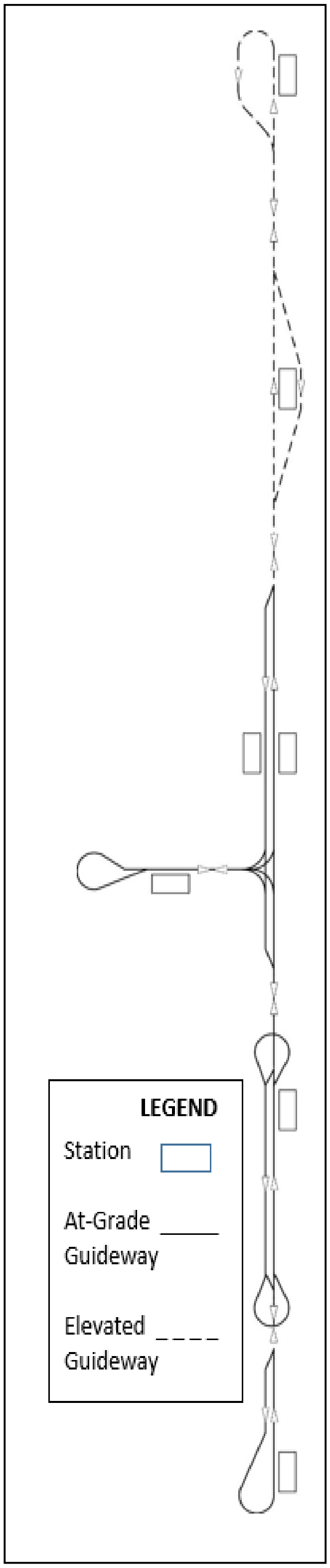


Figure 34 - PRT Alternative 2

The figure above is a schematic layout of Alternative 2 showing how it can be comprised of elevated sections (shown dashed), at-grade sections and one-way as well as two-way portions of track. Turnarounds are located at strategic points and allow nearby station platforms to be located on one side of the system only.

As a result of the above changes PRT Alternative 2 has similar capital costs to Alternative 1. However, it has significantly higher ridership because walking distances are less and stations are better positioned. The service area within walking distance is 6.6 square miles. The potential for intermediate stops and the possibility of having to wait a bit longer are anticipated to add less than 5 minutes to the total trip time (not accounting for any savings in walking times).



This alternative blankets the adjacent Laurens Road with high quality transit service reducing the need for conventional bus service in this area. Greenlink Bus service connecting the Mauldin and Simpsonville communities south of CU-ICAR could transfer their passengers to the system at CU-ICAR. Or an Express Bus service could continue along Laurens Road with only a few stops. These options for bus service increase choices for riders and could increase ridership for both bus service and PRT.

The only PRT supplier that has demonstrated this type of operation is 2getthere at their Rivium application. However, Ultra is expected to be able to operate in this manner after a significant investment in development costs for which they would likely need to be reimbursed.

The capital costs are estimated at $56.2 M while the annual operating costs are estimated at $1.24 M. The average wait time (equivalent to the frequency of service) has been conservatively assumed at 2.5 minutes. The travel time (end to end) would be about 22 minutes. The daily ridership over this 4.2 mile long corridor is projected to be 2,138 riders (see Section 7).

This alternative was simulated, using the proprietary model PRTsim, during the evening peak hour with the following results:

Peak hour person trips:	290
Number of vehicles:	58
Normal speed:	22 mph
% loaded vehicles making 2 stops:	9
% loaded vehicles making 3 stops:	0
Average wait time:	2.5 minutes
98% served in:	7.0 minutes
Average trip length:	2.5 miles
Passengers per loaded vehicle:	1.8
Total passenger miles:	661

The cost per rider for Alternative 2 is over 5 times less than that for BRT. While this is very encouraging, the capital costs of this solution are daunting and a lower cost solution has been sought and is conceptually addressed in Section 6.3.

Figure 35 - PRT Alternative 2 Schematic Layout

6.3 Alternative 3, Automated Taxi System

The primary factors driving the cost of a PRT system are the elevated guideway costs and the system costs (primarily comprised of the vehicles and the control system). While it is not considered possible to lower the guideway costs much more, the vehicle and control system costs could be lowered by considering a system that is a hybrid falling between a PRT system operating on exclusive guideways and an automated taxi (aTaxi) system operating in mixed traffic on public roads. The solution proposed here is an automated taxi system operating on exclusive guideways (elevated and at grade).

PRT vehicles are currently very expensive because they include expensive design features that enable them to operate efficiently and very accurately in and out of stations with a significant passenger demand, a high level of service and a very high degree of reliability. This allows them to park accurately at stations facilitating level boarding and compliance with the Americans with Disabilities Act (ADA). PRT control systems are very expensive because they require a very high degree of reliability and redundancy and must pass a very rigorous independent certification process. The costs of both the vehicles and the control system are also high because the development costs must be spread over a very limited number of small installations.

On the other hand, an aTaxi system operating on exclusive guideways could potentially utilize mass-produced vehicles with built-in automation requiring less capability than an automated car operating in mixed traffic and would only need a minimal central control system. Even though such a system is not presently commercially available, it poses significant possible benefits and has been considered here as an additional alternative.

The GCEDC right-of-way offers a unique opportunity to implement an innovative transportation system as a step towards fully autonomous (self-driving) taxis in mixed traffic and driverless cars on one hand, and PRT systems on the other. The car industry is investing aggressively in driverless cars to be on the market sometime around 2017-2022. The barriers to introduction include regulation and liability issues. The fact that the GCEDC corridor passes through CU-ICAR provides an excellent opportunity for the research, development, and demonstration of aTaxi vehicles and systems.

When autonomous driving becomes legal, the expectation is that it will be the preferred mode of transport replacing a large fraction of private vehicle movements and reducing the need for parking. aTaxis could help reduce congestion and transportation costs with each aTaxi replacing around 10 private vehicles since they are used around the clock.

One of the objectives of this alternative is to demonstrate the concept in a confined setting with existing standard vehicles retrofitted to allow navigation, steering, object detection and communication with a fleet management system for booking and dispatching. Once demonstrated in the corridor, a planned community like Verdae might offer aTaxi shuttle service to on-campus residents in homes and apartments, to nearby offices, shops, dining and recreation – and easy access to multi-modal transportation service at Verdae mobility hubs.

The station/stop and guideway layout would be as shown in Figure 34 for PRT Alternative 2. The system would operate on the GCEDC right-of-way for the most part with restricted-access extensions to adjacent trip generators/attractors. In the city center, vehicles would operate on a single elevated guideway dimensioned for the load of only few vehicles at a time. The traffic area will be fenced except in a few signal controlled intersections with other road and pedestrian traffic which can be provided with automated closed-circuit TV (CCTV) analysis to enhance safety.

Space requirements are modest and will not hinder continuous bike and pedestrian paths throughout the corridor. Vehicles will be light and quiet not disturbing leisure and wildlife and having no on-site emissions. Fifteen taxi stops are planned, each with weather protection for both passengers and vehicles.

Vehicles would be based on small Neighborhood Electric Vehicles (NEV) such as the Street Legal Star EV (Figure 36) or Nissan Leaf carrying two to four passengers, at speeds up to about 25 mph. Each vehicle would be retrofitted with automated steering based on a buried antenna, GPS and/or dead reckoning, plus RFID tags/transponders for calibration. Lack of doors, heating, and air conditioning could allow lower costs. Passenger weather protection could be enhanced by the addition of pull-down screens. The Google car (Figure 37) may already have almost all of the capabilities required to serve as an aTaxi.

Figure 36 - Star EV

Figure 37 – Google Car

At grade intersections would be controlled by traffic lights and/or existing gates. The vehicles would detect traffic signals either by image processing or by radio signals. Automated image processing of CCTV images could enhance intersection safety.

Object detection can be based on one or more of video image processing, radar, lidar or Ultra-wave. The vehicle will react to objects within the fenced area and be able to stop without hitting an obstacle. Stranded vehicles would be detected in the same way as other objects. The challenges of operating an automated vehicle within a fenced guideway are considerably less than on an open road.

Fleet management is considered essential in order to respond to calls for service and position empty vehicles strategically according to demand patterns. Calls for vehicles would be made by phone. The system will decide which vehicle to send and communicate the station number to the vehicle. The vehicle will find the way based on antennas, following left or right antennas in switch points. Alternatively the vehicle will navigate based on positioning and memory maps. Each vehicle will report back when empty and the management system will determine whether it should go to another call, wait or move empty to another station with expected demand, to a parking area, or to the depot.

Ride sharing will further enhance the economy of the system. With all stations being in a corridor, chances are that there will be other calls from stations passed along the route. If they are going the same direction (callers would indicate destination or direction) the car will pick up additional passengers. During rush hours this may be limited only by the vehicle capacity, while during times of low demand, services may be individual (by design or because nobody else was there).

An elevated guideway is foreseen in the city area where land cannot be allocated at grade. For reasons of economy as well as visual intrusion a single guideway is planned. A station and a place to meet other vehicles is planned halfway on the elevated guideway. Traffic will be controlled by conventional signals similarly to those used during road construction projects. There will typically only be one to two vehicles travelling in the same direction on either portion of the single guideway plus vehicles at the halfway station and at the end station. Since the vehicles are lightweight, the guideway can be designed to be slim and relatively inexpensive (cheaper than a footbridge).

One significant difference between aTaxis and the other alternatives is the lack of ability to carry people in wheelchairs and thus to comply with the Americans with Disabilities ACT (ADA). The PRT systems are designed to be fully ADA compliant and can accommodate wheelchair-bound passengers with almost no impacts to the level of service others are receiving. Buses can be fitted with wheelchair ramps and other necessary accoutrements, but deploying ramps and loading/unloading wheelchair-bound passengers can delay other passengers.

Taxis are less strictly regulated than transit. This being a pilot in a confined space could facilitate temporary permits. It may be possible that aTaxis will be classified as taxis and will not require ADA compliance.

Since aTaxis, such as those envisioned here, are not commercially available, a considerable amount of development work would be required that constitutes both a risk and an opportunity. The risk relates to estimating the costs of such a development and the possibilities of failure while the opportunity relates to the potential to develop a technology that could grow into fully autonomous aTaxis capable of operating in mixed traffic and/or a new PRT system. Since aTaxis are not commercially available and the development costs are unknown, it is not possible to predict the costs savings that they may bring. In addition, the passenger demand along the corridor may be sufficient to overwhelm an aTaxi system and require the added capacity provide by a full-blown PRT control system.

An autonomous taxi system offers unique university research opportunities to CU-ICAR. Tasks may include:

- Evaluation of navigation alternatives
- Evaluation of sensors for object detection
- Communication protocols
- In-vehicle installations
- Cellphone apps for ordering and fare collection
- Control system functionality
- Human factors analyses
- User attitude surveys before and after
- Impact on mode choices
- Socio-economic evaluation
- Spin-off development
    - Vehicle manufacturing
    - aTaxi service in mixed traffic
    - Driverless cars
    - PRT

This work may form the basis for developing a center of excellence on autonomous driving and/or PRT at CU-ICAR or at the International Transportation Innovation Center (ITIC) associated with the South Carolina Technology & Aviation Center in Greenville.

In comparison with the previously recommended BRT alternative an aTaxi system would offer the following benefits:

- Short waiting
- Direct trips or only 1-2 intermediate stops
- On demand 18/7
- Guaranteed seating
- Room for continuous bike/foot paths
- No emissions (bikes and pedestrians adjacent)
- No noise
- Less social costs (time, pollution, accidents)
- University research opportunities
- Competence center linked to university
- Cooperation with car industry
- World first based on standard vehicles
- Unique funding opportunities

6.4 Continuation to Mauldin

This section addresses the feasibility of continuing the service modes described in Alternatives two and three above, along the Carolina Piedmont Railroad (CPDR) right-of-way, a distance of 3.0 miles, to the crossing with E Butler Road in Mauldin. The 2010 Feasibility Study indicated that, along this section, "Space is very limited and the bus way could only be one lane wide…" implying that there would probably be space for two PRT/aTaxi guideways. However, the benefit/cost of a PRT/aTaxi solution along this section would likely be much lower than along the GCEDC portion for the following reasons:

1) The service area population per square mile is generally lower
2) The service area employment per square mile is generally lower
3) There are eight at-grade road crossings
4) There are four track merges/diverges, one collocated with a road crossing
5) The track is utilized several times a day to move freight cargo from the GE turbine plant and other manufacturing sites.

Items one and two above are indications that the ridership per mile will be lower. Items 3 and 4 are indications that the costs will be higher. Item 5 is a significant concern for a number of reasons addressed below.

Negotiating space for a guideway that will be aligned close to an operating track and likely require fencing is expected to be difficult. The railroad will undoubtedly have operational and/or maintenance reasons to want unfettered access to their line from either side. This concern is likely to also apply to the BRT option but, possibly, to a lesser extent.

In the last few years freight railroads in Denver have refused to share ROW with light rail trains without a substantial crash wall being installed between the two lines. The concern is that the disparity in weight between a freight car and a light rail car would exacerbate the severity of a collision between the two. This could be a concern for the CPDR ROW too for both BRT and PRT/aTaxi modes. While it is understood that the freight operations are low speed, the BRT operations would not be. While the PRT/aTaxi operations would be lower speed, the disparity in vehicle weight would be even greater.

The CPDR ROW thus seems unsuitable for either BRT or PRT/aTaxi. As discussed in the Feasibility Study, BRT could operate on the surface streets and thus has an alternative route it can use. Operating on the surface street ROW would require an elevated guideway for PRT/aTaxi and this would be prohibitively expensive until the ridership potential increases significantly.

6.5 Connectivity with Southeast High Speed Rail

An I-85 option has been proposed for the Southeast High Speed Rail (SEHSR) corridor that would cross the GCEDC corridor near CU-ICAR. Since the GCEDC corridor is in a former railroad underpass where it crosses I-85, it is probable that the SEHSR would pass over the corridor at an elevation similar to I-85 and passengers transferring from one corridor to the other will be faced with an elevation change. As described earlier for other crossing roads, the PRT/aTaxi alternatives would facilitate locating a station along the SEHSR corridor and sufficiently far from the GCEDC corridor to accommodate the grade change. Thus, if the Greenville SEHSR station was located anywhere along I-85 between Laurens Road and I-385, a cross-platform transfer to the PRT/aTaxi alternative could be provided. On the other hand, the BRT alternative cannot so easily leave the GCEDC corridor and the transfer would involve the addition of other facilities such as an inclined walkway, stairs, elevators and/or escalators.

6.6 Connectivity with Greenlink Bus and Proposed Proterra Regional Express (REX) Bus Systems at Multi-Modal Hubs

The I-85 corridor between Laurens Road and I-385 is bounded on the north by Verdae Boulevard and on the south by Millennium Drive/Carolina Point Parkway and appears suitable to accommodate an at-grade PRT/aTaxi guideway. Thus the GCEDC corridor system could economically also be extended parallel to I-85 to the shopping areas along Woodruff Road near I-385. This shopping area could be a suitable location for a transfer point between the PRT/aTaxi system and Greenlink's Proterra Electric Regional Express Bus service from Simpsonville through Mauldin to CU-ICAR as proposed in a 2014 Greenville County TIGER grant application.

In conjunction with implementing a PRT/aTaxi solution, consideration should also be given to reconfiguring the bus routes serving adjoining communities. It would seem that bus service along Laurens Road for approximately 4.5 miles from I-85 to I-385 could become Express service with only a few stops at multi-modal hubs located close to Laurens road, while local Greenlink service loops crossing the GCEDC corridor at Pleasantburg Drive, Haywood Road and Verdae Boulevard should have co-located stops at mobility hubs to facilitate transfers between Greenlink bus and PRT systems as well as the bicycle riders and walkers on the southern Swamp Rabbit Trail. These changes could increase ridership on both bus and PRT systems, and increase annual operating income.

Replacing portion of the proposed BRT systems with a PRT/aTaxi solution will require many BRT riders to undertake a mode change. This mode change could increase trip times by about 5 minutes which is not considered very onerous. The added mode change is offset by the fact that the BRT buses will not have to traverse the last mile and a half into Downtown Greenville in mixed traffic – a situation that is bound to become problematic (both to the buses and to other traffic) as congestion increases. In addition, the PRT/aTaxi system will provide a higher level of service from CU-ICAR to Downtown Greenville.

Downtown Greenville traffic congestion will be eased somewhat with all solutions. This is particularly true for those solutions with higher ridership. Further benefits could derive if car drivers can be persuaded to park and ride. Less expensive remote parking facilities could replace more expensive Downtown facilities, saving money while also reducing congestion and pollution.

While bus passengers will no longer be driving cars, a BRT system is likely to have negative as well as positive impacts on congestion. On-street bus stops can cause delays, preferential bus signals can cause delays on cross streets and mostly-empty off-peak buses may take up more road capacity than if the passengers were driving their cars. For a BRT system to function well from a passenger and a car-driver perspective, it "…*should operate on separate rights-of-way wherever possible and on wide, continuous, free-flowing streets where separate rights-of-way are unavailable or removed from markets*"[19]. This could occur for an Express Bus service along Laurens Road, but has not been planned for along Washington Street and McBee Avenue.

6.7 Alternatives Comparison

The following table summarizes and compares the findings for the PRT and BRT alternatives.

PRT 1 = 6 stations mirroring the 2010 BRT stations with at-grade and elevated PRT system
PRT 2 = 15 stations with at-grade and elevated PRT systems
GCEDC BRT = 2000 study numbers up-graded to 2010 Census data/2020 projections

As stated previously, the aTaxi solution has not been considered further because there are too many unknowns regarding this solution.

Note that a 40% allowance for contingencies has been used for the PRT alternatives as opposed to 30% for the BRT alternative since there are more unknowns regarding PRT (especially regulatory/certification requirements) that could add to the estimated costs.

The BRT alternative is significantly better than the PRT alternative in only two aspects – it has a lower capital cost and it is more feasible for an extension to Mauldin. PRT Alternative 1 is preferred or equivalent to BRT on all other items. PRT Alternative 2 is superior to PRT Alternative 1 in a number of aspects such as more stations and higher ridership, etc. However, it requires operational characteristics that are currently only available from one supplier. The best PRT alternative probably lies between 1 and 2 – a more conventional solution with about 10 to 12 stations could probably attract similar ridership as Alternative 2 while also opening up the project to more competition.

The PRT (and, potentially, aTaxi) alternative has the advantage of solving the last mile issue for many residents along the GCEDC corridor. It could allow many families to eliminate costs of owning more than one car for daily transportation, and use part of the savings to pay for aTaxi and PRT services along a

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[19] TCRP Report #118 Bus Rapid Transit Practitioner's Guide

multi-modal transit corridor. Arguably, the improved connectivity of multiple transit options will attract young professionals, empty nesters, and retirees into attractive, dense, GreenVillages mixed-use developments along the corridor. Verdae and other GreenVillages developments will be recognized as urban places where people love to live, work, shop, and play. Connectivity and mobility successes will attract other residents to GreenVillages communities across America and around the world.

Additional analysis needs to be conducted to determine the degree to which different consumer demographic groups adopt aTaxi and PRT solutions for their 21st century urban lifestyles.

ALTERNATIVE	PRT 1		PRT 2		GCEDC BRT[1]	
Capital cost ($M)	$58.5	✖	$ 59.3	✖	$39.9	●
Annualized cap cost[2] ($M)	$1.95	✖	$1.98	✖	$1.33	●
Annual O&M cost ($M)	$1.13	✔	$1.39	●	$1.54	✖
Bus O&M cost savings ($M)	$0.00	●	$0.30	✔	$0.00	✖
Total annual costs ($M)	$3.08	✖	$3.07	●	$2.87	✔
Annual ridership	409,000	●	574,000	✔	165,000	✖
Cost per rider	7.53	●	5.35	✔	17.39	✖
Annual farebox revenues ($M)	0.80	●	1.15	✔	0.25	✖
Net (subsidized) cost per rider[3]	$5.53	●	$3.35	✔	$15.89	✖
Farebox recovery ratio[4]	80%	✔	96%	✔	17%	●
Max travel + wait time (min)	22	✔	26	●	41	✖
Stations/stops	6	●	15	✔	6	●
Intermediate stops	0	✔	0 - 1	●	0 - 4	✖
Guaranteed seat	Yes	✔	Yes	✔	No	●
ADA compliance	Good	✔	Good	✔	Acceptable	●
At grade ROW width	16’	✔	16’	✔	28’	●
On-site emissions	No	✔	No	✔	Yes	✖
Noise	Low	✔	Low	✔	Med	●
Extension to Mauldin	No	✖	No	✖	Possibly	●
Connection to SEHSR	Good	✔	Good	✔	Acceptable	●
Bus and BRT Connectivity	Good	✔	Good	✔	Good	✔
Facilitates trail uses	High	✔	High	✔	Med	●
Enhances property values	Med	●	High	✔	Med	●
Reduces congestion	Some	●	Some	●	None	✖

Legend: Poor ✖ Acceptable ● Good ✔

Table 3 - Alternatives Comparisons

6.8 Potential Niche Applications at Attractor Locations

This section provides a preliminary investigation of niches outside of the GCEDC corridor where PRT may be applicable. Two specific opportunities are investigated – the Greenville-Spartanburg International Airport (GSP) and Downtown Greenville

6.8.1 Greenville-Spartanburg International Airport

According to the Terminal Area Study[20], Greenville-Spartanburg International Airport (GSP) is a publicly owned and operated airport serving the Piedmont region of South Carolina. It is classified as a primary commercial service airport by the Federal Aviation Administration's (FAA) National Plan of Integrated Airport Systems (NPIAS). Currently, the airport has scheduled passenger service by seven airlines: Allegiant Air, American Eagle, Continental Airlines, Delta Air Lines, United Express, US Airways and Southwest Airlines.

GSP serves the air transportation needs for Upstate South Carolina. Its location places it in an ideal position to fuel the economic engines for both the Greenville and Spartanburg areas while serving the growing industrial and business demands of these communities. The growth and improvement of GSP will also result in generation of employment opportunities and local business participation.

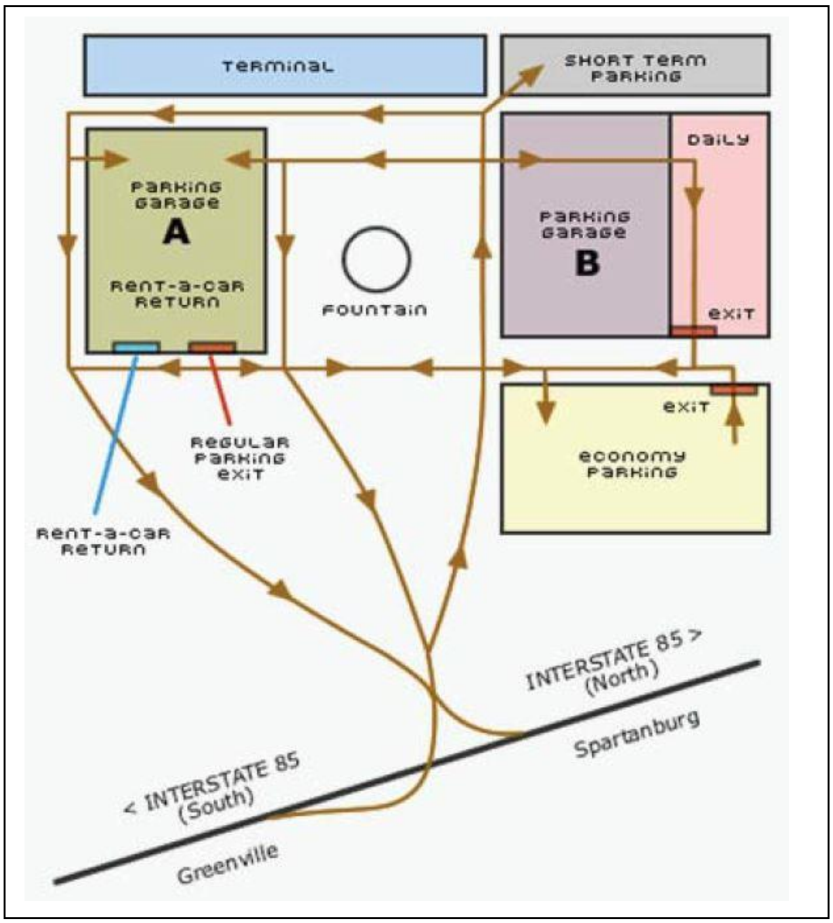

Figure 38 - - GSP Public Parking Facilities[20]

The public parking facilities at GSP are depicted graphically in Figure 38, although the short term lot is now being converted into an expanded terminal facility. No shuttle bus services exist for the parking lots and passengers must walk to the terminal, often dragging their luggage. This is not considered problematic except for the economy lot which is farthest from the terminal. The niche opportunity explored here is to improve parking passenger satisfaction by connecting the economy parking lot to the expanded terminal building with some type of automated shuttle service.

According to GSP staff[21], the economy Lot has 1,506 parking stalls and the daily parking rate is $4.00. Since the Terminal Area Study projects that parking demand will exceed supply

[20] RS&H, Greenville-Spartanburg International Airport Terminal Area Study, 2010
[21] Ernie Kovach, email 5/20/2013

sometime between 2015 and 2027, it has been assumed that this lot will be full on a regular basis in the 2020 design year. In addition, it has been assumed that the average length of stay is three days and the rate remains $4.00. This implies 1,004 daily car trips into and out of the lot, a daily parking revenue of $6,024 ($2.20 M per year) and 183,230 annual trips into the lot (for enplanements). Note that other sources of revenue than parking fees, such as advertising, have not been considered here.

In order to design a conveyance system, the peak hour demand needs to be determined. According to the Terminal Area Study, the total annual and peak hour enplanements in 2020 (Low fare Carrier) will be 1,202,000 and 940 respectively. Based on this ratio, there will be 143 peak hour vehicle trips into the lot. Assuming an average vehicle occupancy of 1.7 as observed at other airports, this represents 243 peak hour person trips into the lot. It has been assumed that the shuttle system should be able to accommodate 219 (90%) of these peak hour person trips. The maximum distance from the furthest point on the parking lot to the expanded terminal area is 1,700’ and takes 6.5 minutes to walk at 3 mph. Thus the target maximum shuttle trip time (walk plus wait plus travel) is seven minutes, in order to be similar or quicker than walking in most cases.

PRT Alternative 1: Elevated plus At-grade Perimeter.

This at-grade Perimeter alternative utilizes a PRT system similar to Ultra or 2getthere operating on an exclusive guideway with five stations laid out as shown here. It includes 0.70 miles of one-way track of which 0.33 miles is at grade in the parking lot (from station P1 to P3) and 0.37 miles is elevated (shown dashed). Of the elevated portion, 0.22 miles is double track, for a route distance of 0.11 miles, alongside parking garage B. Since demand is low, station bays are in line on the station guideway which is very short. This requires vehicles passing by the station to slow to 10 mph in the vicinity of the station. At most, this adds about .75 minutes to a trip from station P1 to T1. The trip time from P1 to T1 is 2.5 minutes. Assuming that the PRT vehicle occupancy matches the occupancy of the cars entering the lot (i.e. one carload of people ride on one PRT vehicle and do not share rides with people from other cars – a conservative assumption), approximately 15 PRT vehicles will be required.

Figure 39 –PRT Alternative 1

This solution provides a very high level of service. The average passenger wait time should be well under 30 seconds. Three of the four parking lot stations are at grade and thus very easily accessible without having to haul luggage up stairs or use elevators. The terminal station could be attached to the upper level of the terminal building with the ability to utilize building facilities for vertical circulation.

On the downside, this alternative is the most expensive, with capital costs estimated at $18.7 M and annual operating and maintenance costs at $0.74 M. The maximum walking distance is about 570’ which takes about two minutes at three mph. However, the total maximum trip time is about five minutes which is less than the target of seven.

While having parking lot stations at grade is advantageous from the standpoint of passenger service and overall capital costs, it does have impacts on the parking lot. One of the three NE/SW circulator roads through the parking lot will be severed and access to the SW portion of the lot will be restricted to the other two roads. The seven foot wide guideway along the eastern circulator road will make this road quite narrow. However, the aerial photograph shows some cars seemingly randomly (and probably illegally) parked along this road causing approximately the same amount of narrowing. Along the NE edge of the lot the guideway would pass through 42 existing stalls. These stalls could be reconfigured to be parallel to the circulator road, in which case there would be 19 of them for a loss of 23 stalls. The parking stalls adjacent to the at-grade guideway in the vicinity of Station P3 would likely have to be restricted to compact cars.

PRT Alternative 2: Elevated.

This is a modification of Alternative 1 whereby all stations and guideways are elevated, as shown here. The parking lot stations are reduced to two which reduces the length of guideway needed to 0.45 miles of track and the number of vehicles to 10. Some additional savings result from the guideway being all double track. The longest trip time is about a minute.

Figure 40 –PRT Alternative 2

While the average wait time is once again under 30 seconds, this alternative requires the use of stairs or elevators for both parking lot stations.

In addition, the maximum walking distance is about 680’ which takes about 2.5 minutes at three mph. The total maximum trip time is once again about five minutes. The impact on parking lot circulation is minimal and the station footprints should only result in the loss of about half a dozen parking stalls. The capital cost is estimated at $17.0 M while the annual operating and maintenance cost is estimated to be $0.67 M.

PRT Alternative 3: At-Grade Guideway

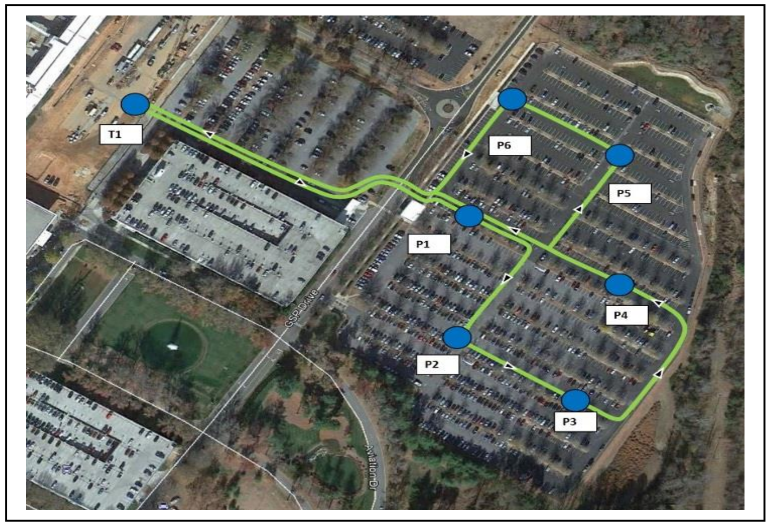

Figure 41 –PRT Alternative 3

This alternative is not really PRT at all since the vehicles operate on surface guideways in mixed traffic along the routes shown in the figure here. Only two suppliers are known to have commercially-available vehicles capable of doing this – 2getthere and Navia. The Navia vehicle is an autonomous shuttle, not previously described since it does not meet the definition of PRT (the vehicles act independently, not under central control and they typically have a maximum speed of 12 mph). A brief description of the Navia vehicle follows. The Navia vehicle is a battery-powered automated shuttle designed to accommodate up to eight passengers. It can park at a raised curb, facilitating level boarding with roller bags and/or wheelchairs. Like the 2getthere vehicle, it has sensors to detect obstacles such as cars or pedestrians and the ability to take evasive action. The system can operate on a schedule, stopping at all stations, or it can be summoned on demand. However, there is no empty vehicle management system. While it is available for purchase, it is understood that it is not yet running in full public service on a continuous basis.

While this alternative has 0.8 miles of one-way track, it is all at grade and almost all on existing pavement. There are six at-grade stations, each not much different than a bus stop. This represents a significant savings in capital costs. The one additional cost that this alternative requires over the others is a set of traffic signals where the vehicles cross GSP Drive. Note that this intersection is north of the parking accesses and so should not interfere with parking traffic. This alternative does a better job than the others of distributing stations evenly in the lot and the maximum walking distance is 300 feet (one minute at three mph). However, this alternative has an at-grade station at the Terminal and details of how this would interface with the Terminal and other traffic accessing the Terminal have not been investigated. Wait and travel times will vary with the particular vehicle used and are discussed next.

2getthere's four-passenger PRT vehicle (PRT 3 at grade) has smaller vehicles operating more frequently and would provide the highest level of service. Top speed would be 15 mph. Approximately 20 vehicles would be required. Once a vehicle has picked up one or more passengers, it will proceed nonstop to the terminal. Maximum trip time would be about three minutes, while the average wait time would be below 30 seconds for a maximum total trip time of about five minutes. The capital cost is estimated at $18.1 M while the annual operating and maintenance cost is estimated to be $0.81 M. A significant flaw with this at grade alternative is that, during peak periods, the traffic signal at GSP drive would be cycling frequently (probably once per minute) causing delays to traffic and to PRT vehicles.

2getthere's 22-passenger GRT vehicle (Alternative 3 – GRT) could meet the demand with four vehicles. Vehicles would stop to pick up passengers at any station being passed unless they were already full. While the maximum trip time would be around five minutes, including stops, the average round trip time is anticipated to be about seven minutes. Note that, after passing P1, the vehicles could dynamically choose to serve the southern or northern loop depending on calls received from the stations. Also, after passing P4, the control system could decide if it is better to proceed directly to the Terminal or to detour around the northern loop.

Vehicles would be scheduled to depart the terminal every two minutes and take about seven minutes to make a complete loop. The average wait time can therefore be expected to be around one to two minutes. The maximum total travel time for this alternative is about eight minutes – slightly higher than the target and this alternative is therefore unlikely to attract 90% of parking lot users. However, it would still provide a useful service to those not wanting to walk. If the average vehicle occupancy is 10, then the capacity in one direction of this system would be about 300 passengers per hour which exceeds the 243 peak hour demand determined at the beginning of this section. The capital cost is estimated at $13.4 M, while the annual operating and maintenance cost is estimated to be $0.62M.

Figure 42 - Navia vehicle

The Navia vehicle (Alternative 3 – Navia) is a bit slower than the 2getthere vehicle and would make the round trip in about eight minutes. Ten vehicles would be required. They would leave the terminal every one minute with vehicles alternating between the northern and southern loop which adds some complexity in that customers would have to remember which loop they parked on. The maximum total travel time of this alternative would be around nine minutes – the highest of all the alternatives. The capital cost is estimated at $5.4 M while the annual operating and maintenance cost is estimated to be $1.05 M. It should be noted that the Navia system has no central control capability and is thus less capable of automatically responding to changing demand. All of the other solutions have the ability to automatically put vehicles into service as demand rises and retract them as it declines. They also have the ability to strategically reposition vehicles depending on the activities of other vehicles, thus leading to a higher level of service being provided more efficiently.

The following table summarizes the pros and cons of each alternative.

ALTERNATIVE	PRT 1 Elevated/ A+- Grade		PRT 2 Elevated		PRT 3 At Grade		GRT 3 At Grade		Navia 3 At Grade	
Capital Cost ($M)	18.7	✖	17.0	✖	18.1	✖	13.4	●	5.38	✔
Annualized Cap Cost[1] ($M)	0.62	✖	0.57	✖	0.60	✖	0.45	●	0.18	✔
Annual Ops Cost ($M)	0.74	●	0.67	●	0.81	✖	0.62	●	1.05	✖
Total Annual Costs ($M)	1.36	✖	1.24	●	1.41	✖	1.07	✔	1.23	●
Annual Revenue[2] ($m)	2.15	●	2.19	●	2.18	●	2.18	●	2.18	●
Cost Percent of Revenue	63%	✖	57%	●	65%	✖	49%	✔	56%	●
Maximum Walk+Wait+Travel Time (min)	5	✔	5	✔	5	✔	8	●	9	✖
Station accessibility	Accptbl	●	Poor	✖	Good	✔	Good	✔	Good	✔
Parking Lot Stations/stops	4	●	2	✖	6	✔	6	✔	6	✔
Interferes w/ Surface Traffic	No	✔	No	✔	Yes	✖	Yes	✖	Yes	✖
Guaranteed seat	Yes	✔	Yes	✔	Yes	✔	No	●	No	●
ADA compliance	Good	✔	Good	✔	Good	✔	Accptbl	●	Accptbl	●

Legend: Poor ✖ Acceptable ● Good ✔

[1] Capital annualized at 0% over 30 years based on possibility of 0% loan.
[2] Assumes parking lot is full each day in 2020, and rate is $4 per day. Variation is due to the number of stalls removed to accommodate each alternative.

Table 4 - GSP Alternatives Comparisons

(Label the chart above GSP ALTERNATIVES. Then remove GSP from the comparison columns and add El+Surface, Elevated, At-grade.)
Note that the Navia vehicle and the 2getthere GRT vehicle have not been considered for the alternatives involving elevated guideways because these larger vehicles would require more expensive guideways. In addition the regulatory requirements for automated transit are very onerous as compared to those for automated road vehicles, which are anticipated to be much less onerous, but are still largely undetermined. The concern is that considerable development and verification will be required (especially for the Navia vehicle) that will take much time and expense.

The above conceptual analysis is not intended to be rigorous, but rather to give an indication of available options and comparative costs. It should be noted that operating costs for small applications such as this tend to be disproportionately high and the costs shown anticipate considerable involvement of existing airport staff to help monitor operations and respond to incidents. If this is not possible, the operating costs could be significantly higher.

The analysis shows that automated shuttle service could be provided in a number of different ways at an annual cost equivalent of about one half of the parking revenue from the economy parking lot. If this is considered feasible, a detailed analysis is suggested to verify the assumptions made here and to develop a more detailed understanding of the options, operations and costs.

6.8.2 Downtown Greenville

Downtown Greenville is Upstate South Carolina's largest central business district.[22] It is alive and flourishing with offices, shops, restaurants, entertainment and many residents. It accounts for over one third of the total office space in the Greenville-Spartanburg metropolitan area and has over ninety restaurants clustered around Main Street. With over 300 event days each year, Greenville leads the region in hosting visitors.

Greenville's downtown is also the cultural center for the region, featuring the Peace Center for the Performing Arts, the Greenville County Art Museum, the Greenville County Public Library, the Museum and Gallery at Heritage Green, the Upcountry History Museum, the Children's Museum of the Upstate and a number of private galleries and theater venues. Additionally, there is fun for the whole family with many parks, the Greenville Zoo, the BI-LO Center arena, and Fluor Field, home to the Greenville Drive minor league baseball team.

This section is intended to offer a vision for Downtown Greenville that could make it even better. This vision is based in part on observations of the impact of the 16th Street Mall on Denver, Colorado. In the early 1980s, Downtown Denver became a ghost town after 5Pm on weekdays and over the weekend. Then traffic, other than shuttle buses, was banned from 16th Street and it was turned into a pedestrian mall. This transformation was strongly resisted by many of the businesses along the mall who faced disruption during construction and an uncertain outcome. However, after it was completed, the mall helped transform the City. Now it comes alive at 5PM during weekdays and is bustling with people all weekend long. While other developments such as the convention center, amusement park and various sports facilities also played a key role, the mall appears to have been a very important catalyst.

The mall shuttle is a key ingredient that helps tie other facilities together. Buses run very frequently (every few minutes during peak times) and are free. They stop at each block, which adds to convenience but slows trips down, and have signal prioritization which helps the buses beat walking speed. Denver has just implemented a new free circulator to help tie the mall into other parts of Downtown.

While the Denver mall shuttle is vital, it is not a perfect solution. The shuttle roads occupy over 15% of the available right-of-way. Furthermore, they are a hindrance to carefree use of the mall since pedestrians have to always pay attention to the frequent buses. In addition, the shuttle roads take heavy pounding from the buses and repairs are disruptive and costly.

Greenville has had its own similar experience with the successful development of Falls Park after many thought it was a mistake to demolish a four-lane concrete bridge and replace it with a steel footbridge. The lovely Liberty Bridge demonstrates that exposing the natural beauty of the Reedy River Falls was more important than a utilitarian bridge. The new award-winning bridge has become an iconic symbol of Greenville's innovative spirit and interest in natural beauty. The vision outlined here would constitute a similar bold move.

[22] http://www.greenvillesc.gov/EconDev/Downtown/

Main Street, Greenville attempts to accomplish three goals simultaneously. With its friendly atmosphere, delightful mix of urban uses and tree-covered shade, it is certainly an attractive, nice place to be. However, its attempts to accommodate both cars and pedestrians result in neither being exceptionally well served. Pedestrians struggle to cross a busy street and cars have to make frequent stops as they deal with crossing traffic and pedestrians. What if portion of Main Street could be turned into a pedestrian mall but, unlike Denver, with no need to accommodate buses? Sidewalk cafes could expand, street vendors could flourish, pedestrians could be carefree and Downtown could be a truly exceptional place to live, work and play.

In order to close Main Street to most vehicular traffic, an alternative form of transportation will have to be provided since it is probably not feasible to just reroute the traffic onto adjoining streets. Fortunately the traffic carrying capacity of Main Street is not very high because it only has two lanes and has frequent traffic signals. In addition, it only provides some 20 parking stalls per block.

Figure 43 - Navia shuttle operating among pedestrians

An elevated PRT system running parallel to Main Street but a block or two away on either side could provide a very useful transportation service for the Downtown area. Such a system could allow residents, business people, shoppers and tourists to park in a parking facility convenient for them and then to have quick access to many parts of Downtown. Vehicular access down Main Street could be limited to emergency vehicles and those deliveries that could not be diverted to back entrances. In addition, it may be possible to allow slow-moving automated shuttles (such as Navia) to travel the pedestrian mall, linking it to PRT stations for those unwilling or unable to walk the short distances involved.

A simple elongated loop of elevated PRT guideway, surrounding Main Street with stations not more than ½ mile apart and integrated with an automated surface shuttle system, would provide exceptional mobility for all Downtown users. Workers could use parking decks or park & ride lots on the side of Downtown most convenient to them. At lunch time they would have quick access to a much larger variety of restaurants and stores. Residents could get around the Downtown area with no need to use a car. Visitors would view the PRT system as an attraction as well as a convenient way to get around. Those without access to a car would suddenly have increased mobility.

The Downtown loop connecting major Downtown attractor locations and current parking decks could be an impetus for a new vision for transit in Greenville. It could be connected to the PRT system described for the GCEDC corridor. This would greatly enhance the utility of both systems. Additional loops could be added serving a wider area of Downtown. Further loops or corridors would expand the area of service. Buses and/or bus rapid transit (BRT) could feed passengers into the PRT network – and PRT could generate passengers for Greenlink service. In this way the PRT network would provide a very high quality of transit service for the denser areas of the community, which could no longer have buses adding to surface congestion. Significant additional choice riders could be attracted as well as significant farebox revenues generated from a wider service area.

This elevated network would further relieve surface traffic in these areas by attracting some drivers from their cars, so motorists and transit users alike would benefit. Feeder buses would operate in less dense areas where traffic is not so problematic. Over time, the balance between PRT, BRT, and buses would be resolved to the best advantage of the whole community. Improved mobility and accessibility for all will raise property values and quality of life for all Greenvillians.

7. Ridership Estimation

TranSystems undertook a ridership study (see Appendix A) to estimate the projected 2020 ridership along the corridor between Downtown Greenville and CU-ICAR as well as between Downtown Greenville and Mauldin. Maps of the projected 2020 population and employment densities used by TranSystems are presented in the following figures.

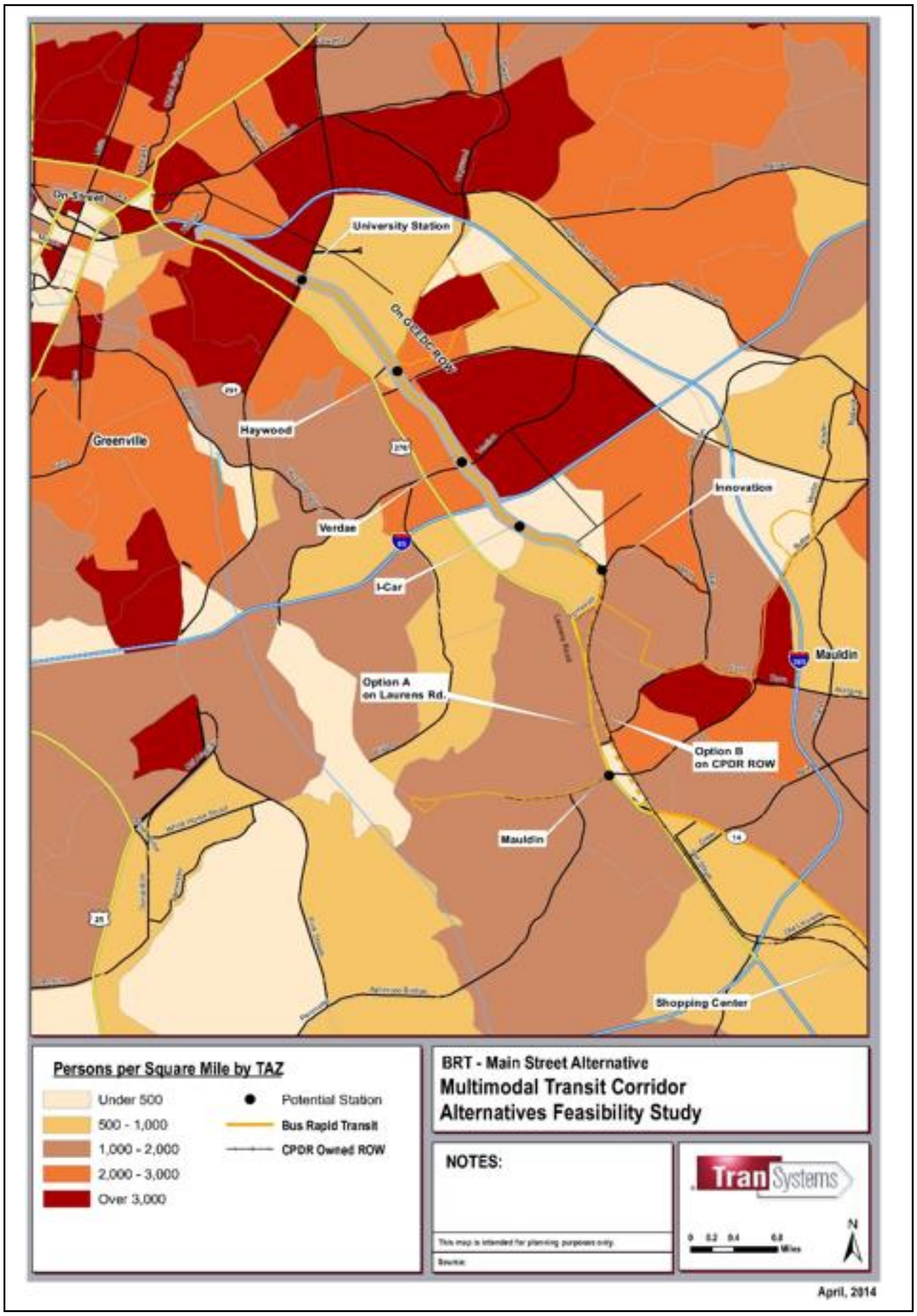

Figure 44 - Projected 2020 Population Density

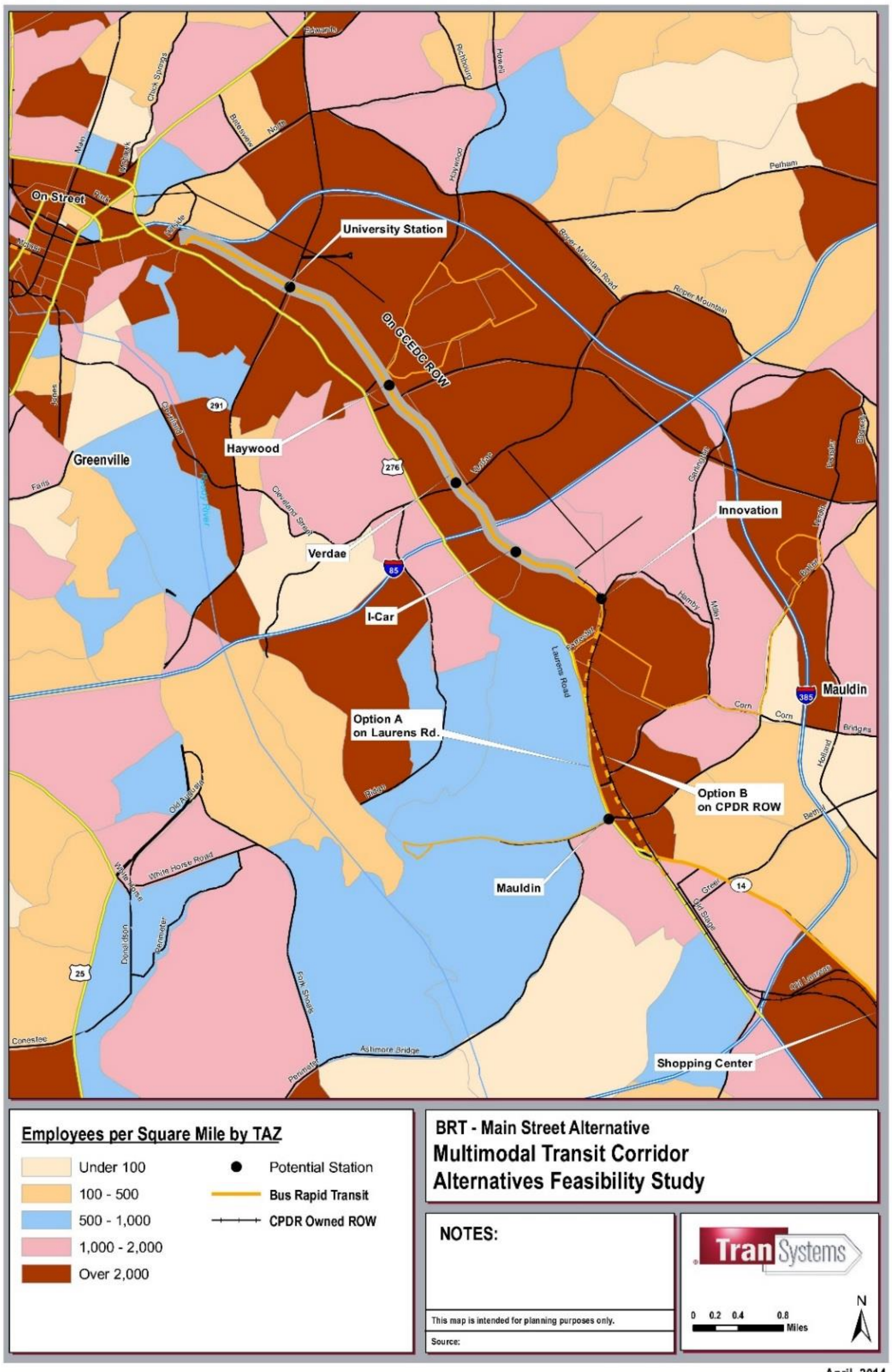

Figure 45 - Projected 2020 Employment Density

A summary of the results of the TranSystems study are presented in the table below.

	BRT		PRT Alternative 2	
	Downtown to CU-ICAR	Downtown to Mauldin	Downtown to CU-ICAR	Downtown to Mauldin
Peak Hour	84	98	343	400
Daily	617	722	2,515	2,943
Annual	165,834	194,026	676,252	791,216

Table 5- Projected 2020 Ridership

PRT is expected to generate over four times as much ridership as BRT for three primary reasons:

1. The service is far more frequent (2.5 minutes average wait time in place of 30 minutes)
2. There are far more stations placing more people within walking distance of the system
3. The service level is high enough to attract some park and ride usage.

The ridership numbers shown above assume a fare similar to the current Greenville bus fare ($1.50 full fare single ride[23]) is charged. As discussed in TranSystems report, the Greenville fare elasticity is assumed to be -0.003 cents. This means that for every one cent increase in fare, the ridership would reduce by a factor of 0.003. Thus at a fare of $1.50 we project an annual 676,252 ridership on the portion from Downtown to CU_ICAR. This would generate annual revenue of $1.01 M. If the fare was increased, the ridership would fall off but, to a point, the annual revenue would increase.

[23] http://www.greenvillesc.gov/RideGreenlink/Routes.aspx Accessed 4/22/14

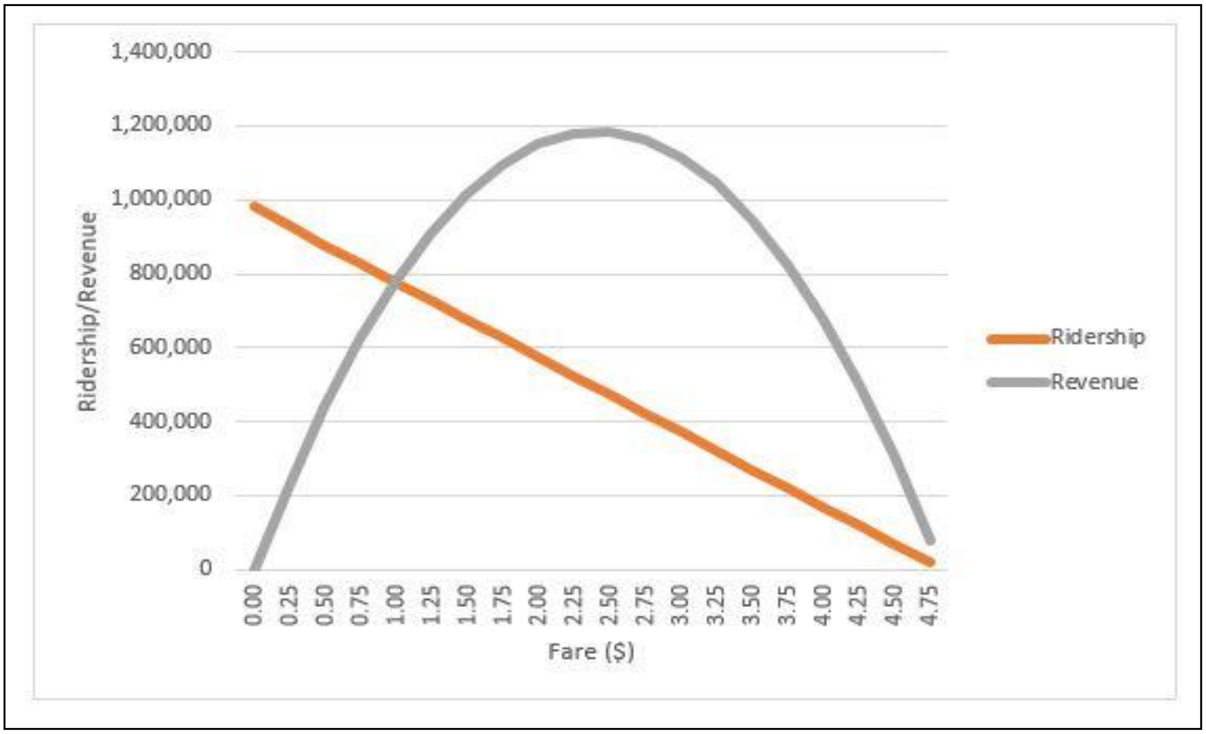

Figure 46 - Relationship between fare levels, ridership and annual fare box revenue

The figure above shows the relationship between fares, ridership and annual revenue. It can be seen that revenue peaks at a fare of $2.50. However, the top of the curve is fairly flat and an optimal fare amount of $2.00 is suggested as a good compromise between generating the most revenue and charging a reasonable fare. A $2.00 fare generates an annual revenue of $1.15 M which is only 3% less than the maximum revenue with a fare of $2.50.

At a $2.00 per single ride fare, the Downtown to CU-ICAR annual 2020 ridership is projected to be 574,814, while the daily and peak hour ridership would be 2,138 and 292, respectively.

8. Implementation and Funding

The 2010 Feasibility Study provides an extensive discussion addressing implementation and funding issues. This section builds on that work and addresses the major differences relevant to a PRT solution from CU-ICAR to Downtown Greenville.

Governance issue would be simpler since the project would be entirely within Greenville County and the City of Greenville. Either of these entities, the GCEDC or a special purpose company could own the system. The owner would likely operate the PRT system through a contract with the supplier initially with a possible future handover to the owner.

The funding sources would remain the same (except for those directed solely at buses) but the markedly better cost effectiveness of the PRT solution would make it much more competitive. While the PRT corridor alternative does attract more daily riders, the number is projected to be about 2,100 which is still below the 3,000 threshold for the FTA's Very Small Starts program. However, the total capital cost would be under the maximum $50 million and the cost per mile (excluding vehicles and control system) would probably be under the maximum $3 million. Other federal funding, such as TIGER Grants, may also be available for this project. Owing to its innovative nature and its ability to cover its own operating costs with little or no subsidy, it is recommended that consideration be given to holding a meeting with the FTA to explore how they could support funding it (bearing in mind that FTA funding may further complicate, and increase the costs of, an already complicated project).

Whether or not federal funds are found for this project, it will require substantial local and/or state/private funding. In all likelihood funding will have to come from numerous sources and will probably include loans as well as grants. Low- or no-interest loans (as may be available) could go a long way toward making the project feasible.

This study has focused on comparing the PRT solution to the previously-preferred bus rapid transit solution (and finding it eminently more desirable). However, it has not investigated the many other benefits that the community could derive from high-quality automated fixed-guideway transit. These include:

- Increased property values
- Better accessibility (to jobs, schools, hospitals, shopping, etc.) with resulting economic benefits
- Reduced accidents, emissions and energy use (increased sustainability)
- Reduced need for Downtown structured parking
- Better multi-purpose use of the corridor
- A starter system than can be expanded to serve a wider area
- The beginnings of a new industry, many aspects of which could be based in Greenville

It is believed that examination of the above benefits will show that their monetary value far outweighs the projected cost of the system. If ways can be found to monetize some of the above benefits, it should be possible to fund this project. An example would be diverting funds for additional structured parking (which typically costs $20,000 - $25,000 per stall) to a PRT system linking large buildings on the periphery to the Downtown core. If people in these peripheral buildings frequently need to go Downtown, they presently require a parking space at each location. A PRT connection would eliminate the need for the Downtown space while also making the trip quicker and more convenient and simultaneously removing traffic from the roads. The following two tables illustrate benefits accruing to different parties and revenue streams and savings.

Land Developers	Transit Operators	Users
Maximize land value	Higher Ridership	Private (seated) travel
Easy to install	More revenue	Direct-origin-to-destination
Integration into spatial planning	Lower operating costs	Transit on demand
Uses little surface space	High system availability	Predictable
Sustainable	Safety	Accessible
Image	Lower energy consumption	User friendly (intuitive)

Table 6 - Business Case Advantages to Land Developers, Transit Operator, and Users[24]

	Revenue	Savings
System	Sponsorship & advertising	Low CAPEX Low OPEX
Passengers	Farebox	Increase staff productivity Reduce travel time
Owner/Developer	Increase rents/service fees Public transit access increases property value	No disruption to services Minimal footprint
Local Government	Increased parking fees	Reduction in traffic congestion Reduction in emissions
Other	3rd party partnerships	

Table 7 – Revenue Streams and Savings[24]

The Greenville Transit Vision and Master Plan, July 19, 2010 stated that a farebox recovery ratio of 20 to 25% was considered reasonable. This implies that it is reasonable to subsidize the fare paid by three times that fare amount. In the case of PRT Alternative 2, the annual fare revenue is projected at $1.15 M. Adding a subsidy of three times this amount ($3.45) results in a total annual income of $4.60 M which is more than the projected annual cost of capital plus O&M. Another way of looking at this is that, if the capital costs were financed at a low rate of interest and the repayments rolled into the annual

[24] ATRA IG From Welcome to the 21st Century Public Transit comple(men)ted Webinar.

operating costs, the required fare subsidy would be less than what is considered reasonable. Yet another way of looking at this is that the farebox recovery ratio of 37% for the PRT *O&M plus capital* is higher than the ratio of 17% for BRT *O&M costs only*.

This study was focused on the GCEDC corridor. While it was tasked with taking a cursory look at other potential niche applications, the scope did not include evaluating a comprehensive PRT system in Greenville. The utility of a transit systems increases roughly as the square of the number of stations (double the stations and you will approximately quadruple the utility). Thus a small corridor or niche system will likely not have the utility, or ridership of a larger, more comprehensive system. It could well be that a larger PRT network would be even more viable than any of those investigated here. A more comprehensive study could investigate land use patterns and suitable station and guideway locations for an optimal PRT solution in Greenville. A detailed benefit/cost analysis could then demonstrate its value to the community. Such a study could help demonstrate the value of a GCEDC Corridor PRT solution as a starter system for the optimal solution.

9. Conclusion & Recommendations

PRT is a form of transit that is more like a car than a bus in the level of service it offers. This high level of service enables it to attract many more riders than conventional transit can. This is particularly applicable when account is taken of the relatively low capital and operating costs of PRT systems.

There are three PRT systems that are presently commercially available and in public service. Many other suppliers are developing systems of which at least two could be applicable to a Greenville application.

The two different PRT solutions investigated for the CU-ICAR to Downtown Greenville GCEDC corridor both are far superior to the previously-selected BRT solution with the exceptions that the BRT system has a lower capital cost and is more feasible for an extension to Mauldin. The PRT ridership is forecast to be sufficient to cover almost all operating costs, which is unusual for a public transit system. More work is needed to determine the optimum solution (which will likely somewhere between Alternatives 1 and 2), to better forecast ridership and to determine funding/financing mechanisms.

A number of alternatives were investigated for an application at GSP. GSP Elevated and At Grade PRT Alternative 1 had the highest capital cost but also offered the best level of service and no interference with surface traffic. Somewhat surprisingly, the total annual cost of the alternatives did not vary greatly since the solution with the lowest capital cost also had the highest operating costs.

A Downtown PRT loop could further enhance the vitality of the Downtown area. If connected to the GCEDC corridor system, the utility of both would be greatly enhanced. Additional loops could be added providing a very high quality of transit service for the denser areas of the community, which would no longer have buses or BRT adding to surface congestion. Buses or BRT could connect outlying areas to this PRT network.

All of the work in this report was of a conceptual nature and much more detailed analyses are required to adequately plan and develop any of the suggested solutions. A widespread PRT network is anticipated to have far more utility than a short, corridor-based system. Consideration should be given to all of the benefits the community would derive from a high-quality transit service. It is anticipated that their value would far outweigh the system costs.

The value of the GCEDC corridor PRT system appears sufficient to justify its implementation. Unfortunately, monetizing all the benefits will be difficult or impossible and funding for the system will have to come from numerous sources. Potential funders should be aware that the GCEDC system may be invaluable as a starter system for a widespread PRT network.

Beyond just being a better alternative to BRT, a PRT solution offers many additional advantages to the community. While these include conventional transit advantages such as increased accessibility and mobility, they also include potentially significant side-benefits such as reduced congestion and increased safety and sustainability. Furthermore, a PRT solution could also offer benefits not typically associated with transit such as the potential to convert portions of Main Street into a pedestrian mall and economic development opportunities related to an automated transportation sector developing in Greenville.

The economic development opportunities could include a university-based center of excellence, vehicle design and manufacturing, control system development, infrastructure development, research and development, etc. Combined with the transit system itself, these developments would lead to seminars, site visits and conferences, generating further economic benefits and increasing interest in the technology.

10. Appendix A: Connecting Greenville

Connecting Greenville

Linking neighborhoods and businesses through innovative transportation
Using multiple modes: walking, cycling, car, bus and personal rapid transit
Creating GreenVillages where connected people love to live, work, shop, dine and play
Anywhere, anytime – it's a moving experience

In a workshop held May 9 and 10, 2013 over 35 community leaders, professionals and citizens agreed personal rapid transit (PRT) solutions in Greenville should be seriously explored in order to:

Create a sustainable future for Greenville by improving accessibility and economic vitality

PRT is like a driverless taxi system and attracts choice riders. Since it operates on overhead guideways, it takes you safely to your destination nonstop. Numerous stations reduce walking distances and wait times are very short. The system can operate 24/7 and, because of the lack of drivers, operating costs are low. Because PRT offers first class private transit, its impacts on land values are expected to at least match those of regular transit (found to increase land values by an average of 42% by the American Public Transit Association). A survey of Greenvillians is finding a surprisingly high proportion of car drivers would consider switching to a high quality transit system like PRT.

In considering the potential impact of PRT on problems associated with cars and roads, the group compared it with other modes and concluded it could be far more effective.

Potential Impact on Car and Road Problems

	Car Share	Bus	Bus Rapid Transit	PRT
Automobile operating costs	✔	✔	✔	✔
Air quality	○	○	✔	✔
Water quality	○	○	✔	✔
Road maintenance	✖	✖	○	✖
Safety	✖	○	○	✔
Accessibility	○	○	○	✔
Congestion	✖	○	○	✔
Sprawl	✖	○	✔	✔
Energy/oil use	✖	○	○	✔
Social disconnect	✖	✔	✔	✖
Walkability/severance	✖	✖	○	○
General health	✖	○	○	○

Helps ✔ Some Help ○ No Help ✖

Will you join us in Connecting Greenville…

When: Starting now! Downtown to CUICAR by 2018!

For more information, contact: Fred Payne (864)884-8899 gfp2kmp@yahoo.com

11. Appendix B: Ridership Evaluation

TO: Peter Muller, PRT Consulting

FROM: Gina Trimarco, Tran Systems
Rick Halvorsen, TranSystems

RE: Greenville, SC PRT Study
Ridership Evaluation

DATE: April 17, 2014

TranSystems, as subconsultant to PRT Consulting, was asked to generate ridership estimates for the Personal Rapid Transit (PRT) mode alternative and the Bus Rapid Transit (BRT) Main Street alternative proposed to operate between downtown Greenville and the ICAR facility/City of Mauldin. The following provides the background of the analysis and the estimated 2020 ridership.

Mode Split

The basic question in estimating the ridership of the proposed transit services is what share of existing travelers in the corridor will be attracted to a new transit service. This has been estimated by reviewing journey to work data contained in the Census Transportation Planning Products. Data was reviewed from both the 2000 and 2010 Census, and the 2006 – 2010 American Community Survey (ACS).[1] The 2010 Census provides population data for the census tracts, but does not include journey to work data. The ACS provides the most current information on the total journeys to work between census tracts, but the small size of the sample means that it does not provide data on the mode used. Therefore, the 2000 Census data was also referenced as it provides more details regarding small groups, such as the mode of transportation used for journeys to work between specific census tracts.

The 2000 Census journey to work data was analyzed to determine the average use of transit for work trips between specific pairs of census tracts with good transit service. Thirty-six of these pairs currently had transit mode shares of 10% or higher (i.e. 10% use transit), with the maximum mode share of 83%. Another 16 census tract pairs had mode splits of between 2% and 9%. Overall, the transit mode share between census tracts where there were any transit riders identified was 12%. While there is a high degree of potential error in some of these results (since they are based on a sample of 1 in 6 census respondents and between 14 and 386 respondents per census pair), this does show that where a reasonable transit alternative is available, many individuals will choose to use it. This analysis will use 12% as the base estimate for the transit mode split of a transit system that has hourly service.

All census tracts along the proposed transit corridor were assessed to determine work travel patterns using the 2006 – 2010 ACS. It was assumed that the journey to work trips made

[1] Effective with the 2010 Census, the Census Bureau no long used the long form census survey, which had previously been the source of journey to work and other key transportation data. The Census Bureau has replaced the long form with the American Community Survey, which surveys a small sample of households every year.

within a census tract most likely would not be made on transit due to the short distance that would be traveled, and were not considered in the ridership model. In addition, it was assumed that the BRT Main Street option would not generate additional transit travel within the downtown core. The journey to work trips that were made between census tracts along the corridor were considered as a potential for future transit trips and included in the ridership model.

The census tracts were then examined from a geographical standpoint to determine how close they were to a proposed station; i.e. what percentage was within one half mile of the station. Typically, transit users living within one half mile of a station walk. Those who live beyond one half mile are much more likely to drive to their destination, while only those who are making the longest trips are likely to drive to the station or get dropped off. These percentages were then applied to estimate the portion of the journey to work trips that can reasonably be served by transit, i.e., for which both the origin and the destination of the trip are within one half mile of a station.

Estimated Ridership

Applying these percentages to the journey to work data along the proposed transit corridor gives an estimate of 964 daily journeys to work that would be served by the proposed PRT service and 585 daily journeys to work that would be served by the proposed BRT service in this corridor. Each journey to work is matched by a second journey from work to home which doubles the potential number of trips. Furthermore, when estimating ridership for most transit services, work trips are assumed to equal about half of the total number of transit trips taken. Thus, after applying Greenville's current journey to work mode split for hourly service of 12%, hourly service along this route would generate an estimated 462 daily passenger trips along the PRT route and 281 daily passenger trips along the BRT route. Considering that Greenville's public transportation system, Greenlink currently operates 11 bus routes across the county with an average daily ridership (NTD 2012) of 2,979, or about 270 daily passenger trips per route, and that these routes would serve relatively high density population and employment centers, these estimates appear to be reasonable.

Greenlink's annual ridership in 2012 was 800,965, or approximately 269 times the reported daily ridership. This factor is used herein for developing estimates of annual ridership for both BRT and PRT.

TCRP[1] indicates that the high quality of BRT service can attract an additional 25% ridership and, since PRT service levels will be as high or higher than BRT, this factor should also be applied to PRT. Since PRT service will be much more frequent and stops more widespread, it is necessary to determine what impact these factors will have on ridership levels. In addition, it is important to understand how ridership will vary with the cost of fares. A web-based transit survey was conducted in the Greenville area in 2013 and ridership coefficients were extracted for each of the above factors. As illustrated in Table 1, the Greenville factors are in line with those reported by the TCRP[2].

[2] TCRP Report #118 Bus Rapid Transit Practitioner's Guide

Table 1: Mode Choice Coefficients

Variables		Coefficients			
		TCRP			GVL
Attribute	Units	HBW	HBO	NHB	
In-vehicle time	Minutes	-0.020	-0.010	-0.020	-0.015
Out-of-vehicle time	Minutes	-0.040	-0.020	-0.040	-0.030
Fare	Cents	-0.003	-0.0012	-0.015	-0.003

Key: HBW: Trips between home and work
HBO: Non-work trips beginning or ending at home
NHB: Trips not beginning or ending at home
GVL: Greenville travel survey for all trips

The coefficients given above are the change in ridership for every change in attribute. For example, for every one cent increase in fare, the ridership for HBW or GVL would reduce by a factor of 0.003 (if there were 1,000 riders and the fare was raised one cent then the number of riders would reduce to 997 (1,000 – (1,000*.003)).

The GVL results indicate Greenville residents value in- and out-of-vehicle time about the same as reported by TCRP and fare cost slightly more. These are not surprising results and the TCRP HBW coefficients will be used in this document.

Service frequency has a major impact on ridership. Based on the 0.040 per minute coefficient in Table 1, the BRT numbers should then be adjusted up by a factor of 60% to account for a 30 minute service frequency (an average 15 minutes less wait time). Similarly, the PRT numbers should be adjusted up by a factor of 113% to account for a 2.5 minute service frequency.

By comparison, the City of Greenville's BRT study[3] uses a range of elasticity factors of 0.44 to 0.58, referencing TCRP Report 118. Applying the mid-point arc elasticity formula from the TCRP Report, these elasticities would result in an estimated ridership increase of between 34% and 48% (an average of 41%) as a result of increasing service frequency from hourly to once every 30 minutes.[4] For increasing service frequency from hourly to once every 2.5 minutes, these elasticities would result in estimated ridership increases of 136% to 229% (an average of 182%).

Both of these methods provide similar results. Averaging the two results gives an estimated increase in ridership of 51% for 30 minute service and 135% for 2.5 minute service. Combined with the ridership increase from the higher service quality of BRT and PRT service this results in an estimated increase in ridership, compared with hourly bus service, of 89% for 30 minute BRT service and 253% for 2.5 minute PRT service.

[3] Study Management Plan, City of Greenville Bus Rapid Transit (BRT) and Transit-Oriented Development (TOED) Feasibility Analysis, January 2013

[4] The Study Management Plan, City of Greenville Bus Rapid Transit (BRT) and Transit-Oriented Development (TOED) Feasibility Analysis, January 2013 estimated a much higher ridership for BRT service as it used a different methodology to estimate the impact of changes in frequency instead of the mid-point arc elasticity formula presented in TCRP Report 118.

Population in the Greenville region is expected to increase by 11.2% from 2010 to 2020, while population in the City of Greenville is expected to increase by 11.5% over that same period. Population in the corridor is expected to increase approximately 16%, due to the large Verdae mixed-use development and the fact that much of the corridor is designated Transit-Oriented Development for the future development. Substantial additional employment development is also expected at ICAR, as well as at Mauldin to the south. Ridership for 2020 was estimated by increasing ridership between any two census tracts by the average of the systemwide increase in employment (8.5%) and the anticipated population increase for each originating census tract (from the Greenville-Pickens Area Transportation Study). This method therefore reflects the anticipated large growth in population around Verdae as well as the anticipated slight loss in population in and near the urban core.

Daily ridership in 2020 with the 2.5 minute PRT service is estimated to be 1,898, while daily ridership with the 30 minute BRT service is estimated to be 617. Annual ridership for PRT is estimated as 510,257, while annual ridership for BRT is estimated as 165,834.

According to the ACS, the peak journey to work time in the Greenville area is the 7 'clock hour, when approximately 30% of trips to work are made. Normally the peak travel hour is during the afternoon, when a similar portion of journeys home are made, as well as some non-work trips. The peak hour ridership was therefore estimated as 30% of the return journey to work trips (work to residence) plus 0.5% of the journey to work trips (residence to work) plus 12% of non-work trips.

Park and Ride

PRT, with an exclusive right-of-way and a 2.5 minute headway, is potentially a very attractive alternative for park and ride service. The PRT provides a quick service to downtown with no downtown parking issues, while the 2.5 minute headway eliminates concerns over significant wait times when transferring from auto to PRT. The majority of the park and ride ridership would occur at the Verdae and ICAR stations and serve individuals living more than ½ mile from a station, or who are driving into Greenville on Laurens Road from either I-85 or from south of ICAR.

Providing parking at these stations would slightly more than double the trips that PRT could potentially serve. However, because riders do need to transfer from their automobile to a PRT vehicle and wait a few minutes for a vehicle, the mode split for park and ride service is generally about 25% that for individuals who can walk to transit. These two factors would result in park and ride service increasing PRT ridership by just over 25%.

Mauldin Extension

An extension to Mauldin would increase the journeys to work served by approximately 17% on both BRT and PRT. Estimated peak hour, daily and annual ridership for both 30 minute BRT and 2.5 minute PRT services are shown in the table below for both the base service and the extended service to Mauldin.

2020	BRT		PRT	
	Base	To Mauldin	Base (including Park and Ride)	To Mauldin
Peak Hour	84	98	343	400
Daily	617	722	2,515	2,943
Annual	165,834	194,026	676,252	791,216