

## THE SMART CITY VISION OF GREENVILLE, SOUTH CAROLINA

### VISION NARRATIVE



**Beyond Traffic: The Smart City Challenge 2016**

**Team Greenville**  
**February 4, 2016**

Smart City Challenge Team Greenville

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## **Vision Narrative**

### **USDOT Grant Ref #DTFH611RA00002. Beyond Traffic: The Smart City Challenge**

#### **Chapter 1 – Current challenges of city development, Greenville’s Smart City Vision, approach to demonstrate the vision**

The City of Greenville was incorporated in 1831 and its original growth was driven by the boom of the textile industry. Infrastructure innovations such as railroad and telecommunication as well as the availability of hydro-power were instrumental in attracting textile mill owners to the Greenville area. With the establishment of textile mills so called mill towns were created where factory workers lived, worked and also could educate their children and which laid the foundation for Greenville to be called “Textile Capital of the World” in the early 20<sup>th</sup> century. Though most mill village owners chose not to incorporate into the City of Greenville, a very high percentage of the mill village citizens connected to downtown by walking, using bicycles, or using electrified buses operated by the local power company for transportation.

In the decades after WWII, Greenville communities changed as textile manufacturing went offshore. The mill villages lost population and their roads, sewer and water lines fell into disrepair. The privately operated bus system service deteriorated as automobiles gradually replaced bus vehicles and utilization dropped. Today, the ring of former mill villages around Greenville City limits still suffers from industry flight. These areas have high population densities and high levels of unemployment, poverty and crime influenced by drug-abuse. Further compounding these major issues, is the lack of transportation options within these areas thus limiting access to the better paying job opportunities and other quality of life amenities.

Over the last few decades, Greenville city and county leadership has transformed the downtown area into a highly attractive residential, business, entertainment, and recreational environment. Greenville’s vibrant downtown supports strategic business sectors and generates well-paying jobs well beyond the city limits. A prime example is the automotive industry.

Greenville envisions a smart city with improved mobility and safety by providing the following core transportation services:

- 1) high density zones of urban activities are being served with low speed automated electric vehicle fleets that are publicly or privately operated
- 2) low density urban zones are being supported by on-demand connected zero-emission enabled public and private shuttles in a ride-share model available to all citizens
- 3) zero-emission public transit buses connect the different high density zones and provide the backbone in a multi-modal transportation system
- 4) high-capacity intelligent parking structures are centered around key multi-modal transportation nodes

Figure 1 illustrates which vehicles types could be used to support the Smart City Vision.

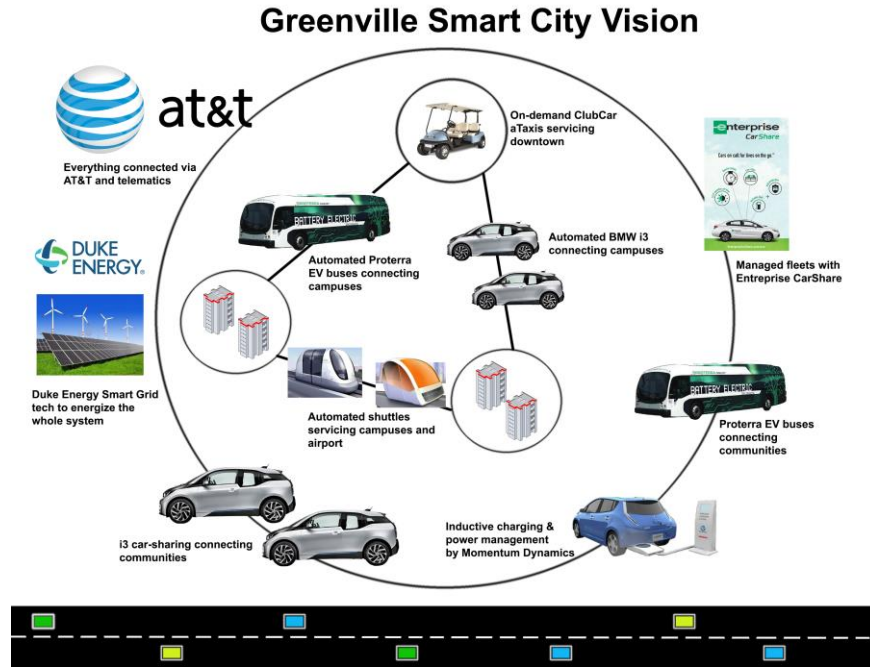


Figure 1. Greenville Smart City Vision

The vision of Greenville Metro is to become a place where every citizen enjoys multi-modal mobility options that are optimized to the personal lifestyle with a minimum environmental footprint and the highest safety and efficiency level that is technically feasible and economically responsible.

Greenville County's crumbling infrastructure and unsafe road conditions are well documented. In 2013, for the third consecutive year, Greenville County ranked in the top five in AAA Carolinas' annual list of South Carolina's most dangerous counties for collisions. Ranking second in the state for collisions for three years straight, Greenville County averaged 334.5 crashes per 100 million vehicle miles traveled.

Many residents choose to accept significant commuting times to their work locations in exchange for affordable housing farther away from job and shopping centers. On the other hand the City of Greenville attracts both younger generations as well as retired people who choose a living place in the downtown area with more options for entertainment. As Greenville is an important manufacturing location – with a specific focus on automotive industry sector - significant numbers of workers need to commute from their homes to manufacturing sites. Of growing importance is the knowledge worker which prefers a work location in attractive business parks or in downtown office locations.

With the population growth both in the City and County of Greenville, driven by an attractive downtown area on the one side and affordable housing in particular for families on the other side, the transportation problems in terms of infrastructure capacity, road safety and lack of public transportation options are continuously increasing.

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The Smart City Vision of Greenville is to create a transportation system that in general reduces the dependency of major groups of citizens on owning a personal car and specifically supports the use of automated and zero-emission private and public vehicles supported by suitable infrastructure and regulations. The main goal is to improve transportation for all citizens by providing a variety of multi-modal choices. A cornerstone of the vision is to find ways where pedestrians, bicyclists and low-speed small electric vehicles can jointly use road infrastructure without compromising safety or increasing congestion. A good starting point is the Swamp Rabbit multi-use trail system. Opened in 2010 after being converted from an original rail road, the Swamp Rabbit Trail is being expanded due to its high popularity with Greenville citizens and visitors.

In 2007, the Greenville-Pickens Area Transportation Study (GPATS) MPO long-range plan envisioned major transportation corridors - north-south from Travelers Rest to Fountain Inn, and east-west from Greenville-Spartanburg (GSP) International Airport connecting Greenville's urban attractors through Easley to Clemson University (see map). An important part of the Smart City vision of Greenville is to fulfill the GPATS plan with 21<sup>st</sup> century transportation solutions on major urban corridors.

The Greenville Spartanburg Airport is currently in the process to initiate the procurement of a \$20 M modern automated transit network (ATN) to connect parking structure with the terminals – likely to be the first of its kind in the US. Clemson University main campus is interested to explore automated transportation systems to connected university buildings with parking structures.

In order to address the challenges of the Greenville transportation system and illustrate the Smart City vision of Greenville, the following demonstration areas have been chosen:

- a) Greenville Main Street → support the vision of a personal car-free zero-emission downtown mobility zone
- b) Woodruff Road/Verdae area → support the vision of a smart shopping area with a fully automated transportation system for people and goods including remote parking connectivity and
- c) Automated transportation-enabled airport and university campus pilot → automated commute between remote parking areas and buildings (simulated for GSP and Clemson Main Campus) at the property of the South Carolina Technology and Aviation Center (SC-TAC) connected to a solar powered smart grid network

Greenville has a very unique situation with the presence of the International Transportation Innovation Center (ITIC) and Clemson University International Center for Automotive Research (CU-ICAR) in terms of transportation innovation research and demonstration capabilities.

Furthermore, Greenville is the home of multiple leading companies that are relevant for transportation vehicle and component design, transportation logistics and transportation infrastructure development. CU-ICAR will play a key role in vehicle and infrastructure concept development for the suggested demonstration projects. ITIC will play a key role in vehicle and infrastructure system validation and supplier selection. The suggested approach is that ITIC will implement a program management office to supervise the design, build and operation of the demonstration projects. Each demonstration project first needs to validate all relevant technology elements at ITIC. For each demonstration project a specific project management team is selected which will be composed of representatives of city/county/citizen community

interest groups, industry and academia.

The planning lead for the demonstration projects is with city/county – the implementation lead is with industry with support from academia and citizen community interest groups. The involvement of start-up companies in the technology demonstrations is highly encouraged and will be supported by incubation centers and investor groups. The operational lead of the demonstration areas will be with ITIC.

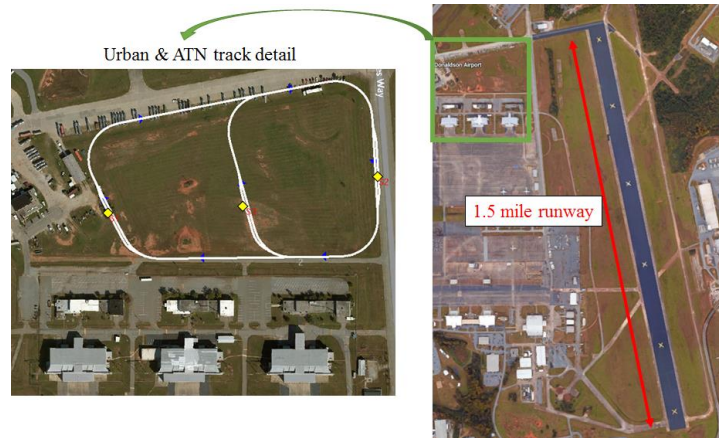


Figure 2. ITIC testing facilities

## Chapter 2 – Greater Greenville’s population characteristics and its alignment with USDOT’s Smart City characteristics

Greenville County’s population was 451,225 according to the 2010 Census and its land area is 785.12 sq. miles and had a density of 574.7 persons per square mile. The City of Greenville is surrounded by contiguous neighborhoods developed as mill villages in the past, other developed communities, and the City of Mauldin. These communities have a combined population of 203,333 and an average density of 2’000 people per square mile. Table 1 provides a list of those communities and their 2010 Census information.

Table 1. City of Greenville and Surrounding Communities Population (2010)

Community	Population C DP (2010)	Land area (sq. miles)	Density
Berea	14,295	7.70	1,855.5
City of Greenville	58,409	28.67	2,037.4
City of Mauldin	22,889	9.95	2,300.40
City of Simpsonville	18,238	8.81	2,070.15
City View	1,345	.52	2,586.54
Duncan	3,671	1.57	2,338.22
Gantt	14,229	9.91	1,435.82

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Community	Population C DP (2010)	Land area (sq. miles)	Density
Judson	2,050	0.79	2,594.94
Parker	11,431	6.82	1,675.6
Sans Souci	7,869	3.31	2,376.6
Taylors	21,617	10.70	2,020.1
Wade Hampton	20,622	8.96	2,301.8
Welcome	6,668	4.64	1,438.3
Totals	203,333	102.35	1,986.64

To effectively plan for big, bold, innovative, smart transportation solutions, the size of our transportation area must be large enough to connect a large portion of the places where people’s life take place. The following statistics are also provided to make the case that the urbanized area of Greenville County meets the desired population characteristics of the Smart City Challenge. The Greenville-Anderson-Mauldin MSA includes the counties of Greenville, Pickens, Anderson, and Laurens. MSAs are developed by having at least one established core of 50,000 persons and is consolidated with other small cores in the region. The population of the Greenville-Anderson-Mauldin MSA: 824,112 (2010 Census). In addition, the Urbanized Area (UZA)—US Census Bureau statistical area—is the official geography that determines the makeup of the MPOs like GPATS (Greenville-Pickens Area Transportation Study). GPATS contains two UZAs, the Greenville UZA and the Mauldin-Simpsonville UZA.

Like the MSA, the core is established by 50,000 persons, but the size of the UZAs is determined by the Census definition of the “Urban Area.” The population of the Greenville UZA: 400,492 (2010 Census) and the population of the Mauldin-Simpsonville UZA: 120,577 (2010 Census). Last, the metropolitan planning organization (MPO) is the federally mandated and funded jurisdiction that fully encompasses the UZA(s) in a region, and including additional areas expected to become urban within the next 20 years. The 2010 population of the GPATS MPO was 621,834 (2010 Census). Table 2 summarizes the population and density for the UZAs, MSA, and MPO.

Table 2. Greenville Urbanized Areas (2010)

Urbanized Region	Population CDP (2010)	Land area (sq. miles)	Density
Greenville-Anderson-Mauldin MSA	824,112	2787.56	295.64
Greenville UZA	400,492	322.92	1240.22
Mauldin-Simpsonville UZA	120,577	84.09	1433.9
GPATS MPO	621,834	904.47	687.51

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Urbanized Region	Population CDP (2010)	Land area (sq. miles)	Density
Combined Greenville and Mauldin-Simpsonville UZAs	521,069	407.01	1,280.24

Greenville population numbers—whether MSA, UZAs, MPO, or the combined population of the cities of Greenville, Mauldin, and Simpsonville and surrounding communities—meet the desired population characteristics of the Smart City Challenge funding opportunity.

To address truly innovative solutions being requested by USDOT Team Greenville believes the logical population size is to plan first for the Greenville CCD or UZA (263,637 to 400,492), and in later phases, to include the larger GPATS MPO or the two UZA entity areas (GTA and CAT).

Greenville’s CCD density is 1,403.05 per square mile, calculated using its 2010 CCD population (263,367) divided by its 2010 CCD land area of 187.71 square miles, as provided by the US Census Bureau. The CCD population includes the City of Greenville and many small communities/places, such as Berea, City View, Dunear, Gantt, Judson, Parker, San Souci, Taylors, Wade Hampton, and Welcome.

The U.S. population is expected to grow by 70 million over the next 30 years, and most of this population growth will be concentrated in metropolitan areas or cities. Metro Greenville population is predicted to double from about 480,000 people in 2015 to over 1 million in 2030.

### **Chapter 3 – Other characteristics**

#### ***Existing public transportation system***

Greenville Transit Authority (GTA)—now named Greenlink—was created in 1974 by Ordinances of the City of Greenville and Greenville County, pursuant to the Regional Transportation Authority Law, originally adopted in 1973 and later amended. The Greenville Transit Authority is governed by a seven-member board. Two members are appointed by Greenville City Council, two by Greenville County Council, and three by the Greenville County Legislative Delegation. Under GTA’s contract with the City of Greenville, the GTA Board retains all duties, powers and responsibilities defined in State law. These responsibilities include the duty to purchase, lease, own, operate or provide for the operation of transportation facilities and services.

Historically, GTA has served the urban core of Greenville. However, in 2012, Greenlink expanded transit services to the cities of Mauldin and Simpsonville and in 2013 they developed express service to Clemson University, 30 miles southwest of Greenville. Today, GTA covers roughly 227 square miles and has seen overall ridership grow from 660,000 unlinked passenger trips in 2009 to more than 1 million in 2015.

While the increased usage of transit in Greenville has been well received, GTA has struggled to



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keep up with the mobility needs of a rapidly growing area. In response to this challenge the Piedmont Health Foundation launched a transit study in 2015 and identified several key themes as a result of soliciting feedback from the community:

- Lack of transportation is a primary barrier to economic success in the region.
- Citizens desire an innovative transportation system and mobility infrastructure,
- Transit service must be improved with more direct route patterns, shorter wait times, and longer hours.
- Infrastructure and land use planning must be integrated into future transit plans.

GTA has been working closely with the Piedmont Health Foundation, Clemson University, local officials, and other interest groups to address these challenges by creating collaborative inter-agency and public-private partnerships.

### ***Environment that is conducive to demonstrating proposed strategies system***

Greenville is the home of institutions and industry partners that are critical to demonstrate the suggested Smart City vision – examples are CU-ICAR, ITIC, GE, AT&T, IBM.

Greenville citizens are open to use new technologies that improve their quality of life and with estimated 5.8 million visitors annually it has the potential to become an ambassador of new transportation solutions to the world.

### ***Continuity of committed leadership and capacity to carry out the demonstration throughout the period of performance***

As illustrated in the long list of support letters by City, County and State level as well as corporate leadership for the Greenville Smart City Challenge proposal, the Greenville team is confident to secure the commitment to implement and operate the suggested demonstration pilots over the time period of performance. CU-ICAR and ITIC are strategic investments on State level and located in Greenville, which will be instrumental to provide the R&D capacity to design, implement and operate the pilots in partnership with leading industry companies.

### ***A commitment to integrating with the sharing economy***

Through partnership efforts with the City of Greenville, Upstate Forever—a nonprofit organization focusing on conservancy and sustainability efforts—operates eight bike-sharing stations located in proximity to the Central Business District (CBD) to facilitate mobility of residents and employees throughout the CBD. Plans include the expansion of the bike-sharing program with the extension of the Swamp Rabbit Trail and expansion of Greenlink's public transit services. In addition, Uber mobility services are also available in Greenville County. Another shared mobility service is the public transit system known as Greenlink; however, in Greenville this service is limited as already described in more detail before.

**Commitment to open, machine-readable data**

Greenville is planning to integrate the use of smart phone and smart cards into its public transportation system. This will allow a bigger and better data collection of what fare types are being used (single ride versus day pass) and how the transit system is being used (small group of heavy users versus large group of light users). Smart phone payment applications can also be used to notify users of service alerts, solicit feedback, and track user locations from origin to destination. Furthermore, it is planned to develop a comprehensive computer-aided dispatch (CAD) and automated vehicle locator (AVL) system which provides dispatchers and passengers the ability to see “real time” locations and predict arrival/departure times. Last automatic passenger counting (APC) systems are being planned to identify geo-coded locations for all on- and off-boardings of transit vehicles.

An important aspect is the willingness of citizens in a Smart City approach to participate in the crowdsourcing process of data. The following diagram illustrates the overview of open data in the transportation sector as it is envisioned in the Greenville community. (Source: <http://www.uitp.org/benefits-open-data>)

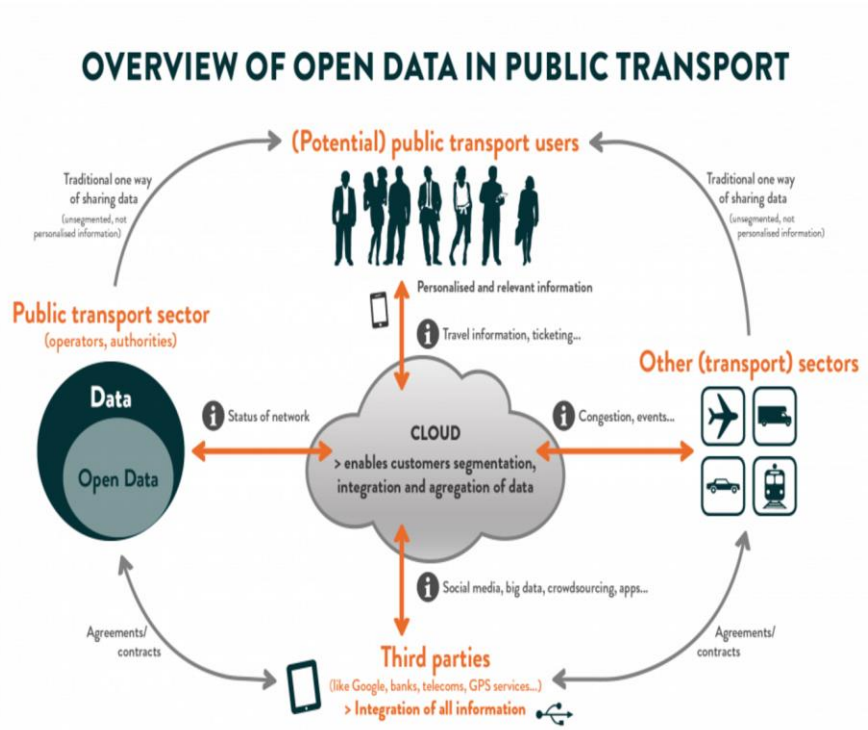


Figure 3. Open Data in public transportation

Chapter 4 – Annotated Preliminary Site Map

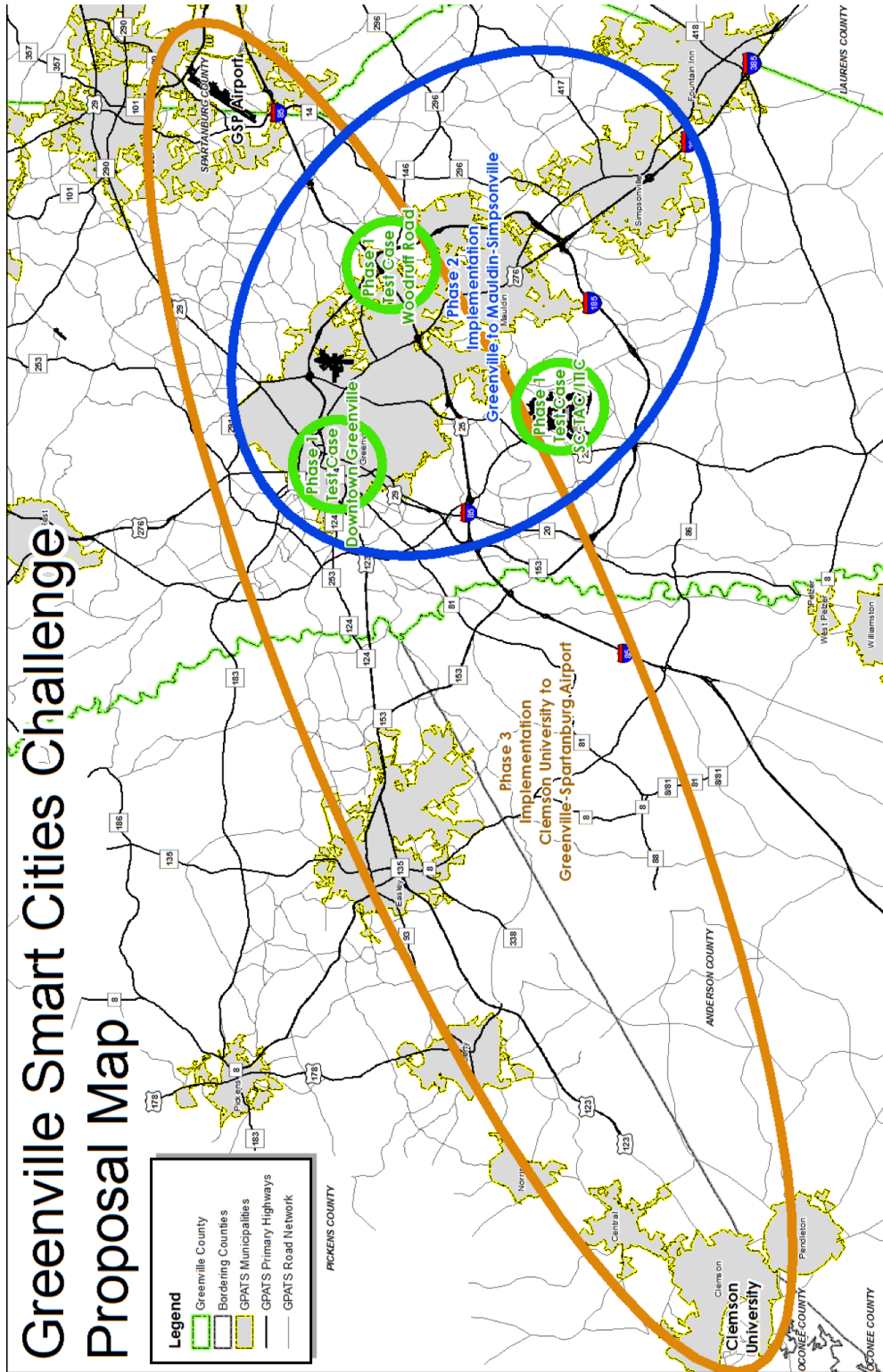


Figure 4. Greenville Smart City Proposed Map

## **Chapter 5 – Alignment of Greenville’s Smart City approach with USDOT vision elements**

### Vision element #1 (Urban Automation):

In Greenville, urban automation can be applied to divert traffic into dedicated parking areas and reduce the vehicle density on key roads in a way that walking, biking and shuttling can co-exist using the same road infrastructure. The automation can allow a shift from a scheduled public transportation model to an on-demand model where the vehicle size as well as the pick-up/drop-off nodes can be dynamically adapted to the demand situation. Furthermore, vehicle automation can be utilized to automatically store vehicles in parking systems as well as automatically recharge them if they are electrified. Automated private taxis can complement the public transportation to feed key commute arteries in a multi-modal transportation network. Last but not least, automation can be utilized to shuttle people from parking structures to key buildings to minimize waiting as well as travel time.

In the Greenville downtown area, existing parking structures can be utilized to connect people with automated low-speed electrified vehicles with their desired downtown locations via a road system that is prepared for automated driving while at the same time allow walking and biking. The automated road system will not allow Main Street parking of private cars. Public transportation – in particular electrified buses - will choose parking structures at the boundaries of the downtown areas as multi-modal nodes where both users of private and public transportation merge and then can choose to utilize the automated LSEV (low speed electric vehicle fleet) or a bike-share fleet for down-town commute.

The Woodruff/Verdae Road main shopping areas will use automation to transport people and goods from dedicated parking structures to the different commercial buildings and restaurants along the demonstration zone. Thus typical traffic choke points can be eliminated and the shopping experience can be significantly improved. The parking areas that are freed up close to the shopping locations can be re-used for open-air markets or events or for recreational purposes (e.g. skate boarding, street soccer, basketball). A fleet of automated low-speed electric vehicles can be utilized to shuttle people along scheduled routes to the different shopping locations. A dedicated fleet of automated low-speed electric vehicles designed for goods transportation bring the shopping items from the stores to the parking structures where they are either stored for customer pick up at a central location or where they can also be hand-delivered to the customer vehicle (either while the customer is present or via authorized trunk-unlock).

At SCTAC/ITIC a pilot system of an automated parking shuttle will be tested under all possible utilization scenarios to prepare a major deployment at the Greenville-Spartanburg International Airport and thus to avoid the construction of additional expensive parking garages close to the terminals or to the university buildings and to use remote parking options instead. The results of these automated parking shuttle tests could also be applied to the development of new parking solutions at the Clemson University main campus.

A key element of the Greenville Smart City Vision is to combine the use of self-driving low-speed electric vehicles in high density urban areas with either higher capacity zero-emission public transit buses connecting the high density urban areas as well as the low-density areas or with the use of private connected vehicles which are being temporarily stored in parking structures at the edges of urban high activity zones with multi-mode transportation connectivity nodes.

Vision element #2 (Connected Vehicles):

Major regional corridors in the Greenville urban area are I-85 connecting Atlanta with Charlotte and I-385 connecting Columbia with Greenville. Interstate 85 connects eight metropolitan centers, including Greenville, in the US Southeast. The Center for Quality Growth and Regional Development reported that the I-85 corridor is the most critical transportation link in the region and is projected to experience a significant increase in demand for freight capacity from intra-region commodity movement alone. I-85 as well as I-385 are perfect candidates to be V2I enabled and Clemson University is already implementing a V2I pilot on I-85 close to CU-ICAR. Considering the fact that the density of V2V-enabled vehicles on the road will be rather low over the next few years, the utilization of mixed networks combining LTE and DSRC technology in a fog-computing network deployment architecture might be an interesting path for V2I communication as many vehicles are already 4G-enabled and in basically all vehicles smart phones are being used. Thus safety, traffic or parking related information can be brought quickly to a large number of vehicles. In particular, the parking structures at the edges of the automated driving zones will benefit from the connected vehicle technology to optimize the traffic flow and to guide vehicles in the most efficient way to available parking spots. Within the automated driving zones all vehicles including bicycles from bike share programs will be V2V and V2I enabled. Citizens will be incentivized to load on their smart phones smart city mobility apps that support safety features and guide through the multi-modal transportation network. All public transportation vehicles operating in the Greenville urban area will also be V2V/V2I enabled to leverage the smart communication infrastructure. In particular, GSP coordinates of transit vehicles will be reported to a central server in real-time where their travel times and arrival times will be estimated and made available to the public via web and mobile apps. A team at Clemson University has created a running prototype of such a system. The data will find many other uses such as estimation of congestion in real time and also provides valuable insights to city traffic engineers to optimize transit routes and schedules.

Greenville may be one of the first pilot cities in the US for 5G network deployment to support vehicle and infrastructure connectivity. High resolution map data and infrastructure generated sensor data can thus be streamed into the connected vehicle and be merged with high resolution data generated from vehicle sensors to create an intelligent awareness zone around the vehicle that can anticipate/predict future events and thus increase the safety level of operation both for passengers as well as the other traffic participants. The idea is to first support the pilot demonstration areas with mixed 4G/DSRC network capabilities and then compare the results with 5G network connectivity. The results will help guide Greenville to determine how it should invest in resilient and high performance communication networks and which public and private partners it will require to achieve the best performance/cost trade off. Within this initiative, we will equip all traffic signals along congested corridors and around the city center with DSRC devices so the timings of traffic lights can be broadcasted to approaching vehicles. This enables several applications within connected vehicles such as intersection collision warning and eco-speed advisory when navigating city streets.

As the Greenville area experiences significant mobility challenges, the team will deploy three connected vehicle mobility applications using multiple communication technologies (i.e. DSRC, 4G, and 5G) following the concept of operations defined in connected vehicle reference implementation architecture (CVRIA) developed by USDOT:

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Application 1: Vehicle Data for Traffic Operations

Application 2: Queue Warning

Application 3: Advanced Traveler Information Systems

It is important to understand that Greenville’s Smart City vision does approach the reduction of traffic congestion and road accidents as well as the improvement of citizen mobility with the combination of vehicle connectivity as well as vehicle automation. Whereas the main urban zones of high activities are supported by automated vehicles systems, the corridors between these zones and the corridors to the parking hubs are optimized for vehicle connectivity.

### Vision element #3 (Intelligent, Sensor-based Infrastructure):

Greenville will implement a cloud-based IT infrastructure solution to manage all relevant transportation related data which will be fed from the data sources of Table 3.

Table 3. Greenville Smart Cities Sensor Infrastructure

<b>Stationary sensors</b>	<b>Dynamic sensors</b>
> traffic light sensors	> vehicle-integrated sensors
> street sensors	> mobile-device sensors
> building-mounted sensors	> wearable sensors
> sensors mounted on street lamps/posts	
> sensors integrated in parking structures	
> security surveillance sensors	

Dynamic sensors can significantly contribute to generate data that can substantially improve the quality of the urban traffic situation in real time. Furthermore it is possible to identify “misbehaving” transportation system participants which support the work of law enforcement. It can also improve the work of first responders to help them find optimal routes and to decide on traffic rerouting patterns with less impact on congestion.

The synergy of stationary and dynamic sensor data can help to operate automated transportation systems and to optimize the balance of infrastructure and vehicle-related cost of automation.

The generated data can also be of commercial value for retail stores and restaurants in an IoT ecosystem where advertising can be targeted towards transportation system participants to stimulate the consumption of services which in return could be monetized by the infrastructure system operators.

The demonstration pilots for the Greenville Smart City Vision will leverage both stationary and dynamic sensors and a dedicated IT cloud infrastructure will be developed and operated in a joint effort between Clemson University and industry partners to manage all transportation related data.

Vision element #4 (Urban Analytics):

One of the big advantages of leveraging urban analytics is to respond faster to demand/supply patterns in transportation system configurations with complex interdependencies. For example in the case of Greenville, the influence of unpredictable events on predictable base traffic patterns requires a quick real-time response in rerouting of traffic. It is essential to actually reach the vehicles and influence driving and routing behavior. Sharing transportation related data both between public and private partners can lead to a significant improvement of the traffic situation (e.g. reporting of shopping-induced or event-induced traffic and proactive rerouting and enhancement of parking capacity or multi-modal transportation options).

One of the big concerns of citizens is to be compromised in privacy or security, so it is essential that proper filtering mechanisms are in place in the data collection process to protect the confidentiality of information. On the other hand data analytics can help to identify people or objects that are posing a public threat.

Price can drive the behavior of transportation system participants – whether using public or private transportation. Dynamic pricing models for parking or dynamic pricing for the use of public transportation (e.g. using smart phone technology) or even the use of subsidized transportation pricing (e.g. using digital coupons) could be relevant to influence traffic patterns. The demonstration areas supporting the Greenville Smart City Vision will deploy the latest methods of data analytics to provide an optimal demand/supply situation of transportation services at all times. This will also include dynamic pricing models and the use of monetary incentives through advertising or promotional models.

Greenville also realizes that the collected data can be of great commercial value for various industry partners in the IoT ecosystem providing innovative services based on real-time information, such as advertising agencies for location based, mobility solution providers like parking, navigation, traffic management, or even retailers for tracking the density of potential customers to name a few. In order to facilitate this, Greenville Smart City Vision will also deploy the necessary cloud services (cloud APIs) so that existing and emerging industry partners in the ecosystem can access the analyzed as well as the raw datasets collected. This will not only foster innovation, but also provide a powerful platform for service-based startups to launch with reduced capital cost stimulating a startup revolution in the area.

Greenville could attract application developers for transportation related services to get involved in these start-up activities, leveraging both the corporate as well as the start-up incubator infrastructure that has been built up recently in Greenville over the last few years and is still being expanded.

Vision element #5 (User-Focused Mobility Services and Choices):

Greenville citizens will have a dramatically improved situation in terms of mobility choices which allows them to reduce the exclusive use of their personal vehicle in general and to use more environmental friendly and efficient transportation options which they can share with others without compromising comfort or privacy. In order to leverage the multimodal transportation infrastructure, it is essential to present the mobility services via a simple and easy to understand interface to the user, and making them available to the most popular mobile devices which can be used by a large proportion of the city population.

Access to almost everything associated with economic opportunity and upward progress —jobs, health care, healthy foods and schools— relies on the ability to get around in an efficient and affordable manner. The recently completed Piedmont Health Foundation transportation study revealed that 78.9% of respondents use a personal vehicle to mobilize. In addition, between 13.4% and 23.8% of respondents have difficulty getting to their destinations including jobs, drug, alcohol, and mental treatment centers, school/training, grocery stores/shopping, doctors and dentists offices, recreation, places of worship, and family visits.

The downtown and Woodruff/Verdae Road demonstration areas are clearly suited to experiment with user-focused mobility services and choices and to also allow industry partners to provide interaction interfaces that support the seamless transition between the different transportation modes. Consider two very different groups of citizens, the one that are dependent on a personal car and do not want to compromise on convenience and comfort and the other group that cannot afford a personal car and must live with the limitations of public transportation. This social gap can be narrowed by a multimodal transportation model but it is essential that the need for personal space and security for transportation system users is not compromised.

#### Vision element #6 (Urban Delivery and Logistics):

One of the key challenges in adapting the transportation infrastructure for automated driving is to minimize the potential disruption of traffic patterns by large trucks delivering goods as well as the need of personal goods delivery services that require vehicle access to specific buildings. In order to overcome these challenges, it is important to establish urban goods delivery terminals that can be used for trucks and delivery vehicle as single point of entry. Then the goods are “micro-distributed” via a dedicated goods delivery system. One of the disadvantages is that the end-to-end delivery is disrupted and an additional hand-over is needed, furthermore there could be a discomfort that the service is not controlled by the delivery company that guarantees with its brand for the quality of service. Therefore, it is important to provide distribution choices to companies that are in the delivery business from total channel control to commoditized service. In the Woodruff/Verdae as well as the Main Street demonstration area Greenville wants to experiment with a new shopping experience which provide the following options:

- > personal pick-up of goods at the parking terminal
- > personal delivery to the vehicle in the parking structure
- > automated delivery with remote owner-authorized trunk opening via mobile devices

These goods delivery system for individual customers can also be used for businesses, although this may require a dedicated parking terminal structure for larger trucks as well as larger or special purpose goods delivery vehicles. Another important aspect is to optimize temporary goods storage with integrated warehouse structures into parking structures and to automate the handover of goods between different transportation modes (e.g. using material handling robots).

#### Vision element #7 (Strategic Business Models and Partnering Opportunities):

Greenville has a long tradition in forming public private partnerships in transportation technology development and deployment. CU-ICAR has been developed in a public private partnership model. For example the highly successful Deep Orange Program of CU-ICAR is a



partnership between automotive OEMs and academia where advanced vehicle concepts are being developed by students under the guidance of experienced engineers from the industry. CU-ICAR offers courses where students can apply their knowledge in automotive engineering to develop new business models as well as infrastructure concepts for smart urban transportation. Thus students are stimulated to create or join start-up's to transfer their knowledge or at least apply their acquired skills in innovation projects of more mature automotive companies. But also the 250 acre CU-ICAR campus itself attracted more than 20 industry partners to co-locate with the university, most of which are active in the automotive sector. ITIC has been designed as a test and technology demonstration site on more than 500 acres of the 2600 acre business park of SCTAC which promotes the partnership between public and private entities and which successfully demonstrated in a DOE-funded research activity to implement a testbed for wireless charging of electrified vehicles between university, government lab, utility, automotive OEM, ICT company and a start-up company. ITIC plans to partner not only with CU-ICAR but also with the UTC Southeast as well as UTC Portland to help implement technologies required for the demonstration areas. Furthermore, ITIC has a large portfolio of industry partners it already works with as well as a large number of international partnerships. It also has longstanding partnerships with SAE and IEEE. As Greenville has been selected as one of the Top 10 cities of Envision America, it has access to alliances of private sector companies willing to support smart city programs, for example the Smart City Alliance (AT&T, IBM, Ericsson). Furthermore, Greenville in partnership with Clemson University has been an active participant of the NIST Global City Team Challenge.

Vision element #8 (Smart Grid, Roadway Electrification, and Electric Vehicles):

CU-ICAR in collaboration with ITIC has been working on road electrification since 2012 in partnership with Oakridge National Lab (ORNL) and a wireless power transfer testbed has been implemented to support both stationary and in-motion wireless charging for power levels of up to 250 kW. Thus both electrified passenger vehicles as well as electrified buses can be tested. ITIC has designated expansion areas for road electrification which cover both urban driving scenarios (opportunity-charging, quasi-dynamic charging) as well as in-motion wireless charging on dedicated highway lanes.

CU-ICAR also experimented over multiple years with wired and wireless charging systems of electrified of different power levels in the CU-ICAR parking garage serving a larger fleet of electrified test vehicles. The combination of wireless stationary charging and automated parking could be very significant to support commercial EV fleet charging but could also optimize the design of charging infrastructure for private EV's being parked in public or private parking garages or even on the street. The charging infrastructure can be shared and the utilization of the infrastructure can be optimized. For example, in the future it would be possible to automatically re-park an electric vehicle in a parking garage to be charged wirelessly and then re-parked again after the charging process is completed. The process to move the car could be authorized by the owner without the need of being physically present.

Electrified roads could play a significant role in building automated transportation systems with low speed electric vehicles where the vehicles could be in continuous operation without the need to have significant downtime for charging, leading to smaller fleet sizes to serve a specific transportation demand. We need to distinguish between roads that are continuously electrified or

where only certain sections are electrified. In the latter case, the power level of the energy transfer needs to be adapted to the charging needs of the vehicle. The available battery capacity will determine how often the vehicle needs to be recharged within a defined operational cycle and what the cost distribution of vehicle-side energy storage and V2I energy transfer capability will be. The standardization of the vehicle-to-infrastructure power transfer technology is key to ensure interoperability of different vehicle types and OEMs with the charging infrastructure. Clemson University collaborates with SRNL on a 15MW smart grid simulator. The Real-Time Power and Intelligent Systems Laboratory (<http://rtpis.org>) at Clemson University has a real-time power grid simulator capable of simulating the distribution system of Greenville. Thus the Greenville team could simulate the impact of a major vehicle and road electrification strategy in the Greenville area. We propose to utilize models of load and EV charging patterns for intelligent charging to perform frequency response control, balancing phase power, voltage regulation and peak shaving. By adjusting the charging times, we can minimize the impact on the grid by avoiding peak hours, and still guarantee EV functionality.

With respect to the demonstration areas of the Greenville Smart City Vision, electric vehicles – in particular low speed electric vehicles and electric buses – will play a very important role to develop a zero-emission vehicle environment. Parking structure can become very important charging hubs, both for parked electrified vehicles, but also for electric buses that can be fast charged at the multi-mode terminals as well as automated fleet LSEV's which could be fully automatically charged between their operational cycles. The Greenville team thinks that LSEV's could use specific "electrified" lanes that allow in-motion wireless charging. The results of the demonstration areas by using wireless charging technology could be utilized as an input for the improvement of SAE and IEEE WPT (wireless power transfer) standards.

#### Vision element #9 (Connected, Involved Citizens):

Greenville's Smart City Vision, deployment outreach events will be organized at CU-ICAR and ITIC for Greenville citizens to explain and demonstrate mobility technologies that are relevant to them to be an active part of the pilot activities. Most important is to explain the use of mobile devices and applications in context of multimodal transportation. Social networks can be used to organize shared rides as well as organized food shopping. Bus or shuttle transit systems could be organized in a manner utilizing smart phones to determine optimal pick-up and drop-off points depending on the demand pattern. It would even be possible to think about models where citizens could serve specific routes as volunteers for underprivileged groups such as people with disabilities or older people with private vehicles or in a ride sharing model. The citizens could act as a proactive self-organizing transportation community leveraging technology. This could also include retail to sponsor trips with electronic coupons whether these trips are automated or not. Using such collaborative transportation social networks would generate data which can be valuable both for the city and private sectors as it generates insights in consumer demand patterns. However, it is the goal to guarantee a minimum level of safety, security and privacy for those who provide transportation opportunities as well as those who use them which requires the use of appropriate technology solutions.

To move in an automated transportation environment, it is important to train citizens to use mobile devices and wearables as sensors to enhance their awareness of moving objects that can harm them and to make those moving objects aware of them and their mobility intent.

Vision element #10 (Architecture and Standards):

The US DOT emphasizes building a foundation of reference architectures and standards upon which to build emerging transportation applications. Several strategies that can be applied to leverage the existing National ITS Architecture and the Connected Vehicle Reference Implementation Architecture (CVRIA) to address the various dimensions of automated transportation. Domain specific architectures focus on an aspect of the larger context, much like AUTOSAR provides a reference architecture for vehicles. The Greenville team's strategy is to define a framework within which reference architectures and open standards can be integrated and aligned to provide a more complete, correct, and consistent structure within which specific aspects of the transportation domain can be researched. The architectural framework should emphasize flexibility, interoperability, and modularity to be able to respond to the maturing of technologies.

The framework would tap into existing work such as that of the ISO/TC 204 which coordinates ISO efforts, but would be more comprehensive. It would integrate reference architectures such as CVRIA, and open standards such as the DSRC protocols for intelligent transport systems. The framework organizing the interactions of architectures and standards, enhances the flexibility and modularity of the ecosystem. For example, the logical structure of the framework can be built on the concept of a model bus. Like a computer bus, the model bus allows elements to be hung off it without interfering with the existing elements on the bus. As technologies emerge, mature, and give way, the framework makes the network of design information easy to maintain.

The Greenville team is leveraging Clemson University's work with the Software Engineering Institute's Architecture. This work leverages open standards such as the Architecture Analysis and Design Language (AADL), an open standard from SAE, the world's largest automotive and aerospace standards setting body. The use of open standards in the architectures prevents vendor lock in to so-called "solutions," which usually are not sufficiently flexible to respond to change rapidly. AADL is a system modeling language with constructs to model systems from an abstract reference architecture level to a level of detail from which compilable source code can be generated. The tooling that accompanies AADL allows even abstract architectures to be quantitatively analyzed. This environment supports the definition of highly specialized architectures that can refine, or encompass, selected concepts in existing reference architectures. SAE has agreed to support Greenville's Smart City proposal. SAE currently has 65 active committees working across the passenger and commercial vehicle sectors on an expansive set of critical Connected Vehicle subjects—including Safety and Human Factors (incorporating driver-vehicle interface); Vehicle Architecture for Data Communications; Active Safety Systems (including sensors); Functional Safety; Cybersecurity; Vehicle Event Data Recorders; Reliability Prediction for Automotive Electronics; Advanced Lighting, and Driver Distraction, among many others.

Vision element #11 (Low-Cost, Efficient, Secure, and Resilient Information and Communications Technology):

To implement the Smart City vision of Greenville, a low cost, open standard based computing and networking infrastructure is chosen. With such infrastructure, current academic and industrial R&D is swiftly realizing the vision of software defined infrastructure (SDI) - a

software driven, highly automated paradigm for future highly diverse and agile network-based application deployment, from network services to connected vehicles to Internet of Things. In addition to vehicle applications, mobile apps on smart phones become the primary means of interaction with the transportation ecosystem for citizens, enabling bidirectional real-time information exchange with cloud based application, such as real time public transportation map, real-time help line (requesting shared ride or public transport, or reporting issues such as traffic accidents, or reporting needs of additional public transportation coverage). Greenville will pursue big data analytics methodologies to allow citizens to quickly get the information they need, connect to service providers they wish, to allow city agencies to have real time visibility to the city's operational efficiencies and service priorities, and to allow first responders to have real-time visibility.

On networking standards, in addition to DSRC, Greenville will explore an Internet based, cloud driven, network technology agnostic paradigm. Via any wireless or wired infrastructure, the city envisions its residents to utilize smart phone apps, personal computers, and kiosks, to access the same range of rich services through a single city portal.

Privacy and security play a critical role in enabling smart cities. Sensors in a smart city can generate a large amount of data, including user private information. In such a data-rich environment, private information pertains to any emitted, collected, or stored data about individuals. A key concept in privacy protection is personal identifiable information (PII), which is any information that can be used to distinguish or trace an individual's identity. With the network connectivity and the Internet, PII can be accessed by a wide range of parties.

Privacy management in our smart city solution will ensure the privacy is protected and any required PII is handled appropriately, considering the different types of protection based on the Fair Information Practice Principles (FIPPs).

(1) *Transparency*: The smart city deployment will be open and transparent about policies, procedures, and technologies that directly affect individuals and/or their PII. Individuals are notified by our system that their information is being captured for records.

(2) *Individual Participation and Redress*: In the smart city development, individuals will be active participants in the decision-making process regarding the collection and use of their PII and be provided reasonable access to their PII and the opportunity to have their PII corrected, amended, or deleted.

(3) *Purpose Specification*: The smart city deployment will identify the legal bases that authorize a particular PII collection, activity, or technology that impacts privacy and specify the purpose(s) for which its collects, uses, maintains, or disseminates PII.

(4) *Data Minimization*: The smart city deployment will collect, use, and retain only PII that is relevant and necessary for the specified purpose for which it was originally collected.

(5) *Use Limitation*: The smart city deployment will limit the scope of its PII use to ensure that we do not use PII in any manner that is not specified in notices, incompatible with the specified purposes for which the information was collected, or for any purpose not otherwise permitted by law.

(6) *Data Quality and Integrity*: The smart city deployment will ensure that any PII collected and maintained by the system is accurate, relevant, timely, and complete for the purpose for which it is to be used.

(7) *Accountability and Auditing*: The smart city deployment will implement effective governance controls, monitoring controls, risk management, and assessment controls to minimize the privacy risk to individuals.

To support the overall privacy and security of participants in the smart city development, we will adopt the Security Credential Management System (SCMS) developed by USDOT in our smart city deployment to enable “Privacy by Design”, and support the security of general deployment communication and of all proposed applications. A key goal of the system is to protect the privacy and security of end-users. To maintain the systems against attackers from outside and inside the SCMS, the SCMS can do frequent certificate changes, dividing operations among its different components.

In addition, the security solution in our smart city deployment will accomplish the following objectives:

- (1) Best-practice implementation from a security perspective for each information and communication technology. Naturally, network and system engineers are concerned more with connectivity and performance, but not security.
- (2) Identification of all the communications in the smart cities; analysis of the security requirement of the communications and determination of the right level of protection accordingly.
- (3) Detection and isolation of insecure devices in a smart city environment before they can negatively affect transportation networks. Upon discovering a potential threat, our solution identifies the problem and automatically adopts the necessary strategies to resolve it. After the threat has been contained, our solution automatically allows the devices to rejoin the network.
- (4) Security vulnerability testing after the security solution is implemented.
- (5) Consideration of the physical security of the components in the smart city deployment. We will provide the physical protection around equipment such as tamper-proof casings.

Vision element #12 (Smart Land Use):

The Greenville County Comprehensive Plan and the Comprehensive Plans for the municipalities include Housing Elements that show an increasing focus on affordability, adaptive reuse of infill sites, and creating walkable communities. The market does drive where new housing will go, but investments in municipal downtowns and in infrastructure such as the Swamp Rabbit Trail have increased the amount of development and density in units over the last decade. This trend is expected to continue, opening up possibilities for sustainable developments, adapting communities to be more walkable, and maintain housing affordability while improving quality of life.

The Greenville-Pickens Area Transportation Study (GPATS), which serves as the Metropolitan Planning Organization for the Greenville and Mauldin-Simpsonville Urbanized Areas, since 2007 has adopted Long-Range Transportation Plans that would implement transportation infrastructure across all modes. The knowledge that traditional transportation infrastructure upgrades cannot solve congestion issues and do not improve the quality of residential, commercial, or industrial developments has caused a shift towards supporting alternative transportation modes. Support has grown for improvements such as greenways, on/off-street paths, expanded sidewalk networks, bicycle facilities including bike share options, transit hubs, electric bus lines, regional commuter bus service. Plans are also in place to support eventual expansion and upgrade of transit systems to include but not be limited to Bus Rapid Transit,

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Light Rail, Automated Transit Networks, Personal Rapid Transit, and High Speed Rail. These infrastructure improvements will spur and accelerate paradigm shifts with regard to where people want to live and how they chose to mobilize there, making Smart City choices the norm rather than the current exception.

The Greenville Smart City Vision will lead to more efficient land use in high density and high demand urban areas. A core aspect is to channel private cars into dedicated parking hubs with multimode connectivity options reducing waiting time in traffic congestions or time to search for available street parking. The freed up transportation zones that offer multiple ways to be mobile (either by foot, bicycle or small electric vehicle) need to be equipped with sensor capabilities that ensure the safety and security of citizens. Smart street lights, smart light poles as well as building sensors can enhance the mobility awareness capabilities.

Also be considered, shared bicycles and fleet LSEV’s do not need individual street parking but can be stored in central locations equipped with suitable charging options.

The parking hubs can be designed in a way that fleet vehicles, private vehicles as well as goods can be stored in an integrated way providing energy, security as well as maintenance services.

### Integration of the USDOT vision elements:

The demonstration areas of the Greenville Smart City vision combine the different vision elements in the following manner (Table 4):

Table 4. Integration of Greenville Smart City with USDOT vision elements

<b>Greenville downtown demonstration area</b>	Vision of a zone free of personal cars (walkable, bicycles, low speed electric vehicles)
	Urban automation, urban analytics, urban delivery and logistics, road way electrification/EV/SG, smart land use
<b>Woodruff road demonstration area</b>	Vision of congestion and accident free arterial roads
	Connected vehicles, urban automation, intelligent sensor-based infrastructure, road way electrification/EV/SG smart land use
<b>SCTAC/ITIC demonstration area</b>	Vision of an automated transportation-enabled airport with zero-emission multi-mode transportation options
	Urban automation, user-focused mobility and choices, road way electrification/EV/SG

Overall, the implementation of the Smart City vision of Greenville will lead to a substantial reduction of traffic and accidents on the roads while at the same time the desire for a

personalized and customized transportation experience is not compromised. A major advantage is that valuable land that is currently being occupied by surface parking can be utilized otherwise as parking is shifted towards the edges of key urban activity zones. Also the creation of expensive parking garages on prime real estate can either be avoided or at least be reduced. The implementation of high capacity parking hubs with multi-mode connectivity options is key to the success of the smart city strategy. These parking hubs need to consider not only vehicle, but also goods storage.

## **Chapter 6 – Risk assessment**

ITIC first will test the vehicle and infrastructure technologies at their facilities and testbeds before they are being deployed at the pilot demonstration areas. Furthermore, the Greenville team will seek guidance from legislation experts to ensure that all systems can be operated based on a valid legal framework. All operational aspects of vehicle automation, vehicle charging and IT service delivery will be assessed from independent auditors.

Risk assessment is a fundamental activity that will be an explicit part of every systems engineering process under this project. The lead organization for each major project element will have the primary responsibility for risk assessment for that element. Members of the other organizations will participate in each assessment. Risk assessments will be carried out for building, acquiring, and operating each piece of hardware and each software system. These assessments will include appropriate levels of security and safety analysis depending upon the operational profile for each system. Techniques such as Functional Hazard Analysis, Failure Modes and Effects Analysis, and Fault Tree Analysis will be used to identify safety requirements that need to be added to the system requirements. The architecture definition tools mentioned under Vision #10 take advantage of early architecture information to conduct these analyses early in the development process. Linking the analysis results to the newly added requirements and to verification and validation activities, allows the faults to be identified and removed. Risk assessments will be carried out for any services offered by the project.

Operational risks will be reviewed prior to each major test or demonstration. All operational aspects of vehicle automation, vehicle charging and IT service delivery will be assessed by auditors independent of the project. Vehicles and infrastructure technologies will be tested using ITIC facilities and testbeds before they are deployed at the pilot demonstration areas. Teams inviting vendors in for demonstrations will first assess any risk associated with those demonstrations and will require the vendor to mitigate or justify any outstanding risks. The iterative nature of most modern systems engineering techniques ensures that risk assessment will be applied repeatedly. Newly identified risks are fed into a risk repository and reviewed during each subsequent iteration. Risk assessment techniques will be periodically reviewed to ensure that the techniques being used are still appropriate and effective at identifying and quantifying the types of risks associated with the new technologies being introduced into the ecosystem as responsibilities shift from hardware to software and from statically defined actions to dynamically configured services.

As project manager, ITIC has the responsibility for assessing project level risks related to

operations, funding, and goal achievement. ITIC will interact with the appropriate authorities to ensure that all activities operate lawfully as well as safely. The project will use a standard hierarchical risk management strategy with an easily understood risk rating system such as the Red, Yellow, Green system used by NASA. ITIC will roll up the individual team risk reports into an overall project risk report that will be reviewed periodically. The project management may push down required risk mitigations where the individual team is not maintaining acceptable levels of risk.

Given the nature of new technology projects we can identify some examples of risks:

1. A technology refresh cycle that operates faster than the integration and test cycles for applications that apply the new technology results in always testing the previous version. There will be pressures to skip some “non-essential” activities such as detailed design and testing, resulting in even longer debugging sessions.
2. The time required to fabricate parts is difficult to predict. Aggressive schedules will often lead to chaos with time overruns propagating and affecting related activities.

## **Chapter 7 – Partnership structure and governance processes**

CU-ICAR was founded in 2003 on a 250 acre site right next to I-85 and with more than 250 million USD invested CU-ICAR developed into a magnet for automotive engineering students from all over the world. More than 20 faculty members and more than 200 students provide an excellent talent pool for the automotive ecosystem and the CU-ICAR campus itself attracted private sector tenants with several hundred highly qualified employees to co-locate with the university to form a public private partnership. In 2010 CU-ICAR started an economic development partnership with SC-TAC, with 2,600 acres the largest business park in South Carolina and located on a former Air Force base to support automotive companies, IT companies and utilities to test vehicle and related infrastructure systems in real-world sustainable and connected mobility scenarios. SC-TAC established as result of this partnership the International Transportation Innovation Center (ITIC) to design, build and operate a test site to validate advanced communication technologies, charging technologies and different road configurations in context with connected, automated and zero-emission enabled vehicles. ITIC has also access to 120’000 square feet of mixed used buildings for incubation, confidential testing and prototyping, vehicle storage and events as well as to a 20 mile highway segment (I-185) which can be completely closed from public traffic for dedicated private testing. ITIC finalized its masterplan for a major expansion of the test site in 2015 with the leading German engineering firm in race and test track design Tilke and is currently moving towards implementation via a public private partnership model.

The City and County of Greenville engages SCTAC/ITIC with the overall program management of the pilot implementation of the Smart City Vision. ITIC will implement a program management office and engage with CU-ICAR/CU, other local university partners and industry partners such as BMW, Proterra, Clubcar, Michelin, Duke Energy, AT&T, IBM to name a few. Each pilot demonstration project reports to the program office and will be staffed by a project manager, a technical implementation team and an operations team.



## **Chapter 8 – Existing transportation infrastructure**

### Arterial miles

There are 476.23 miles of arterial roadway infrastructure within the Greenville-Pickens Area Transportation Study (GPATS) Metropolitan Planning Organization.

### Freeway miles

There are 68.5 miles of Freeway roadway infrastructure within the Greenville-Pickens Area Transportation Study (GPATS) Metropolitan Planning Organization. This includes the Interstates of I-85, I-385, and I-185

### Transit Services in Greenville

Greenlink routes are currently oriented in a hub and spokes system with the downtown transfer center serving as the nexus of the system. All Greenlink bus routes begin and end at the transfer center and return to the facility every hour. Greenlink currently offers 11 fixed routes serving the cities of Greenville, Mauldin, and Simpsonville. The earliest trip begins at 5:30 AM and the latest trip ends at 7:30 PM. On Saturdays, all fixed routes operate from 8:30 AM to 6:30 PM. Greenlink also offers an express route to Clemson University, a connector service that runs between CU-ICAR and downtown Greenville, and a shuttle service that connects CU-ICAR, St. Francis Hospital, and Haywood Mall. The regular adult fare for riding one-way on Greenlink is \$1.50. Reduced fares are available for the elderly and disabled persons. All transfers cost \$0.50.

In addition to these services, Greenlink also provides complimentary paratransit service. This service is designed primarily for individuals whose disabilities prevent them from using the fixed route vehicles. Greenlink operates this service during the same hours as its regular fixed routes and the fare for such services is \$3.00 for a one-way trip.

As Greenville continues to attract more businesses and its population grows, the transit system must adapt to serve these populations efficiently and effectively. This awareness was the impetus behind the City of Greenville's recent TIGER VII application, which was developed in conjunction with Greenlink, Greenville County, and more than 40 other partners in the region. Building off the success of the Swamp Rabbit Trail, an 18.7 mile rails-to-trails greenway, the TIGER VII application looked to implement a wide-reaching multimodal public transportation network in Greenville County. Fed by neighborhood circulators and an extended Swamp Rabbit Trail, the creation of two transit expressways served as the basis of the application, connecting the farthest points of Greenville to areas of employment, recreation, health care, and education. The plan called for zero-emission electric buses, twenty-four transit hubs equipped with electronic pay stations, and fourteen bike share stations. Each of the transit hubs would serve as incubators for smart technology projects. While the city was not awarded a TIGER VII grant, they did receive positive feedback from USDOT and they intend on re-applying this year.

Shared-use mobility services miles

Greenville B-cycle, a partnership of Upstate Forever and Greenville Health System, launched with six stations located primarily in the City's downtown area in March 2013. Since then the system has grown to eight stations and 243 annual members. Since launch, more than 4,550 unique riders have taken trips on B-cycle, and more than 9200 rides have been made. Ridership has steadily gained since the program's inception with a total of nearly 4,000 rides taken in 2015 - approximately 50% more than the year prior.

Information and communication technology (ICT)

The present situation of ICT in Greenville SC shows basically 2 cable providers (Charter and ATT). The fixed broadband provider levels are 25 mbps/3mbps, and the speed of the broadband is 100mbps/5mbps. These levels for residential areas and commercial areas may have to be improved for future data needs. The wireless network is dominated by CDMA technology and would be insufficient for future technology and needs. LTE coverage for Greenville, SC is good, however, this coverage may not support the new ICT of the future. There are about 750 FCC registered cell phone and antenna towers at Greenville ([http://www.city-data.com/towers/cell-Greenville-South-Carolina.html#mapFCC\\_Antenna\\_towers](http://www.city-data.com/towers/cell-Greenville-South-Carolina.html#mapFCC_Antenna_towers)). Although they would be sufficient for 3G and 4G networks, future technology needs may require their upgrade to other network types such as 5G. Also, more antennas at lower placements around cities highways, lamp posts, signs, etc. will be needed for better coverage to achieve faster and more reliable speeds. During and after the Smart City program, Greenville and its partners will analyze and suggest ICT improvements for Smart Cities, generating a knowledge base that can be extrapolated to other parts of the country.

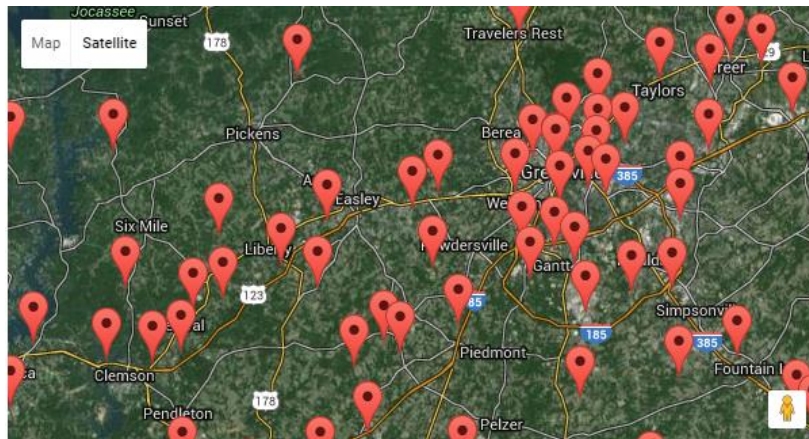


Figure 5. Cell Towers locations. Source: [http://www.cellreception.com/towers/towers.php?filter\\_att=1&city=greenville+&state\\_abr=sc](http://www.cellreception.com/towers/towers.php?filter_att=1&city=greenville+&state_abr=sc)

Intelligent Transportation Systems (ITS)

SCDOT has installed ITS boards on the interstates of I-85 and I-385 approaching the major joining interchange. Cameras and sensors have also been installed in these sections within two miles of the I-85 @ I-385 interchange to measure traffic speed and congestion.

There is a formal memorandum of understanding (MOU) between Clemson University and South Carolina Department of Transportation (SCDOT) in place that allows university researchers access to the SCDOT right-of-way for installation of test bed equipment, technical support as needed, intersection infrastructure to support intersection-related applications, and SCDOT fiber network for back-haul communication.

Smart grid infrastructure including electric vehicle charging infrastructure

In 2011, Greenville implemented with General Electric the EV Ecosystem Pilot program to substantially enhance the number of EV charging stations. A network of more than 30 charging stations are installed in the Greenville Metro area ([http://www.afdc.energy.gov/fuels/electricity\\_locations.html](http://www.afdc.energy.gov/fuels/electricity_locations.html)) with the highest density being in the downtown area (see Figure 6).

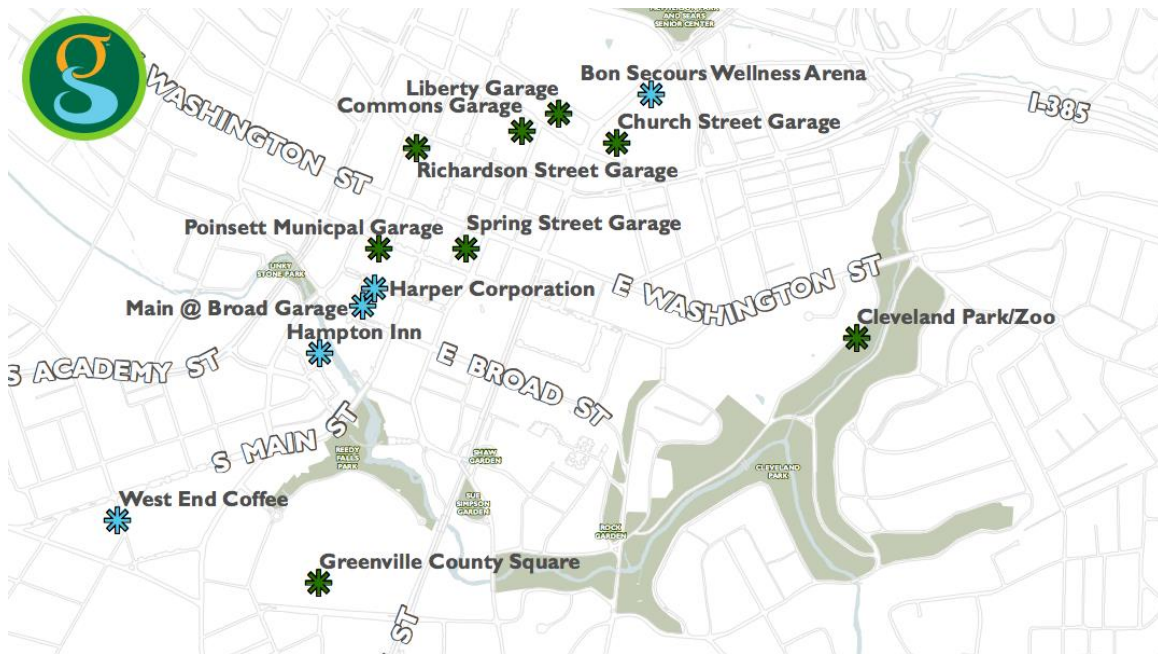


Figure 6. Electric vehicles charging infrastructure in Greenville. Source: <http://www.greenvillesc.gov/DocumentCenter/View/4599>

**Chapter 9 – Smart City data approach**

Following are the data the State of South Carolina collects for Greenville currently:

1) Average annual daily traffic data collected from about 12000 major roads in the SC state by SCDOT where 575 of these are in the Greenville county. The analyzed data is accessible at

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<http://www.scdot.org/getting/annualTraffic.aspx>. The information is updated yearly. Each location provides two-way daily vehicles counts on the respective road, averaged over a year.

2) Traffic count data on an hourly basis generated from traffic counting devices. The counts can be accessed from the Traffic Polling and Analysis System at the following link (<http://www.scdot.org/getting/trafficCounts.aspx>). These data are uploaded on an hourly or nightly basis. However, there are no current provisions for real-time availability of data. Further, there are no APIs provided to use these datasets and can be accessed only manually through a web server currently.

3) <http://www.511sc.org/#> has live streams to 82 different cameras installed around Greenville. The feed however is not accessible through an API.

4) The city also has traffic loop detectors at the actuated traffic signals. While these work fine for four wheelers, they are not equipped well enough to detect motorcycles, mopeds and bicycles. Due to this reason, South Carolina is one of the 6 states in the US where bicyclists/ motorcyclists are allowed to proceed through an intersection with a red light.

All the data above are curated directly or indirectly by SCDOT currently. The 3 sites identified for pilots will be equipped with new infrastructure to collect new data. The data sources will include, but not limited to, V2I communication equipment, traffic vision cameras, parking sensors, smart traffic signals & signs, smart charging infrastructure and weather sensors.

For the new data, the curator will be ITIC. To have the existing data from SCDOT available along with the new one, SCDOT will be requested to provide its data centers to share the raw data with ITIC. With that, ITIC will be the central entity responsible for ensuring the sharing of this data with other partners is as per the policies. Amongst the partners, Clemson University will use this data for the research work and publications as follows: the traffic engineering department at CUICAR will study the traffic patterns, identifying the root causes of the current traffic problems and suggesting methods for improving the operations; the computer science department will work on data processing algorithms for big-data; the automotive engineering department which has groups focusing on connected vehicles and autonomous vehicles, will perform research related to safety of transportation; and finally ITS department will study the network traffic that an in-vehicle communication unit as well as a road side communication unit handles to understand the bandwidth requirements, while the communications security group will work on security protocols to ensure the sanctity of the communications.

With the sharing of the collected data between the partners, policies will have to be put in place to facilitate safe exchange of data. The consortium will abide by Articles 1 and 3, Chapter 2 of the South Carolina Code of Laws (<http://www.scstatehouse.gov/code/t30c002.php>) to ensure no personally identifiable information (PII) is present in the data. The consortium will also draft the terms of use similar to the Research Data Exchange (<https://www.its-rde.net/>) while sharing the data between the partners. That being said, it needs to be noted that new policies and legislations will be required to put in place for data collection as well as sharing with the advent of connected vehicles and autonomous vehicles. Hence, this will be an opportunity for the research institutions, USDOT, SCDOT and the state legislature to evaluate and draft the necessary laws



and policies to ensure the privacy and security of the citizens.

After the necessary analysis and research from the experiment, ITIC will publish the necessary guidelines for the data collection and the best practices, so that the data centers at the Transportation Management Centers can be upgraded accordingly.

Data from grid monitoring especially at the charging stations will be metered, transmitted and analyzed at the respective distribution system control centers of Greenville. This will provide us insights to effective and optimal power management systems. Importantly, we will harness the use of renewable energy sources including solar PV at the charging stations and parking lots. This is expected to reduce the additional load from electric vehicles in the city of Greenville.

Power system operation analysis will be implemented in a real-time fashion to guarantee security of the Greenville distribution power system. The capabilities of the Real-Time Power and Intelligent Systems Laboratory (<http://rtpis.org>) under the direction of Dr. Kumar Venayagamorthy will allow us to study the impact and operation of the charging stations and data collection.

## **Chapter 10 –Use of standards, architectures and certification processes**

As it was stated in the vision element #10, the Greenville team will apply all existing standards for vehicle automation, charging infrastructure, IoT, connected vehicles (CVRIA using SET-IT software tool), cybersecurity and ICT and grid infrastructure operation. By collaborating closely with SAE and IEEE, it will leverage opportunities to provide input towards standards development and to seek advice from standardization experts. Furthermore, it will work with certification agencies to ensure that the operation of automated vehicles is safe and secure. Lessons learned, conclusions and recommendations resulting from the use of these standards and architecture will be documented properly and shared with the standards community.

To support the processing of real-time collected data from sensors and infrastructure, a data analytics framework will be developed that includes data sources, processing and distribution to process the data and develop analytics models. Greenville will leverage supercomputing facilities at Clemson University for developing and evaluating the data analytics framework that is based on a multi-tier data infrastructure to support smart application that is based upon big data tools and management systems and well understood data and SLA requirements of the different applications. Data requirements from the Connected Vehicle Reference Implementation Architecture (CVRIA) will be used. The Intelligent Transportation Systems Laboratory at Clemson University, directed by Dr. Chowdhury, has built a simulation network of the City of Clemson that provides a baseline for the architecture in the proposed project.

The middleware systems and technologies for the management of large scale data infrastructure can be divided into: relational databases, key-value stores, document stored and extensible record stores. Relational databases include choices such as MySQL or PostgreSQL. As raw connected transportation data streams typically come from a variety of sources with different data structures under XML/JSON format the one component of the information infrastructure should be a document store in order to support rapid, large-scale data ingestion in the absence of a unified data schema. MongoDB and CouchBase are among the most popular open source solutions for document stores. At the next stage, the data documents need to be normalized, indexed, and integrated with other data to support near-real-time analytics, trend detections, and forecasting. This requires the implementation of extensible records store solutions due to the unstructured,

dynamic, and temporal characteristics of the data. Available solutions include HBase, HyperTable, HPCC, Cassandra, and Accumulo, which also supports security and privacy of data elements. In-memory databases (SQL or NoSQL), such as VoltDB and MySQL can be part of the data infrastructure to support applications that require very strict SLA.

## **Chapter 11 – Greenville’s Smart City goals and objectives**

The main goals that are related to the Smart City vision of Greenville are the following:

Goal #1: Reduce traffic-related congestions in high density urban zones

Goal #2: Enhance the mobility of all Greenville citizens

Goal #3: Reduce traffic-related CO2 and emissions

Goal #4: Improve safety level on roads

Goal #5: Increase efficiency of point-to-point travel

Goal #1 and #4 can be measured with sensor-based traffic statistics.

Goal #2 and #5 can be measured via surveys as well as testing mobility options via defined standard use cases at different demand situations.

Goal #3 can be measured by vehicle statistics as well as utilization of charging infrastructure.

Regarding objectives for the concrete demonstration areas, the Greenville team has the following roadmap:

### Greenville Main Street area:

Objective 1: Convert Main Street into a zone which can only be used by pedestrians, bicycles or automated LSEV’s (both for people and good transportation).

Objective 2: Establish parking hubs for private and commercial vehicles entering the downtown area with multi-mode connectivity (bicycle share program, LSEV’s)

Objective 3: Provide sensor-based connected vehicle support to route vehicles to the parking hubs with available capacity

Objective 4: Introduce dynamic pricing models for downtown parking structures in high-demand situations to encourage the use of offsite-parking with public transit shuttles

Objective 5: Develop mobility awareness apps for mobile devices and wearables to ensure safety of walking and biking citizens

### Woodruff/Verdae road area:

Objective 1: Establish dedicated lanes for automated driving between parking structures and The Shops at Greenridge (TSGR)

Objective 2: Eliminate parking in pilot zones of TSGR mall area and reuse surface parking areas

Objective 3: Establish new model of people and goods delivery between shops, restaurants and parking area

Objective 4: Integrate charging infrastructure both in parking structure as well as on designated

road areas (quasi-dynamic and dynamic wireless charging)

Objective 5: Establish an EV bus terminal at parking structure

SCTAC/ITIC:

Objective 1: Validate reliability of automated transportation service between terminals/building and parking areas

Objective 2: Validate business case assumptions

Objective 3: Improve vehicle and infrastructure technology

Across pilot zones:

Objective 1: Use of Open API for mobility applications for smart phones and wearable

Objective 2: Use of Mobility Cloud Service

**Chapter 12 – Evidence of capabilities**

SCTAC developed over the timeframe of 6 years a joint economic development initiative with CU-ICAR (Project Green) which addresses the redevelopment of more than 500 acres of property into a testbed for connected, automated and zero-emission vehicle and infrastructure technologies. The maturity level of this initiative is now at a point where the Smart City initiative can be supported in an optimal manner both from a facility development as well as from an organizational perspective.

Greenville County and the GPATS MPO have served as the regional transportation planning entity for the Greenville Region since 1969. The GPATS Policy Committee is comprised of 29 voting members and six (6) non-voting members made up from mayors, council members, and legislative delegates concerned about transportation, and supported by a Study Team of administrators, planners, and engineers from every GPATS jurisdiction. GPATS is staffed by the Greenville County Department of Planning and Code Compliance. GPATS coordinates projects with SCDOT, FHWA, and FTA, directly programming \$18 million per year from the Surface Transportation Program, and indirectly programming several hundred million dollars per year from SCDOT towards Interstate, Resurfacing and Bridge, Safety, and Transit projects.

**Chapter 13 – Leveraging opportunities of Federal resources**

ITIC as well as CU-ICAR developed a large network of industry partnerships that can be utilized to leverage Federal resources through cost-share and in-kind donations. In addition, the Greenville team is working on partnerships with VC/PE entities that are willing to invest in start-up companies with a transportation focus that could leverage the incubation facilities in the Greenville area and directly engage in the pilot demonstration projects.

In its TIGER VII application the Greenville team demonstrated its ability to leverage federal resources by mobilizing more than 40 different project partners and matching the federal investment with a 43% local match investment. This local commitment from various

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government agencies, educational institutions, research centers, health care organizations, and nonprofits confirms that the region is eager to implement smarter, cleaner and more effective public transportation initiatives.

Greenville participates regularly in the application of Federal grants and partnership opportunities. Greenville applied for USDOT TIGER grants since 2009, and received positive comments on the TIGER VII grant, although it was not funded. Anticipation is high for the application to TIGER VIII.

In January 2016, Greenville was selected one of ten (10) U.S. municipalities in the “Envision America” workshop, held in Charlotte, NC. During the workshop, many partnerships were made that Greenville intends to capitalize on for the SCC, future TIGER and other grant opportunities, and its own “Envision Greenville” effort.

In addition, longstanding partnerships between Greenville, Greenville County, and GPATS allow for the application of state and Federal funding beyond the local level, and inclusion into Federally-mandated Long-Range Planning processes. Through the MPO processes, Greenville can leverage local support for Federal funding, create regional partnerships, and call upon state resources if needed.

Greenville County, SC, is waiting on SCDOT approval to submit, as a sub-recipient, a FHWA grant proposal for \$1 million to deploy electric, connected, assisted/automated Taxis (**aTaxis**) in a multi-modal environment and develop a business model that is financially sustainable. We will evaluate several aTaxi shuttles under commercial conditions in order to assess their life-cycle costs, performance, and reliability that will serve as the initial link in a community network of aTaxi vehicles. The Greenville pilot also involves a true public-private partnership with significant financial and marketing support from Verdae Properties, a 1,100 acre GreenVillages development that will use the aTaxi shuttle services to improve mobility.