Cover Page
NOFO 693JJ319NF00001

Smart-Cart Infrastructure: Safety, Security, Implementation of ADS

Louisiana Tech University
Ruston, Louisiana 71272
March 21, 2019

PI: Dr. Sumeet Dua, PhD

LOUISIANA TECH UNIVERSITY

OFFICE OF THE PRESIDENT

March 20, 2019

To: U.S. Department of Transportation (USDOT)
Federal Highway Administration (FHWA)
Sarah E Tarpgaard, Contracting Officer
Washington DC 20590
NOFO # 693JJ319NF00001

Subject: Louisiana Tech Smart-Cart Infrastructure Project

Dear Ms. Tarpgaard and Proposal Review Team,

It is with great enthusiasm that Louisiana Tech University submits the "Smart-Cart Infrastructure" Project for review. As President of Louisiana Tech University, I am sincerely grateful to the U.S. Department of Transportation for providing this outstanding opportunity for interdisciplinary research, collaboration and demonstration on our campus. The overarching goal of this innovative proposal is to design a unique Automated Driving System (ADA) Demonstration environment that would allow leveraging our interdisciplinary research programs and faculty across three academic colleges on campus to create a safe, affordable, technology-integrated, interoperable, data-rich, and scalable demonstration system. This initiative will enable us to introduce ADS technologies to our researchers, students and partners and equip them with the knowledge and skills that will be required of leaders in the field.

This proposal aligns fully with the University's Master Plan and ongoing commitment to pursue innovative technologies, promote safety, and improve accessibility on our campus. Next fiscal year, the University will be making a significant investment in the campus infrastructure. A portion of the investment will be directed toward parking improvements, multimodal pathways, and street upgrades. We would welcome the opportunity to collaborate with the Department of Transportation and leverage our investment to create a demonstration facility in the center of our campus. Currently, our Master Plan illustrates a corridor that will dissect our campus and connect the campus to the historic downtown of Ruston, Louisiana. We have successfully renegotiated a lease with Kansas City Southern Railroad that provides seventy feet of unencumbered easement along the existing railway. This real estate provides a unique opportunity to design a multimodal testing facility that will be both functional and effective for data collection.

Louisiana Tech University is fully committed to providing five million dollars in matching funds to construct the new infrastructure that aligns with the Smart-Cart Program and the campus master plan.

A MEMBER OF THE UNIVERSITY OF LOUISIANA SYSTEM

P.O. BOX 3168 • RUSTON, LA 71272-0001 • TEL: (318) 257-3785 • FAX: (318) 257-2928

AN EQUAL OPPORTUNITY UNIVERSITY

In addition, this research initiative will establish a new Center of Excellence on Tech's campus: The Center for Autonomous Technology Safety and Security (CATSS) will enable us to showcase new technology to a variety of stakeholders. This center is built on the firm foundations of our existing research centers and educational programs. The assembled SCI Team represents a diverse and talented set of PIs fully capable of executing the bold vision of this project and CATTS.

Multiple unit leaders from our campus and regional partners will actively support the proposal through their participation in the Project Management Council. I am fully committed to supporting their efforts. The project has also identified an outstanding External Advisory Council to provide expert guidance on various thrust dimensions of the project, align those with national trends, identify needs and opportunities for enhancement, and serve as an independent project evaluation group.

Louisiana Tech has a long history of innovative research, partnerships, technology development, outstanding education, and workforce training that are at the disposal of the team in the pursuit of this work. The University Planning Team is also fully committed to work alongside the PIs as this SCI project indeed informs the future of safe mobility at Louisiana Tech and provides a lasting ADS technology proving ground and research center that benefits the region and Nation.

I look forward to working closely with the Project Team and the USDOT in this excellent opportunity to build a demonstration system that could serve as a model for the Nation.

Sincerely,

Leslie K Guice

Leslie K. Guice
President

Summary Table:

Summary Table	
Title:	**Smart Cart Infrastructure (SCI)**
Eligible Entity Applying to Receive Federal Funding	Louisiana Tech University P O BOX 3168 TECH STATION Ruston, LA.71272-3178
Point of Contact	Sumeet Dua, PhD Associate Vice President for Research and Partnerships Email: sdua@latech.edu Phone Number: 318-257-2871
Proposed Locations	Ruston, Louisiana
Proposed Technologies for Demonstration (briefly list)	Advanced Communication Systems for ADS, Security and Data Handling, Innovative mobility Solutions, Data Exchanges for safe, efficient secure integration of ADS, Roadway Marking / Infrastructure Sensors for V2X advanced data acquisition & rulemaking
Proposed Duration of Demonstration (period of performance)	4 Years
Federal Funding Amount Requested	$5,438,376
Non-Federal Cost Share Amount Proposed	$6,074,016
Total Project Cost	$11,512,392

Table of Contents

Listing of Tables

Listing of Figures

Smart-Cart Infrastructure: Safety, Security, Implementation of ADS

1. Executive Summary

1.a Vision, Goals, and Objectives

The Vision of Smart-Cart Infrastructure (SCI) is to implement new ADS technology across users and infrastructure including cybersecurity that **demonstrates safety**, new methods for **affordable ADS implementation**, and **demonstrates** outcomes that show the path forward for ADS Nationwide.

- Building from current cores of expertise, *a new center of excellence is established*, CATSS (Center for Autonomous Technology, Safety & Security), that promises both immediate and lasting impact of the work across research, education, and workforce training in this important field.
- The project makes a significant and lasting contribution to real-world physical plant that establishes safe, mobility solutions via ADS technologies. Louisiana Tech University has committed matching funds of $5M to establish infrastructure upgrades guided by this SCI effort and is working closely with the SCI team to achieve these objectives that will scale to the nation and provide blueprints that inform ADS rollout and rulemaking.

Final Goals of this demonstration project are centered around (1) Safety; (2) Data generation for Safety Analysis and Rulemaking; and (3) diverse Collaboration that spans technologies, users, and stakeholders. **Safety** and **Data Generation** are key goals accomplished via infrastructure V2I implementation that includes **data availability** with **unique cyber-security and infrastructure**. The project will enhance deep learning and test cybersecurity of implemented systems that will be key for scaleup nationally. **Collaboration** will successfully **demonstrate aspects of ADS infrastructure** that yield **insight into user level acceptance,** illuminating methods that <u>promise marketplace success and increased mobility for those with disability</u>. Finally, new education and workforce training goals are achieved for increased, long term impacts. *These Goals represent a wholistic set,* demonstrating outcomes that span technology and human factors.

Significant Objectives are accomplished via CATSS in two Thrust areas. These closely match critical areas of needed advancement noted by the DoT in “AV 3.0” [2].

<u>Thrust 1</u>: Improve and demonstrate Vehicle to Infrastructure Sensing and Data Acquisition that is fast, secure, and highly available. New cybersecurity measures and techniques are deployed with cloud-based deep learning, allowing formal outcomes that drive implementation across the Nation. Further, we advance the deployment of useful infrastructure sensors that lower cost and increase safety, advancing real-time localization of vehicle assets and users crucial for designing intelligent transportation systems.

<u>Thrust 2</u>: Increase knowledge and demonstrate pathways to increase ADS adoption across different population demographics and users, including those with disabilities. The team is working with the diverse set of campus students and personnel to achieve these insights through understanding the initial market drivers and perceptions in these core user groups. This is then followed up through interaction with real ADS technology and exposure to the real systems that are achieved in Thrust 1.

1.b Partners, Stakeholders, Team Members and Participants

Louisiana Tech University (LaTech) is uniquely positioned with varied infrastructure and users including those with disabilities to demonstrate the significant goals of the SCI project. Key partners are assembled for the work and provide project input and guidance via two mechanisms: External Advisory Committee (EAC) and internal Project Management Council (PMC). The EAC includes local representatives from future stakeholders in the public sector (City of Ruston, Louisiana DoT) as well as representatives from the autonomous driving industry and infrastructure experts. Within the PMC, the SCI Project has brought together on-board legal expertise, University planning expertise, on-sight security, and infrastructure insights. These committees promise to help guide the project and offer key outcome evaluation. An additional partner is the Professional Development and Research Institute on Blindness at LaTech with ties to nationally recognized Louisiana Center for the Blind, located a short distance from Tech's campus. This partnership enhances the project's interaction with users with disabilities.

Beyond the scope of this work, these teams will continue to work with CATSS to promote the long-term vision for ADS research, education and workforce development.

CATSS (Center for Autonomous Technology, Safety and Security) is formed from the collective experience and partner of centers already on LaTech's campus, represented by the group of PIs. These centers connect industry, research, and education / workforce development in key areas of National / DoT interest. These include:

- **Cyber Research Expertise**: PI Dua is the SCI Lead and has contributions across an extensive array of cyber research efforts. LA Tech has generated over $20M from agencies including NSF, DHS, DARPA, AFRL, AFOSR, ONR and LA Board of Regents. More than 125 peer-reviewed publications, 20 Ph.D. dissertations, 20 master's theses, 4 books and 10 patents have been generated across 12 years. Multiple PIs on the SCI project contribute to these efforts with expertise that has included big data analytics, behavioral biometrics, situational awareness in layered sensing environments, information assurance, mobile sensor networks, combating insider threats and intrusion detection, social network cybernetics, cloud computing, and cyber education.
- **CIA** (Center for Information Assurance): PI Maasberg is the Point of Contact for the NSA/DHS at Louisiana Tech working through the CIA.
- **TTC** (Trenchless Technology Center): PI Matthews is the TTC Director and brings infrastructure, industry, and workforce training solutions to the project.
- **IfM** (Institute for Micromanufacturing): Sensor resources and capabilities represented by PIs Weiss and Moore who serve as Executive Committee Leadership Members of IfM.
- **PDRIB** (Professional Development and Research Institute on Blindness): PI Bell leads this institute, whose research mission is to broaden and deepen our

understanding about blindness and the best methods for increasing the independence of blind and visually impaired individuals.

- **AROS** (Applied Research for Organizational Solutions): Behavioral scientists specializing in integrating the reactions and preferences of end-users into planned change efforts, including human-machine interaction. PIs Apter-Deselles and Jacob are key members of AROS.
- **Deasil Cognitive**: Industrial collaborator with key support for data collection and analytics as well as expertise in deep learning (AI and Machine Learning), blockchain, and cloud computing with user interaction that streamlines data availability and interfacing.

1.c Issues and Challenges with anticipated outcomes

Challenges in ADS include system technologies and user interactions. These challenges are captured by DoT AV 3.0 [1] and inform the Thrusts of the work.

Thrust 1 focuses on *Sensor and V2X (Vehicle to Infrastructure or people and users)* *deployment that is secure, and useful for existing infrastructure settings.* These settings require safe and cost effective solutions that allow use and scaleup across diverse infrastructure types. Louisiana Tech includes this diversity through pedestrian, railroad, bridge, and a general setting that represents a scalable proving ground for nationwide rulemaking.

- Key demonstration will be safety and cyber-security as well as data management and asset protection of ADS V2I technologies in the varied infrastructure environment. The team will monitor sensor performance across a wide area of settings and interactions to advance safety and security. Deep learning and data asset interpretation will be key outcomes demonstrated as quantifiable improvements over current state of the art. Outcomes will also yield data that informs future NIST series publications that can govern the ADS space.
- In addition to technology challenges, legality is a significant challenge to full ADS implementations. New infrastructure work is funded via Louisiana Tech matching funds to establish a set of mobility-focused paths for ADS vehicles and user transport. Outcomes will include successful signage and multi-path data driven outcomes.
- Other challenges include user interaction and interactions with ADS. The DoT AV 3.0 publication notes the importance of identification of pedestrians and usability of devices like smartphones for ADS interaction. The team will address these challenges through incorporated outcomes from smartphone and app deployment and use data.

Thrust 2 focuses on *enabling and expanding ADS use across varied user groups* *to overcome market barriers and increase safety and mobility solutions.* The project is ideally positioned with excellent partners to overcome user barriers and gain important outcomes that drive adoption of ADS. Users with disabilities are a point of emphasis including those with visual disability. Further, population sets without access to current public transportation face significant mobility challenges and are part of the SCI work.

- Demonstrations include user interaction as well as a progression of ADS acceptance across a phased-in approach that considers of pre- and post- ADS interaction for these user groups. This formally maps acceptance and challenges to adoption from the user perspective and yields data based on real-world population. National scaleup and adoption of fall-out recommendations are natural outcomes of this work that will guide increased user acceptance.
- The team is working fully with established Internal Review Board procedures and providing outcomes and data that reflect de-identified data for national scale-up. Further, we enhance safety through incorporated smartphone use and show the potential outcomes and advance made through this effort.

1.d Geographic area of demonstration

The proposed SCI project is ideally situated. **Louisiana Tech is committed to an aggressive infrastructure and safety improvement plan already in place.** The plan focuses on the mobility needs of Tech students, faculty, and visitors from locations outside the Campus core to the Campus heart. SCI will work alongside, inform, and integrate with this plan to produce a futuristic mobility solution for the campus community and the new **Center for Autonomous Technology, Safety & Security (CATSS)**. This guarantees a lasting impact of the SCI project beyond the 4 year scope of the proposed DoT funding. The University is committed to a $5M infrastructure improvement project that will be used to support the required infrastructure for the SCI Project. This is being executed independent of DoT award, however, given DoT approval of the SCI proposal, the project team and SCI goals will inform the infrastructure work to achieve the visions and goals of this effort (Section 5.e fully describes this cost share, source and management of these funds for this project). Further this will provide a dedicated proving ground that becomes a campus mobility highlight and continuing research focus. Figure 1.1 shows the final operating corridor in place, at the heart of campus.

Figure 1.1: Artist View of Planned Mobility Corridor

The SCI project will roll out in two phases that improve safety and provide important, highly available data that is well suited for national scaleup across the two Thrusts of focus. An optional video of the Corridor Areas around the University is included for optional reader interest at: https://vimeo.com/325084679/3f0809767b

Phase 1: Mobility Corridor 1 - Campus Heart Mobility & ADS Demonstrations

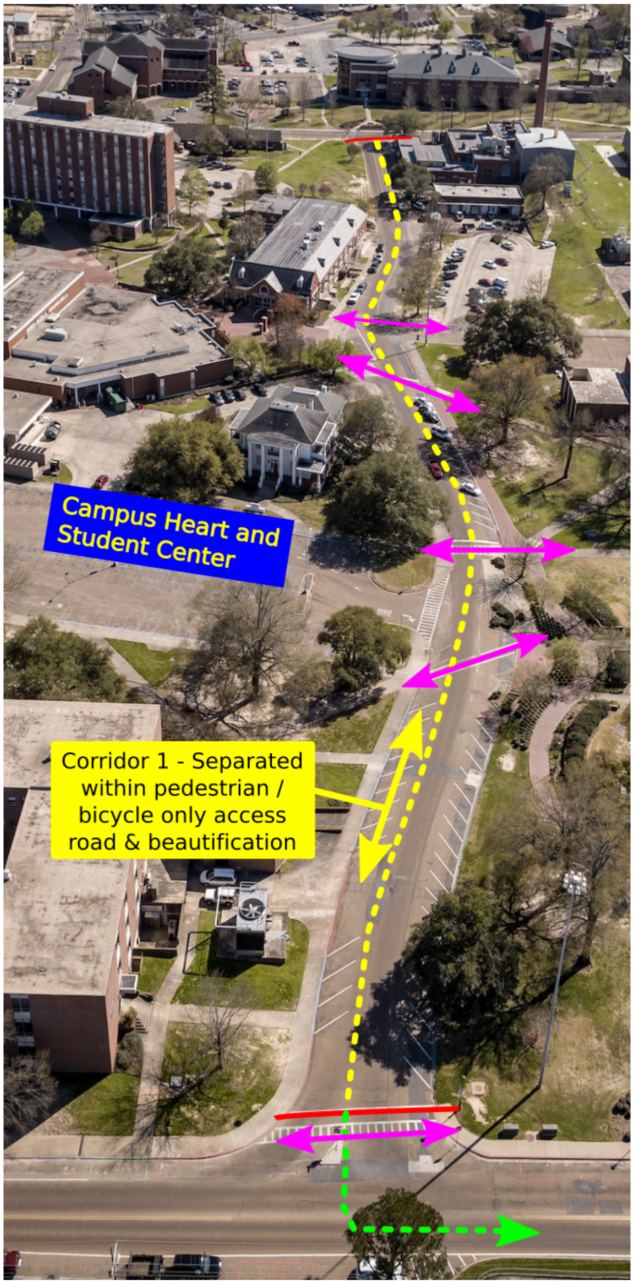

Figure 1.3: Phase 1 Mobility Corridor 1 Map

Figure 1.2: Corridor 1, Wisteria st, prior to use in SCI project

Across a four-year phased-in approach, two specific ADS demonstration "mobility corridors" are planned. Corridor 1 initiates work and demonstration on V2I aspects of the project in a campus core setting with heavy pedestrian interaction. Initial deployments include the rollout of the supporting data network, cyber security, deep learning, and sensor integration for V2I. Figure 1.3 illustrates the planned Corridor 1 with Figure 1.2 showing the corridor prior to university investment and use in this project. Pedestrian crossings are noted in pink, and the demo path in yellow. The corridor is implemented as part of a beautification and safety / mobility plan that closes the street permanently (red lines) to public traffic and establishes a separated corridor currently used for street parking. This provides initial safety and controlled pedestrian interaction. Vehicle interaction for data collection will be conducted using access vehicles using the remaining part of the corridor or other ADS equipped carts (personnel movers) within the segregated demo section.

Phase 2: Mobility Corridor 2 - Off-Campus Access

The SCI project expands in Phase 2, creating Mobility Corridor 2 that connects with Corridor 1 and is shown in green in Figure 1.4. The connection to Corridor 1 can be noted. Corridor 2 is established to incorporate mobility and safety that lay groundwork for moving people on and off the campus core to off-core parking. This corridor is within feet of the busy KCS railroad, crossing beneath the railroad on a new Z-Crossing while interacting with a highly used four lane street, Tech Drive. Frequent pedestrian and university user interactions are projected as the corridor is in close proximity with both a new pedestrian walk and street. Pedestrian crossing and new walkway are noted in pink. Corridor 2 is separated as with Corridor 1; however, it crosses at-grade to connect with Corridor 1 (yellow) and to off-campus parking accessed across Tech Drive via the Z-Crossing. Of note, this provides a lasting infrastructure demo site for the current proposed SCI project as well as continued development of ADS beyond the 4-year project scope, guided by CATSS.

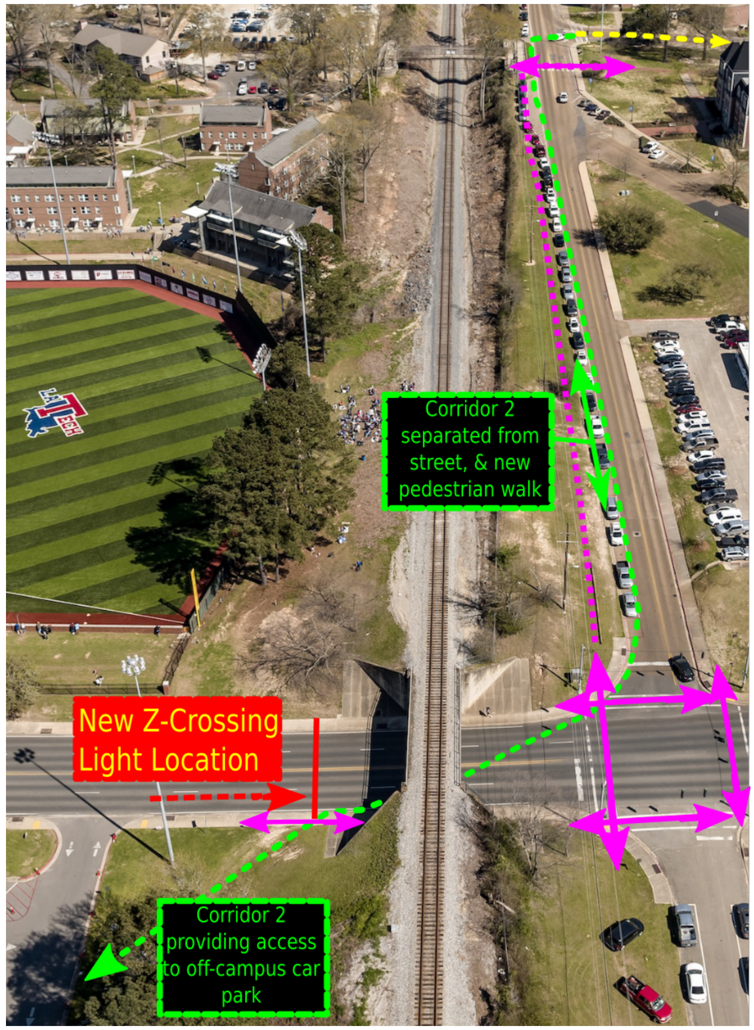

Figure 1.4: Phase 2 Mobility Corridor 2 Map

1.e Period of Performance and Project Schedule for Demonstration Evaluation

The proposed period of performance across the 4 year project is included in Figure 1.5. Critical demonstrations are shown in red. Other milestones or deliverables include the required kick-off meeting with the DoT (within 3 weeks of awarding) as well as execution of formal Project Management (using the below demonstration plan as a general guide) and Data Management plan within 2 weeks and 60 days of awarding respectively. A detailed project evaluation plan as well as all required DoT reports will be executed following the prescribed schedule provided by the DoT. Some tasks are show with multiple demos / milestones indicating continued progression and demonstration within the task.

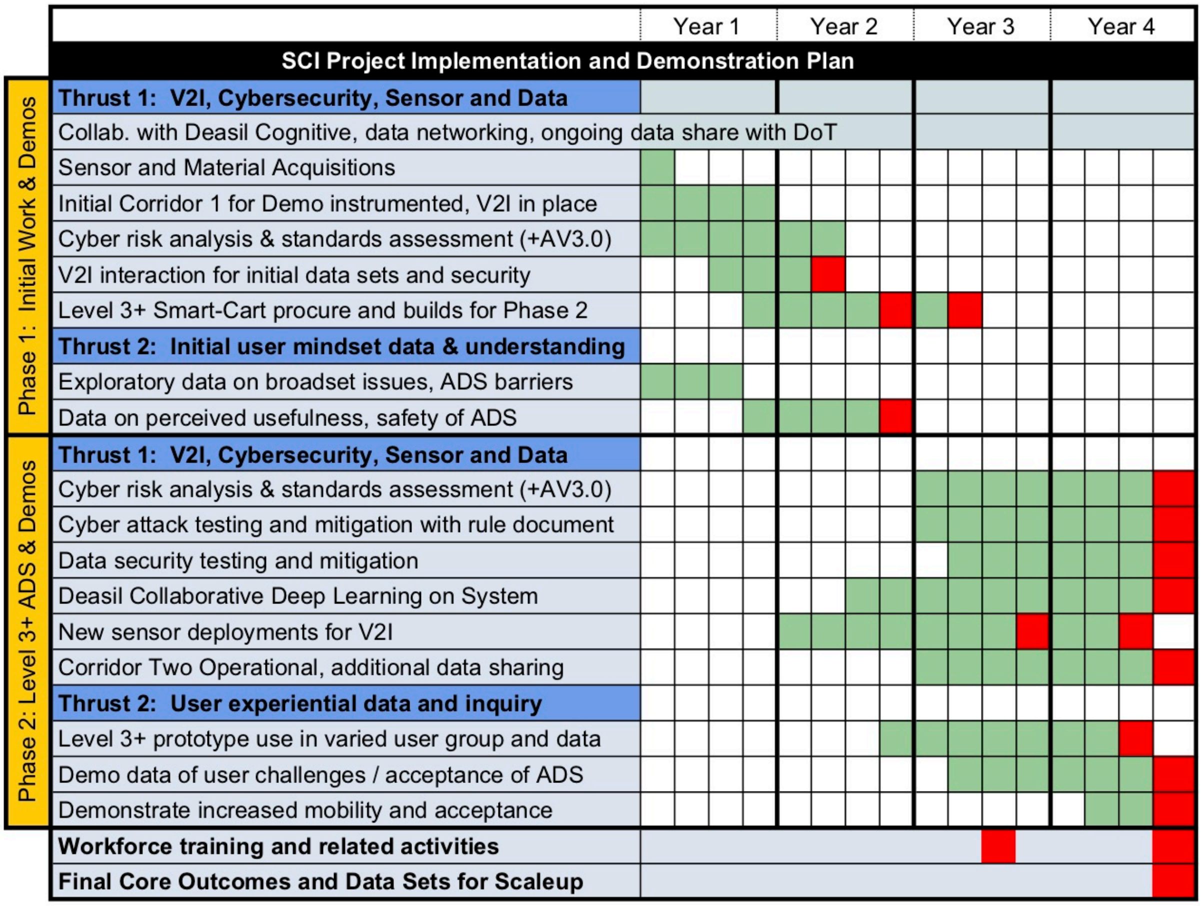

Figure 1.5: Proposed Period of Performance and Project Schedule

2. Goals

The SCI Project Goals flow through:

(1) Safety
(2) Data for Safety and Analysis Rulemaking
(3) Collaboration

These goals result in new data for V2X interaction that includes deep learning / cognitive capability on safety, cyber security, and asset management, and user interactions that result in national scaleup outcomes. Section 5 includes details on achieving these goals.

2.1 Safety and Data for Safety Analysis and Rulemaking

Safety is the overriding goal for every aspect of the SCI effort. A phased-in approach will achieve safety in autonomous vehicle operation, unique insight into user acceptance and safety perception, and direct efforts that test for system vulnerabilities in the data chain and V2I network.

Phase 1 consists of a planned Mobility Corridor in the heart of Campus (Figure 1.3). Initial efforts allow work as described in Section 5 to establish networks and prove safe sensor operations with onboard diagnostic capabilities. This establishes baseline for safe implementation and initial data gathering for the remainder of the SCI project. Further, this serves as a diagram for initial V2I infrastructure rollout nationwide. The system will specifically interact with:

- Multiple pedestrian crossings and nearby pedestrian foot traffic
- Variable road conditions
- Nearby railroad interference (vibration, and sound for sensor interference)

Phase 2 increases autonomous level capability of test vehicles ("Smart-Carts") to L3 for full demonstration purposes with ability to continue work to L5 as ADS work continues beyond the scope of the proposed effort, guided by CATSS. This allows further interaction, study, and deep learning as real users continue to interact with and use the system. Increased emphasis on network vulnerabilities will be probed through the team's cyber security expertise while new infrastructure sensing will be established to generate real-time proximity and system functional data while data management and cloud networking set a standard for scaleup and DoT rulemaking. The Phase 2 Corridor extends across intersections and interacts with railroad infrastructure where ADS system performance is closely monitored (Figure 1.4). Specifically, this second Phase achieves:

- True Level 3+ (5 capable) V2I systems and data / fleet health monitoring for safety and deep learning / cognitive capability
- Expanded public interaction and V2I predictive / monitoring data studies
- Direct railroad interference and vulnerability investigations
- Users with disabilities as part of established partnerships
- New infrastructure V2I sensing capability to assist national ADS scaleup

Through both phases, the team will study existing state of the art infrastructure sensors as well as autonomous vehicle sensor interaction. As part of the effort, new sensors will also be implemented that are cost effective for typical infrastructure settings. These offer unique data generation and safety enhancement. Additionally, Infrastructure sensor durability, fault recording, and resulting conditions will be important dataset acquisitions to support rule making for safe operation and design of ADS.

2.2 Collaborations

In each phase, there is emphasis on both technology thrusts and collaborations with stakeholders and users. Collaborations form a complete package of V2I data and security capabilities through partnership with Deasil Cognitive. This enhances the team capabilities already in place for sensor query and cybersecurity with blockchain and deep learning / cognitive capabilities. Security and Deep Learning of sensor networks will be critical ingredients for national scale-up especially since current state of the art has left this an area of more limited study.

The team is also partnered with important stakeholders that represent users, the general public, and transportation. The team is collaborating with the Louisiana Center for the Blind via the Professional Development and Research Institute on Blindness to asses user interaction with ADS where there are disabilities. Further, the V2I systems and sensing capabilities will be safely interacting (and monitored) in environments where these, and other members of the pubic, are in proximity. A unique plan to engage a wide ranging, local demographic enhances this insight and effort. This is primarily achieved through the objectives of Thrust 2. Full details of these efforts as well as the outcomes are detailed in Section 5.

3. ADS Focus Areas

SCI project goals are achieved through unique objectives housed in two Thrusts. Thrust 1 initiates infrastructure buildup (for data and vehicle) and initiates new data sets on V2I sensing and data acquisition that is fast, secure and available. Thrust 2 increases data and knowledge building, engaging real users across demographics including those with disabilities and building on deep learning outcomes in an expanded mobility corridor. Each of these thrusts meshes with ADS Core Focus Areas as described in this section.

3.a Public Benefit

The SCI project works with a cross-section of public and private to achieve broad public benefit. This is encapsulated through external (EAC) and internal (PMC) councils as noted in Section 1.b. These councils guide and help evaluate progress to assure significant public benefit across all interests. Further, SCI leverages the outstanding history of education and workforce training at LaTech to generate broad impact, excellent awareness and new opportunities for industry and public at large. This is achieved through the new CATSS center of excellence, incorporating inputs from prior workforce and Louisiana Department of Transportation contacts and training.

The work also investigates and produces outcomes geared for national scaleup and rulemaking that enhances ADS safety as a public good. V2I with Level 3+ (depending on project phase) sensors designed for typical infrastructure are validated as are supporting network safety and cybersecurity, for example. Different user groups are engaged across the project to create wholistic outcomes that are not only technology based, but also address key market acceptance and safety perception from the people who will use the technology (Section 2.2).

Real-time data is made available in an open framework while deep learning and cognitive capability is expanded in a security enhancement all geared for public benefit and safety.

3.b Market Failure / Compelling Public Needs & Diversity

The wholistic approach of the Thrusts of this work allow unique perspective and insight into national scaleup and marketability. As encompassed by Thrust 1, V2I itself has been an area of more limited study in general. Based on insight from the assembled EAC (External Advisory Board), V2I is an important aspect of future national scaleup and critical to prevent large market failures of ADS technology. This is a critical area of interest for rulemaking and safety across both the sensing technology and data management, networks, and all associated security.

There have been some prior studies on public perceptions of ADS, however, a detailed study that includes a public set with current infrastructure in frequent use, across a wide variety of users in real-time has been lacking. Understanding public perception is key to making recommendations that enhance national ADS scaleup. The SCI project provides this critical insight and allows progress that supports current industry efforts where incentives to study this is lacking. The outcomes of Thrust 2 specifically enlighten public needs and highlight accessibility plays in mobility.

The SCI project also exists in an area that is market challenged: smaller town with rural components and a diverse set of users, expectations and needs. Northern Louisiana resides in a lower income area. For example, 67% of all K-12 students live in poverty and qualify for free or reduced lunch [3]. In fact, three of Louisiana's highest poverty school districts are in North Louisiana. Data on the use and expectations / needs of useful ADS that engages across socio-economic groups allows scaleup and national marketability. This is especially critical given a recent AAA study that indicates 3 out of 4 Americans are afraid of self-driving vehicles [4]. Thrust 2 specifically engages and spans these groups to better understand and address this challenge. Further the approach for this project reflects the realities of the larger, national infrastructure network in its present condition, requiring solutions that can be affordably implemented.

3.c Complexity of Technology

The Smart-Cart Infrastructure project includes a phased-in approach that establishes different autonomous technology across the 4 year plan (Figure 1.5). Phase 1 includes activities with V2I in place and being tested in sensor sets. These are placed on the initial mobility corridor, as well as in human piloted carts to achieve initial networking and cyber advance as the sensors interact and identify objects, people, and react to the diverse set of conditions present in Corridor 1. Phase 2 increases infrastructure complexity as well as autonomous technology capability with true Level 3 ability and development of the level 3 capable "Smart Cart" itself. This increases interactions with a diverse set of real-world users through builds that allow multiple-person transport well-suited to a variety of people transport across different infrastructures. The details of these technological rollouts are included in Section 5.

3.d Diversity of the SCI Project

The scope of the SCI project includes a wide variety of stakeholders that enable insight as well as project evaluations through the assembled PMC and EAC. As noted in Section 3.b, part of the key to addressing marketability and compelling public need intersects a diverse population set directly. This is a strength of the SCI two-Thrust approach and diverse collaborator set. Further, the new Center of Excellence, CATSS, incorporates direct outreach, workforce training, and affects real Louisiana Department of Transportation officials and employees to guide statewide rulemaking and ADS deployment.

3.e Prototype and Demonstrations

Demonstration and prototypes work in a rollout plan of initial familiarization and infrastructure baselining via Phase 1 that initiates V2I deployment, networking, and cyber thrusts. This allows initial demonstration as projected by Figure 1.5 where infrastructure network demonstration is generated using market available sensors mounted in user piloted vehicles or carts around Corridor 1 infrastructure components. This quickly leads to demonstrations at more advanced autonomous levels.

During Thrust 1, in concert with the infrastructure sensor build and networking roll-out, the team builds Level 3+ autonomous transports as described in Section 5. This allows the team to access and share all data in an open environment, thus enabling critical elements of data acquisition, networking and cybersecurity engagement without proprietary manufacturer constraints.

This work leads to Phase 2 Demonstrations of the prototype V2I infrastructure and vehicles in real-world operating environments on Corridors 1 and 2 (Section 1.d). V2I demonstrations include:

- Cyber-attack demonstrations and system robustness analysis
- Data networking security demonstrations
- Deep learning demonstration through data sharing and collaborations
- Unique sensor deployments and demonstrations in the infrastructure space

Additional demonstrations fall out of the human factors work that engage users across diverse groups and in the varied settings represented by the project. These include:

- Engagement with Level 3 ADS technology, and a driver acting only as a "shepherd"
- Demonstration of different groups with disabilities and specific needs and interactions via partnering with Louisiana School for the Blind and University students that span physical abilities.
- Demonstrations of increased mobility in both Corridors through this SCI initiative

4. Requirements

4.a Level of Demonstration

The proposed SCI Project initiates work swiftly in Phases. Phase 1 establishes basic V2I sensor and required networking solutions that offer up to Level 2. Level 3 Demonstration commences in Phase 3 activities as fully described in Section 5. Key demonstrations including V2I interaction, security, safety and recognition as well as new sensor deployment are conducted at Level 3. Technology in place during Phase 2 will allow work at Level 4+ as the project continues with established infrastructure capabilities in place and continued collaboration across the assembled stakeholders.

4.b Physical Demonstration

Physical Demonstrations are noted as part of Figure 1.5 and Section 3.e. The projected timeline of these demonstrations is noted in Figure 1.5. Section 5 fully describes the approach and technology.

4.c Data Sharing and Accessibility Plans

The project provides safety and performance data through V2I networking and cybersecurity advance as fully described in Section 5. Data is available in an open framework to the DoT and maintained for 5 years as part of this work. Further, the project will work on deep learning and cognitive capabilities to enhance ADS operations and provide national recommendations for use. These outputs are also made available in an open framework. Cybersecurity and system response as well as any vehicle / infrastructure related events are key elements of the proposed data sets and will be fully available. **Part 3, The Data Management Plan**, elaborates on many of these details.

While infrastructure and sensor / vehicle interaction data are primary outputs from Thrust 1, human factors data that collects important user data is also made fully available as part of Thrust 2. Open and anonymized data sets will be fully available and maintained for 5 years beyond the project period in compliance with the award. Further, the team will also analyze data sets to achieve insight and make forming recommendations that assist national scaleup and overcome market challenges. Data can also be made available and visualized for City of Ruston Public Works employees in real time via a Smart City of Ruston Online Dashboard program. Using this dashboard, public officials can make the most well-informed decisions possible about critical issues, and act upon them with shorter delays.

4.d Demonstration Plans for Users with Varying Abilities

To achieve data and safety progress in thrust areas, a unique demonstration sequence is adopted both within the main Louisiana Tech campus and then expanding out to include different populations, different interactions, and additional learning and data on ADS. During Phase 2 of the proposed project, Level 3 autonomous technologies are fully deployed and operating on the Mobility Corridors. While specifics are fully detailed in Section 5, some highlights include interactions across users that do/don't drive, have different disabilities and socioeconomic backgrounds. Demonstration that highlights which groups are more / less comfortable, or specific vehicle interactions with different people are important aspects. In addition, there will be significant user study conducted that also includes pre- and post- autonomous system interactions to fully baseline the final outcomes and data sets / recommendations generated. User comfort with the technology, perception of security and 'in-the-moment' interview techniques will support the studies as well as demonstrations.

This approach is made possible by Tech's unique positioning in the community that includes varying infrastructure and people all within a mile of the university campus with continuous demonstration capability:

- Pedestrians
- Traffic
- Bridges
- Users with Disabilities (including visually impaired)
- Railroad

4.e National Scalability

Plans are fully placed in the Demonstration and Approach that enable project outcomes both desirable and scalable to the national level. Data is generated and made fully available highlighting safety as a key driver in V2I sensor networks, sensors, and interactions with users and ADS technologies. This is conducted in a unique setting that makes the project highly germane to the National setting. Broad infrastructure types are in place on both demonstration corridors and key partners exist to inform, evaluate and add to the project through both EAC and PMC groups. This includes public and private transportation and expertise, as well as local jurisdiction input and collaborations.

The Project also provides a continual analysis of data in full compliance with DoT requirements and availability. In addition, the experience of the team across the Thrust areas informs Best Practices reporting as an outcome and gives new insight into the important area of V2I usability and adaptability in varied infrastructure settings with a mixed group of users and situations. The important incorporation of human factors data and analysis reporting assures a widespread application potential for this work.

5. Approach

The goals of the SCI project are achieved via two key thrusts: Thrust 1 improves and demonstrates V2I/X sensing and data acquisition that is fast, secure, available, and cognitive / deep learning enabled. Thrust 2 increases data and knowledge building that engages real users across demographics including those with disabilities. Each of these thrusts meshes with ADS Core Focus Areas (Section 3). Experts associated with each demonstration thrust area are highlighted in this section along with details on the technical approach. Multiple **Work Areas** are included within these Thrusts and are noted in **green** as appropriate in this section for ease of reference. Different projects are identified as noted to specifically achieve the final demonstrations.

5.a Technical Approach to Demonstrations

Thrust 1: Big Data and Cybersecurity Integration, Sensors for ADS

Overview:

The DoT has expressed its commitment to supporting the safe, reliable, efficient, and cost-effective integration of automation into the broader multimodal surface transportation system as part of its Automated Vehicle 3.0 (AV3.0) principles. The thrusts are informed by these principles. The SCI project then adds to the array of best practices, voluntary standards, targeted research, and modern regulations. Among the goals are the initiation of on-campus Corridor 1 work via SAE automation level 2 personnel transport carts and the improvement of the accuracy of the automated responses. As the project grows and expands, a true Smart-Cart is built to demonstrate the full set of objectives in Level-3 in Demonstrations on Corridors 1 and 2.

General Platform for data collection

The data collection platform is called "Smart-Cart" and will be a Level-3 autonomous set of mobility vehicles (4, built across the grant phases) capable of transporting small groups of people within the prescribed mobility corridors. Assembly and build will be based around the open source autonomous vehicle architecture. Most mass produced self-driving solutions currently available on the market are closed systems. These are not flexible enough to access the internal data stream from their onboard sensors. Thus, the team will assemble a platform

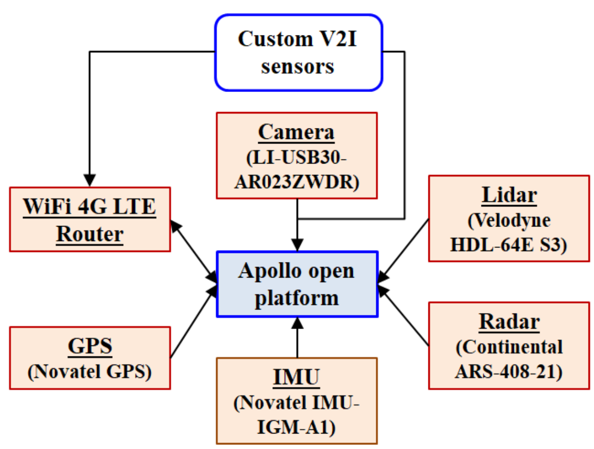

Figure 1.6: Proposed platform for Data Collection

integrated with COTS sensors that are typically found in self-driving cars for the purpose of data collection. The open source architecture Apollo (http://www.apollo.auto) will be leveraged for this purpose. The team will acquire the necessary COTS sensors (Figure 1.6) compatible with Apollo and integrate it into drive by wire carts. All major equipment acquired will adhere to the Buy American Act as available in agreement with the Act. Data collected from mass produced vehicle and the custom platforms will be complementary. This approach will allow the team to determine and query / interrogate performance of open source systems subjected to various safety and security scenarios such that safety protocols can be formulated for rulemaking. The custom platform will also enable research on unique V2I sensing concepts as described in this section (Thrust 1C).

General Data and Cybersecurity Approach

In order to develop the Smart-Cart, the PIs will implement utilities for situational awareness, which enhances overall security of the system. IoT devices are key for developing situational awareness; data collected from IoT-enabled sensors will be uploaded to the Cloud for post-processing involving machine learning. Both static data and data in transit will be monitored for Cyber Security. Resources for data management and cloud computing will be made possible through the contributions of the subcontractor Deasil Cognitive. The PIs intend to develop specific AV communities, including an ACM special interest group and an IEEE community, for putting forth journal and conference publications.

The PIs will integrate data management with cybersecurity procedures to form Cyber-enabled systems that will comprise the backbone of the AV framework. The generic goals for data and infrastructure are to be an open source, anonymized community resource that is accessible to the research community for inspection, enabling the scientific community at large for input. The PIs will leverage the AV community researchers (formed above) to exchange data and programs with Auto-ISAC. **To achieve these goals, specific technologies must be incorporated related to Infrastructure**. These form projects within the Thrust 1 focus.

The infrastructure established as part of Phase 1 and that must be in place to initiate the studies are cloud-based virtual machines for processing, cloud-based storage, IoT devices including Raspberry Pi microprocessor boards, and digital sensors. Networking infrastructure includes wireless modules to communicate data from IoT devices to central servers, and an optical fiber backbone to aggregate data in the Cloud. Cyber Security must be in place for the networking infrastructure, incorporating cryptographic routines, authentication protocols, risk analyses, and penetration testing techniques to identify any new vulnerabilities. Cyber security must also be put into place for the IoT devices, including low-cost protection from malicious software (bots, viruses, malware, etc.), the central servers, and cloud VMs. In the Cloud, adequate compute capability must be instantiated to form neural networks for Deep Learning procedures.

<u>Thrust 1A Project: Cyber security - risk analysis and attack scenarios for ruleset</u>
<u>PIs:</u> Dua, Chowriappa, Drozdenko, Maasberg, Chen
<u>Partner</u>: Deasil Cognitive
<u>Work Areas:</u>

- ***Demonstration and validation of exchanges of data supporting, accelerating the safe, efficient, and secure interoperable integration of ADS & development of voluntary consensus standards***
- ***Advanced Communication Systems supporting safety / mobility***

The proposed work takes a cost effective, risk-based approach following the National Institute of Standards (NIST) 800 series as required by Title III of the E-Government Act (Federal Information Security Management Act (FISMA); PL 107-347) and amended Federal Information Security Modernization Act of 2014 (PL 113-283) as well as the U.S. Department of Transportation Automated Vehicles 3.0 (AV 3.0) strategies and principles for security that also reference the standards. Accordingly, the project will contain a customized risk analysis strategy that spans the four years of the project. The risk analysis 7 stage process addresses the protect aspect of the cyber security framework related for AV 3.0 [5] and for implementation and adaptation for a risk management framework (RMF) for autonomous vehicles and specifically for this project. The 7 stage process is based primarily on a bottom-up methodology to maximize the technical vulnerability assessment and penetration testing for development of rulesets and documentation to support NIST 800 series publications, Information Sharing and Analysis Centers (ISAC), and DoT objectives. The methodology is depicted as follows along with anticipated year of completion (Figure 1.7):

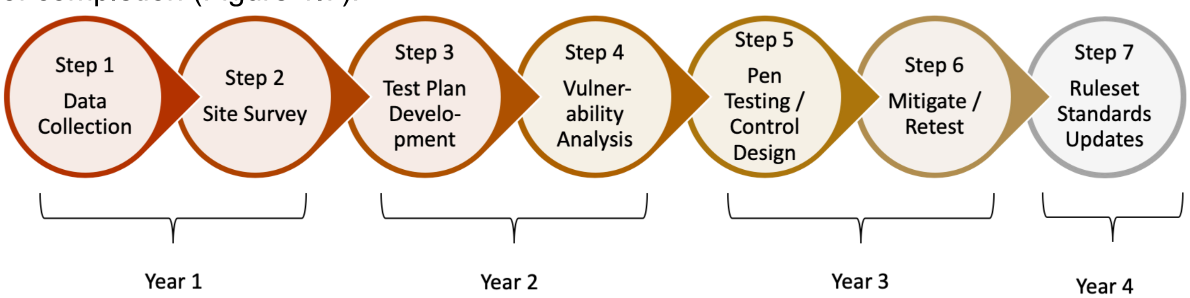

Figure 1.7: 7-Stage Risk Analysis Methodology

Step 1 is characterized by collection of data including all pertinent NIST 800 series publications, federal, state and local laws, available documentation, areas of concern, and creation of a list of all known vulnerabilities for AV in the current test environment. For example, AV 3.0 documentation references IEEE 1609 family standards based on 802.11p Wireless Access for Vehicular Environments (WAVE) approved enhancement to 802.11; however, evidence suggests that these can be compromised [6].

Step 2 contains a site survey of all current hardware, software, protocols, communications, and information exchanges pertinent to the current system design and implementation during build. This includes type of network protocols on the target network, location and type of sensitive information, number and location of servers, specific media types, software specifications, and so forth. This project projects open source-based sensors emanating from Apollo and similar vendors. A site survey will be conducted to determine all known vulnerabilities to these sensors, particularly as many originate from inorganic sources (non-U.S.). Projected sensors include Lidar, which has been shown to have vulnerability to spoofing attacks.

Step 3 will complete the full remaining test plan for analysis, including a formal checklist for vulnerabilities, intended penetration test techniques, intended ruleset and standard enhancement outcomes for metrics, and obtaining necessary hardware and software for analysis and testing. Guidelines will be used to test the plan, for example known threats and vulnerability information obtained from open source outlets or ISAC will be incorporated into the analysis and testing. Of note Louisiana Tech University is able to obtain access to a partnership program for Academic Institutions for the Auto-ISAC and will use information gained during Step 3.

Step 4 will commence at the end of year 2 as the overall project moves from initial Corridor work (Phase 1) to expanded Mobility Corridor efforts (Phase 2) and consist of the formal vulnerability analysis.

Step 5 will consist of penetration testing techniques, which will be based on Step 3 test plan coupled with Step 4 vulnerability analysis formal results. These penetration techniques also include running attack scenarios where rulesets can be created from the cases as well as measures of criticality, and data gathered for standards implementation. This data will be shared with Auto-ISAC and made available to the rest of the research community via the web to increase data availability and project impacts across a larger community. Step 5 will also include security control design considerations as a result of the vulnerability and penetration testing results.

Step 6 is comprised of the control implementation and testing; as an example, we will apply lightweight cryptography and physical layer security to the system design. Lightweight cryptography is a promising solution for constrained devices, including RFID tags, smart cards, and other mobile devices with limited size and energy, in this case some of the sensors. Physical layer security is another emerging solution for secure data transmission by exploiting the physical layer properties of the communication system, without using encryption keys.

Step 7 is dedicated to the compilation of the rulesets and standards based on the results. While ongoing data share is accomplished with the ISAC community and DoT, formal compilation and detailed interpretation / analysis will be made available. These are expected to enhance AV 3.0 framework risk management and lay the groundwork for expanded NIST 800 series publication addressing the security AV and related technology, standards for Department of Transportation, information sharing for ISAC, and rulesets for community in research and practice.

Thrust 1B Project: Post-Processing and Wireless Networking
PIs: Dua, Drozdenko, Maasberg, Chen
Partner: Deasil Cognitive

Work Areas:

- ***Demonstration and validation of exchanges of data supporting, accelerating the safe, efficient, and secure interoperable integration of ADS & development of voluntary consensus standards***
- ***Advanced Communication Systems supporting safety / mobility***

Communication of the sensor network is an important outcome. Present protocols such as Bluetooth are highly vulnerable, poor for mobile vehicular units, and have been shown to be inadequate with regards to the timing constraints required by V2V and V2I communication. For this reason, we plan to study communication advances to enhance mobility and safety, as described in this section. As an example, image processing techniques must be put into place to recognize the road and obstructions, including pedestrians. Distributed processing algorithms can be studied for video processing to perform face and object recognition. This requires a robust and reliable communication network. As a note, anonymity is required in data gathering, so the PIs will ensure that subjects are not identified, and that image data is secure. Additional Details are fully included in **Part 3**, the **Data Management Plan**.

Wireless networking protocols must be implemented to establish this communication across V2X. This will improve safety and prevent congestion, increasing acceptance and marketability of ADS as a fallout result. Initially, the IEEE 802.11p variant will be prototyped for wireless communications in this effort. The framework will include Mobile Apps such as Waze, which use GPS for real-time route determination operating as user and V2X type apps integrated with the work. Currently, the City of Ruston is engaged in discussions with service providers about 5G network availability; LA Tech University's contacts at City of Ruston Public Works Department, Darrell Carraway and Andrew Halbrook, will keep the PIs informed of this progress. As available, the team will begin investigation of this framework to enable studies in 5G and adapt the framework to use them. Progress of the 5G network is beyond the control of the SCI team and will be investigated as possible. However, this will be an ongoing focus of CATSS and future ADS development.

In post-processing efforts of captured data, a containerized Cloud Computing platform, provided by the subcontractor Deasil Cognitive, will be utilized to share larger datasets and run deep learning algorithms. Special attention will be given to the microprocessor operating systems, wireless protocol encryption and authentication algorithms, and the classification of sensor data as public or private when uploading to the Cloud. Once the data is present in the Cloud, artificial intelligence and deep learning algorithms will be developed to perform data fusion making the most relevant statistics available to interested parties including the AV community researchers previously noted to exchange data and programs with Auto-ISAC.

Thrust 1C Project: Infrastructure and V2I Sensor Advance
PIs: Jaganathan; Matthews; Chowriappa; Weiss

- ***Work Area: Technologies associated with ADS***

As network standards and capability are critical, sensor technology itself will be a point of emphasis for the team in Thrust 1. PIs from the Trenchless Technology Center (TTC) of Louisiana Tech have a strong track record of developing advanced sensors for condition assessment of buried infrastructure and this expertise will be leveraged for this project. Sensors developed at TTC include Ultra-wideband radar (UWB; 3-5 GHz) for condition assessment of buried pipes [7], electromagnetic wave sensor (~10 GHz) for imaging of polymer liners inside pipes [8], drill head installed capacitive sensor (~30 kHz) for obstacle detection in Horizontal Directional Drilling (HDD) [9], magnetic field based drill-head tracking device for HDD and elastic wave based characterization of concrete pipes [10].

The data from various digital sensors is collected at various sampling rates and should be combined on-device to make real-time edge decision before upload to the Cloud via network and data efforts ongoing in other Thrust 1 activities. Experiments involve the synchronization and correlation of different data feeds in order to enable the best decisions within small amounts of time. Sensors will be placed strategically on static locations off the road and vehicles. Sensors placed on the sides of the road including Smart light posts, will lead to the creation of a Dynamic Road Network that shows a path forward for national scaleup and rulemaking.

The team will investigate several projects within this sensor work thrust to develop low cost pavement embedded sensors that will complement the onboard sensors carried in vehicles. This effort will consider various aspects of V2I sensors including low cost embeddable hardware, signal processing (both onboard and remote), communication and finally the mechanical durability aspects. Novel techniques for sensor placements will be studied, as well as integrations with infrastructure and design for durability. Sample placements include sidewalks, ground adjacent to railway lines, pavements, and aerial (posts, trees, buildings). The sensors will be subject to Endurance Testing, to gauge the durability of every individual sensor type, and life cycle studies to gauge the cost-effectiveness of the solution.

Real-time localization of autonomous vehicles is crucial for designing an intelligent transportation system. While much of the self-driving car industry continues to rely on the onboard sensors such as camera, Lidar, GPS, and Radar (millimeter wave electromagnetic and ultrasonic radars) in order to determine the asset position with respect to road and nearby vehicles, it will be beneficial to install sensors within pavements for tracking these vehicles. This approach will bring the much needed reliability, especially during the initial stages of rolling out these AVs. Road embedded magnetic marker concepts have been experimented in the past for vehicle localization [11]. For instance, the Swedish automaker Volvo conducted a research project with pavement embedded magnets to determine the position of cars [12]. Such sensors provide redundancy to the system when performance of vision based sensors is poor (e.g. during weather events) and other worst case scenarios. However, impediment to these embedded sensors and V2I in general is the higher cost of construction involved and the quantity of sensors required to cover a vast network of roads. In this project, we will investigate low cost embedded sensor network for vehicle tracking and localization. Two sample projects are listed below.

- ❑ **Magnetic coating for pavements:** In this project, we will investigate paint based magnetic markers that can be coated on the existing surface to guide AVs. This will have minimal disruption to the surface and provide a wider coverage than installing localized sensors beneath the surface. Ferromagnetic additives will be added to road paint and induction coil type pickup units will be devised to pick up lane markings inductively. The research team will collaborate on the optimization of hardware, chemistry and localization/tracking algorithms involved in this concept. In the past such technology has been tested for snow plow guidance and it was proven to be effective, but it has not been adopted widely [13]. The emergence of autonomous vehicles necessitates the renewal of this technology and customize it for various forms of transportation systems. In the past PIs have worked on magnetic field based tracking system for buried Horizontal Directional Drilling (HDD) machines [14]. The hardware developed in that project will be leveraged for vehicle tracking application. PIs will collaborate with chemists at the Institute for Micro Manufacturing (IfM) of Louisiana Tech to develop a paint using commercially available additives to provide magnetic properties.

- ❑ **AI enabled embedded vibration sensors for vehicle identification**
  Inductive loops on pavements are widely used for vehicle identification [15]. Recently, deep learning algorithms have been proposed for classification of signatures from these loops [16]. While these loops are effective, they are relatively large and have bulky electronics that limit broader application. In this project we will investigate a low cost vibration based vehicle classification sensor. It will consist of miniature accelerometers installed on the pavement to pick up elastic Lamb waves generated as the vehicles pass by. The entire module will be self-contained with its own energy harvester, data-acquisition and communication capability built into a miniature package such that it can be installed on the pavement (e.g. lane markers). Deep learning algorithms will be trained to classify the vehicles from acquired waveforms. Recently, PIs have proposed a novel elastic wave based characterization of concrete pipes [10], and the lessons learned will be leveraged for successful completion of this project.

- ❑ **Smart-cart based RFID communication with critical infrastructure**
  RFID tagging technology has matured over the past couple of decades to track a wide variety of objects. We will implement an RFID based V2I sensing system to monitor critical above ground infrastructure closer to the roadway. As a demo, RFID tags will be attached to above ground pipes (e.g. fire hydrant) located along the driving route and vehicle carried RFID reader will be used to communicate with the tag. The information gathered will be relayed using the established network. Developing such a capability will allow us to develop several applications in the future to monitor critical infrastructure where data from tags over a wide area can be gathered and processed using clustering algorithms and carry out predictions and forecasting for traffic flows, event predictions, or other situations.

Thrust 2: Human Factors
PIs: Apter-Deselles, Jacob
Partner: Louisiana Center for the Blind with CoPI Bell

- ***Work Area: ADS that enhances safety and mobility for transportation-challenged populations, including travelers with disabilities and older adults, as well as the general population***

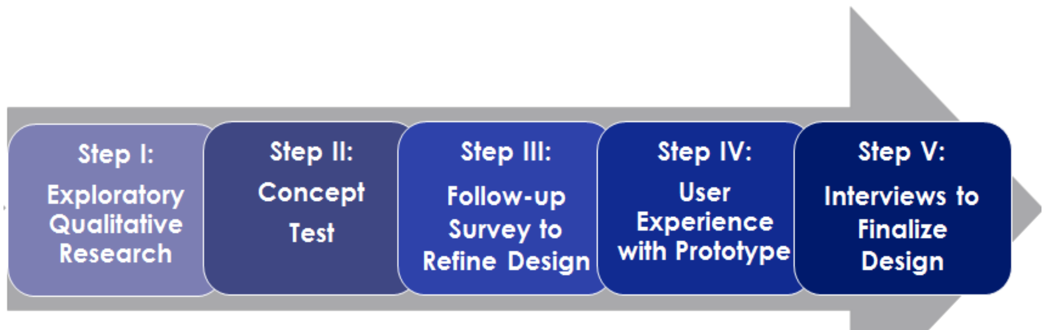

Figure 1.8: Human Factors Thrust, Process to Completion

Step I: Exploratory Qualitative Research
Timing: Year 1

Purpose: To learn first-hand about the people who will be using the ADS system, capture broad and deep understanding of what key populations expect from and how they think about the proposed ADS implementation, and to provide early input to the design team.

Method: Ten focus group discussions of 8-10 participants each, lasting 2 hours each.

Topics: Awareness and familiarity with autonomous vehicles, initial reactions to a description of the proposed plan, expectations regarding design and safety elements, barriers to use, and perceived benefits.

Participants: Driving age adults who are Louisiana Tech University students or residents of Ruston and the surrounding community. Two focus groups will be conducted with each target audience: traditional college students (18-22 years old), visually impaired individuals, older drivers (65+), non-driving individuals (due to disability or other reason), lower SES individuals (annual HHI below the median for the community).

Recruitment: Via community outreach, leveraging existing relationships with business and non-profit organizations, and utilizing traditional and social media. We will develop a communication plan for key stakeholder groups to build interest and engagement across all four years of the project.

Results: Used to develop the topics and questions included in the subsequent quantitative survey (Step II).

Step II: Concept Test
Timing: Year 1, subsequent to completion of exploratory qualitative work in Step I

Purpose: To assess attitudes, beliefs, and preferences regarding the proposed ADS system (e.g., vehicle, smartphone app, route, stops) among prospective users. The data will also be used to estimate how large the pool of interested users may be.

Topics: Ease of use, intuitiveness of design, safety concerns, areas of confusion, usefulness, perceived benefits, value, overall appeal, and likelihood of using. Survey content and nontechnical language will be informed by user input from Step I.

Method: Anonymous survey of 300 prospective users lasting approximately 25-30 minutes. The survey will include a *concept test* to assess user reactions to a mock-up of the system and relevant details of how it will operate. A 3-D visual depiction will be used with sighted participants in the research and may include a virtual reality demonstration. The visually impaired participants will listen to a verbal description. Participants will be paid a small honorarium as an incentive to complete the survey.

Participants: Driving age adults who are either Louisiana Tech University students or residents of Ruston and the surrounding community. The overall sample will include readable data on the following subgroups: age group (18-24, 25-44, 45-64, 65 and over), gender, race, ethnicity, social economic status, physical or visual impairment, and drivers or non-drivers. We will augment the sample to increase participation from low-incidence groups.

Results: Guide product design and implementation, based on input from prospective users. Step II allows acquisition of statistically meaningful results and measurable trends on many of the same topics covered in Step I.

Step III: Follow-up Survey to Refine Concept and Design
Timing: Year 1-2

Purpose: To drill down on issues and opportunities identified in Step II Concept Test and incorporating any changes to the mock-up design.

Method: Anonymous survey of 150 prospective users lasting approximately 10-15 minutes. Participants will be recruited in Ruston and the surrounding area via outreach efforts, leveraging existing relationships, and employing traditional and social media. A small honorarium will serve as an incentive to take part in the survey (included in requested SCI Budget).

Participants: Driving age adults who are either Louisiana Tech University students or residents of Ruston and the surrounding community. The total sample will include readable data on a smaller number of subgroups: by age group (18-35, 35-64, 65 and over), gender, race, ethnicity, social economic status, physical or visual impairment, and drivers or non-drivers. To ensure the data are readable by each of these important groups, we will over-sample in order to reach n=50 for groups with low natural incidence.

Results: Guide refinements to the design and implementation of the prototype.

Step IV: User Experience Assessment: Prototype Testing
Timing: Year 2

Purpose: To provide prospective users opportunity to interact with the autonomous vehicle and its supporting smartphone app, and to give meaningful feedback on what they like and dislike about the experience. Observation of user-ADS interaction will inform design team of obvious errors or barriers to use. The process will also determine the effectiveness of the system in automatically avoiding blind persons who inadvertently walk into the path of the vehicle. For example, when blind people have their walking sticks vertical, they don't intend to cross the street. **Linking input from cameras and image processing techniques, we intend to identify walking sticks** and determine their angles to minimize risk to visually impaired pedestrians.

Topics: Ease of boarding, quality and comfort of the rider's experience, perceived safety, effectiveness of voice-activated interfaces, overall appeal, likelihood of using, expected frequency of use, and likelihood of recommending to others.

Method: Recruit 150-200 individuals from the following subgroups: by age group (18- 24, 25-44, 45-64, 65 and over), gender, race, ethnicity, social economic status, physical or visual impairment, and drivers or non-drivers, to take part in product testing. Data will be obtained by observing participants interacting with the vehicle on corridor, followed by a structured interview. Participants may be asked to "think aloud" while they board, ride, and disembark from the vehicle; their responses will be recorded for later transcription and analysis. Regarding the smartphone app, PI Bell and his colleagues will assess the app for accessibility and ease of use prior to testing among visually-impaired users.

Topics: Potential risks to safety, feelings of security, comfort, utility, and motivation in using the autonomous vehicle. Users' ease in accessing and navigating the app, clarity and relevance of content (especially information about route stops, wait times, and status updates), and overall appeal will be assessed. Participants will be paid an honorarium for their time.

Results: Identify recommended design improvements and opportunities for optimization of ADS and smartphone app, as well as provide a narrative for the design team outlining features and benefits of the system.

Step V: Follow-up User Experience Interviews to Finalize Design and Implementation
Timing: Years 3 and 4

Purpose: To assess the effectiveness of the design modifications made as a result of Step IV, by collecting feedback from users after they have interacted with the smartphone app, autonomous vehicle, route, and stops.

Method: Recruit 100 individuals to interact with the modified ADS system, representing the general population, as well as transportation-challenged subgroups (i.e., physical or visual impaired, drivers or non-drivers), to take part in product testing. Similar to the protocol in Step IV, "think aloud" responses will be recorded as participants interact with the vehicle and app, followed by a structured interview. This process will take approximately 25-30 minutes and participants will be paid an honorarium for their time.

Topics: Based on areas of improvement identified in the prior step.

Results: Used to refine ADS and app design before deployment on the Louisiana Tech campus.

Best Practices Outcomes

The two thrust areas present significant data availability for rulemaking and National scaleup as the SCI project moves forward across the 4-year plan. There is also opportunity for significant Best Practices outcomes, or Core Outcomes at project completion. These outcomes will be based on the two Thrust area specifics and be used to inform industry, public, and DoT as well as inform Workforce training and Louisiana DoT interactions. Documentation about how public officials in other cities and university researchers can replicate our testbed (including sensor deployment for advanced V2I) can be provided on the Louisiana Tech University website. The outcomes will also influence Grand Challenge-type calls to the research community that are made via CATSS. These are based on the generated, publicly available data that encompass the Thrusts and Work Areas. This will allow broad problem solving in this Grand Challenge type environment.

5.b Legal and Regulatory Approach and Compliance

As part of the team's commitment to safety mobility improvement, key personnel are part of the PMC/EAC that will inform and work with the PIs to maintain full regulatory compliance. This includes legal counsel as well as representatives from the City of Ruston and Campus Safety, Planning, and Security personnel. Further, by establishing demonstration in access-controlled corridors within the campus itself, many regulatory challenges inherent to the work are managed.

The SCI project will work with all FMVSS and FMCSR standards as applicable. Further, as noted in Section 5, the team will focus on American products that include the sourced carts as well as sensor technologies as available. Pursuant to the Buy American Act, technology and software availability will determine point of manufacture (origin) and procurement by the team. Partners associated with this effort will work within the same guidelines to satisfy Buy American Act requirements.

5.c Data Provision Commitment

As described in this Part 1, as well as in Part 3 (Data Management Plan) all data will be made available to the DoT as generated. Further, additional data reflecting deep learning and analysis of events resulting from the raw operating data will be made available following acquisition and interpretation. User-based Thrust 2 data on interactions increasing mobility, especially for those with disabilities, will also be made available as described in full compliance with the RFA. These will be analyzed by the team of assembled experts to ensure that the effectiveness is accurately communicated and meaningful for National scaleup and rulemaking.

5.d Risk Identification and Management

Risk minimization of those working on the project and the general public interacting with ADS technologies is our top priority. The internal Project Management Council is filled with safety and campus infrastructure expertise. Further, as legal aspects of the work are satisfied with mobility corridors (separated and marked) we also successfully establish a safe working environment for the SCI team and, as the project advances, pedestrians and others who interact with the work. During this work, each Smart-Cart will also achieve a max Level 3 capability, ensuring an on-board safety "shepherd" is continuously available as the system is operated and data generated.

SCI also adopts a Risk Management strategy in stages, looking to identify safety risks and incorporate mitigation strategies resulting from the phased roll-out and Thrust areas. We'll ensure that execution of the risk management framework will satisfy the requirements of federal transportation regulations and AV3.0 initiatives. This strategy will be implemented from early stage development, testing, and deployment of the project through a customized process that will result in a defense in-depth control implementation. We're planning to develop test cases for the following security scenarios:

a. Extreme Weather Conditions
b. Pedestrian detection / safety
c. Impaired Driver detection
d. Overcrowding within vehicles
e. Sabotage
f. Theft
g. Software Vulnerabilities: Patching / Revision Control

5.e Cost Shares Approach and Management

The team of PIs has been provided with significant release time from university teaching activities as noted in the budget as an in-kind match from the University. Significant cost share for infrastructure upgrade (Corridors 1 and 2) are also provided by the University as a Cash contribution. These funds are part of a planned upgrade to university safety, beautification, and mobility and will be executed independent of DoT support for the SCI project. However, given DoT support, funds will be guided by Goals and Demonstration requirements as outlined in this proposal, forming the two Corridors specifically for ADS demonstration purposes and national rulemaking capability.

Louisiana Tech commits $1,250,000 (per year) in infrastructure development and supports directly related to the proposed work. This match is for investments in infrastructure upgrades that the University is planning on making, through the monies raised using a bond issue, regardless of this proposal's success. These monies are reserved to be used for only infrastructure projects that could be influenced and adjusted based on the project's needs and findings. In brief, the project, if funded, will intelligently guide the timeline, sequence, target and extent of where that investment goes as a result of the proposed efforts. The Project Management Council will be responsible for providing direction for these project-driven infrastructure investments on behalf of the University.

References

[1] M. Ratcliffe, C. Burd, K. Holder, and A. Fields, "Defining Rural at the U.S. Census Bureau: American Community Survey and Geography Brief." Issued December 2016 ACSGEO-1. Online: https://www2.census.gov/geo/pdfs/reference/ua/Defining_Rural.pdf.

[2] "Automated Vehicles 3.0 Preparing for the Future of Transportation," Department of Transportation, Oct. 2018.

[3] Louisiana Department of Education, "Closing the Equity Gap." [Online]. Available: https://www.louisianabelieves.com/resources/library/closing-the-equity-gap. [Accessed: 08-Aug-2018].

[4] E. Edmunds, "Three in Four Americans Remain Afraid of Fully Self-Driving Vehicles | AAA NewsRoom," *AAA NewsRoom*, 14-Mar-2019. [Online]. Available: https://newsroom.aaa.com/2019/03/americans-fear-self-driving-cars-survey/. [Accessed: 14-Mar-2019].

[5] U.S. Department of Transportation, "Preparing for the Future of Transportation," Oct-2018. [Online]. Available: https://mentor.ieee.org/802.18/dcn/18/18-18-0124-00-0000-preparing-future-transportation-automated-vehicle-3-0.pdf. [Accessed: 13-Mar-2018].

[6] D. Woodbury and N. Haltmeyer, "Linux-Stack Based V2X Framework: All You Need to Hack Connected Vehicles," presented at the DEF CON 25, Las Vegas, NV, 29-Jul-2019.

[7] Jaganathan, Arun P., Erez Allouche, and Neven Simicevic. "Numerical modeling and experimental evaluation of a time domain UWB technique for soil void detection." *Tunnelling and Underground Space Technology* 25.6 (2010): 652-659.

[8] Jaganathan, Arun P., and Srilakhsmi Kodali. "An electromagnetic sensor to locate service laterals during the trenchless lateral reinstatement." Tunnelling and Underground Space Technology 83 (2019): 18-26.

[9] Jaganathan, A. P., et al. "Modeling of an obstacle detection sensor for horizontal directional drilling (HDD) operations." *Automation in Construction* 20.8 (2011): 1079-1086.

[10] Jaganathan, Arun P. "Multichannel surface wave analysis of reinforced concrete pipe segments using longitudinal and circumferential waves induced by a point impact." *Journal of Applied Geophysics* (2019).

[11] Byun, Yeun, and Young Kim. "Localization based on magnetic markers for an all-wheel steering vehicle." *Sensors* 16.12 (2016): 2015.

[12] Volvo, https://www.media.volvocars.com/global/en-gb/media/pressreleases/140760/volvo-car-group-tests-road-magnets-for-accurate-positioning-of-self-driving-cars [Accessed: 11-March-2019].

[13] Safe plowing, https://www.fhwa.dot.gov/publications/publicroads/01janfeb/safeplow.cfm [Accessed: 11-March-2019].

[14] Montoute, Jonas, and Arun Jaganathan. "Numerical Modeling of Magnetic Field Emissions from a Horizontal Directional Drilling Walk-Over Locating System.", Proceedings of COMSOL conference, 2016.

[15] Gajda, Janusz, et al. "A vehicle classification based on inductive loop detectors." *IMTC 2001. Proceedings of the 18th IEEE Instrumentation and Measurement Technology Conference. Rediscovering Measurement in the Age of Informatics (Cat. No. 01CH 37188)*. Vol. 1. IEEE, 2001.

[16] Huang, Wenhao, et al. "Deep architecture for traffic flow prediction: deep belief networks with multitask learning." *IEEE Transactions on Intelligent Transportation Systems* 15.5 (2014): 2191-2201.