Program Progress Performance Report
for University Transportation Centers

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National University Transportation Center

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Reporting Category 1 Accomplishments and Impacts
(Note: Category 4, Impacts, has been incorporated with Category 1, Accomplishments, for this report)

Impacts are highlighted

1A Major Goals of the Program

Research, Development, Deployment
The TSET UTC focuses on safety. Our research is specifically targeted at improving the safety of automotive drivers and passengers, bicyclists and pedestrians, and the safe usage of trucks and mass transit vehicles. The thrusts of the TSET UTC are structured along 5 core areas: In-Vehicle Technologies, Infrastructure Technologies, Human-Vehicle Interactions, Mobility/Data Analytics and Policy.

Metrics:
- Faculty scientific leadership as reflected by the number of publications and citations of faculty work in transportation-related areas;
- The number of staff, faculty and students involved in leadership positions in academic, industry and government transportation organizations;
- New research collaborations in fields related to this work;
- Successful technology deployments and their impact; and
- Patents and start-ups.

Education and Workforce Development
Education and workforce development are important complements of the TSET UTC research program.

Metrics:
- Number of transportation-related courses,
- Students participating in transportation research projects,
- Advanced degree programs funding TSET UTC students,
- TSET UTC-funded graduate students,
- TSET UTC-funded students who receive degrees,
- Institutional educational partnerships, and
- Participants in workforce and educational programs.

Technology Transfer
The UTC will fully use the resources and the experience of these university centers to promote enterprises arising from its research program. Faculty who already created startups in the past, serve as mentors to colleagues interested in this activity.

Metrics:
- Simple adoption of the innovation by a transportation operator, company or public, to more formalized outcomes such as licensing, patents, commercialization, and spin-off companies.
- Quantify numbers of meetings, attendance, publications, and social media and website activity.

Collaboration
Collaboration is the heart of the entire TSET program. CMU and Penn seek to ensure our research and development program leads to deployment of technologies in the transportation systems serving our communities and state, providing pilot applications for global use. The CMU-Penn team will collaborate with related centers on the two campuses, state and local public partners, non-profit community partners and industry partners.

Metrics:
- Number and diversity of members of both the TSET Consortium and Advisory Council, and by the Number and impact of deployments achieved through collaboration
PROGRAM ADMINISTRATION AND MANAGEMENT

Objective: To maintain a program that effectively achieves the required deliverables in support of the center’s primary goal.

Accomplishments:

- Participated in UTC Spotlight Conference on Bike and Ped Safety, both disseminating our UTC’s research and learning about other pressing needs in the bike/ped research space.
- Continue to use a webinar-based system of linking faculty and students for our bi-monthly TSET meetings. A faculty member interactively presents their research at the beginning of each meeting.
- Participated in the Council of University Transportation Centers Summer meeting, which resulted in exchanging best management practices and discussion of UTC priorities.
- Transferred all of our TSET research into our new online, project database. The database allows for research projects to be organized online in a dynamic, searchable environment and will live on after the life of the grant.
- Hosted the Third Annual National UTC Safety Summit in Washington DC.

TSET’s major accomplishment for this reporting period was hosting our third and final National UTC Safety Summit on Thursday, April 6, 2017. The Summit is a critical forum to convene UTCs with government and industry partners, and ensuring that safety research continues to address real-world transportation needs. Following the Summit, CMU has handed the baton over to a newly awarded National UTC for Safety – the Collaborative Sciences Center for Road Safety housed at the University of North Carolina at Chapel Hill.

There were three panels throughout the Summit. The first panel, “Rebuilding our Infrastructure with Technology for Improved Safety,” was moderated by David Harkey, Director of the Highway Safety Research Center at the University of North Carolina, and featured Una Connolly of the American Road and Transportation Builders Association, Sue Chrysler with the Texas A&M Transportation Institute, Art Guzzetti from the American Public Transportation Association, Brian Watson representing the American Traffic Safety Services Association, and Tom Weakley with the Independent Drivers Association Foundation. During this discussion, panelists covered ideas of incorporating new technologies to meet the goal of improved safety.

The second panel, “How Do We Safely Deploy Connected and Automated Vehicles,” was moderated by TSET’s Stan Caldwell, and featured Mike Knodler, Director of the UMass Transportation Center, James Pol of the Federal Highway Administration, Ian Reagan with the Insurance Institute for Highway Safety, and Vinn White of Deloitte’s Future of Mobility and Smart Cities. The panel featured a discussion on enabling and embracing new innovations while maintaining that safety is paramount. Panelists talked about distinctions in terms related to autonomy, expectations for connected infrastructure, dealing with human factors in automation, and liability.

Over lunch, various safety-themed University Transportation Centers gave brief presentations on their research and education efforts to improve transportation safety.

The last panel, “Safety Issues for Rural Transportation,” was moderated by Steve Albert, Executive Director of the Western Transportation Institute at Montana State University. The panel featured Rosemarie Anderson of the Federal Highway Administration, Max Donath with the Roadway Safety Institute at the University of Minnesota, Peter Kissinger representing AAA Foundation for Traffic Safety, and Darrin Roth from the American Trucking Association. Panelists, shown in the photo above from left to
right, discussed key themes in rural transportation, including infrastructure, working with limited resources, improving communication and connectivity, and balancing the need for safety with other important needs.

The Summit closed with a networking reception and Research and Technology Showcase highlighting students and faculty work supported by UTC funding.

Program Impacts:

- Participated in the TRB Future Interstate Study Meeting in Detroit on 5/15/17 to determine research topics needed to understand the topic discussed.
- Produced CMU Energy Policy Briefing on "Pipelines, Trucks, Buses and Automobiles: Where, When, Which?" for distribution to the policy makers and the public.
- Faculty served on the Pennsylvania Autonomous Vehicle Policy Task Force and provided expert advice and legislative testimony that was incorporated in the final report and state legislative language.

Accomplishments:

- Hosted the National Renewable Energy Lab at CMU to discuss research collaboration on 4/19/17.
- Deloitte visited CMU on 5/25/17 to discuss research collaboration.
- CMU faculty researchers visited PennDOT’s new western Traffic Management Center on 6/5/17 to discuss research collaboration. Discussions continue.
- The Taiwan Investment Office and Trade Office visited CMU on 6/14/17 to discuss research collaborations with TSET researchers.
- Participated in the FHWA Research and Technology Coordinating Committee on 6/15/17.

RESEARCH
The TSET UTC develops research specifically designed to respond to real-world problems. Engaging with real world partners and ensuring that the research has a real-world test bed is core goal of TSET.

Below from Pages 4-15 Include Individual Research Project Accomplishments and Impacts

Multimodal Detection of Driver Distraction
PI: Maxine Eskenazi <max@cs.cmu.edu>

Research outcomes
We expect that we will furnish:
- a database of subjects driving our simulator and answering questionnaires and annotating where they were distracted
- a set of features that will be used to build the model of the driver’s distracted state (as opposed to attentive state). These features include forward camera information, backward camera information (gaze, head movement), CAN information and cognitive load information
- a set of algorithms that model when a user is distracted based on the features mentioned above
- a demonstration of the ability of the system to detect distraction (that can be presented at conferences, to industry visitors, etc.)

Impacts
We strongly believe that the algorithms we are developing will achieve better results than present in-car systems in detecting distraction due to both the massively multimodal nature of the data we capture and use and the way in which we implement the neural networks so that we leverage their predictive nature in detecting when an individual is distracted much earlier than present systems can. We also believe that our datasets, which will be shared with the research community, will help advance the field of distraction detection in general.

Did research results confirm or change practice?
So far we have:
- set up the distracted driving study - the simulator, the conditions, the questionnaires, the annotation interface
- collected a data from fifteen drivers
- set up the first level of feature detection using the data we have collected so far

**Web Links:** [http://ppms.cit.cmu.edu/projects/detail/46](http://ppms.cit.cmu.edu/projects/detail/46)

**Accomplishments**
We have, as mentioned above, created the first level of features for the forward-looking information, the cognitive load and the CAN information. We are working on the backward-looking information at present. This first level of features represents the raw data that we receive and, for the second level, will need to be combined with other information. For example, steering wheel turning will be combined with forward looking curve vs non-curve detection; head turning can be combined with forward looking appearance of a sign, etc.

**Crowdsourced Traffic Calming**
Principal Investigator: Bob Iannucci <bob@sv.cmu.edu>

**Research Outcomes**
A sensor device, called the TrafficDot that can be applied like a Botts Dot to road surfaces.
The TrafficDot will sense vehicular movement and, through long-range, low-power radio, communicate sensed information to a cloud server. The success metric for the TrafficDot is an in-situ lifetime of six months or longer and the ability to sense vehicular movement at 80% or greater accuracy for passenger vehicles when the dot is placed in the center of the travel lane.

- A wide-area network prototype, called the CROSSMobile LoRa network, deployed in a suitable suburban and/or urban setting, with the ability to receive Botts Dot signals over a one square mile area. The success metric will be the network’s ability to regularly receive data from 80% of all TrafficDot sensors in the target area.
- A website, in which the collected sensor data can be visualized. The success metric will be the website’s ability to plot traffic density as a map overlay as a function of time-of-day.
- A hackathon engaging local junior high and high school students in using the TrafficDot, network and web site to engage in the science of traffic analysis.

**Impacts**
Improved ability to quantify traffic flows (both spatial and temporal accuracies are improved by virtue of a dense sensor network)

**Did research results confirm or change practice?**
Our interactions with the City of Palo Alto regarding the design principles, the specific sensor, and the web dashboard have confirmed our sense that that our approach, if deployed at city scale, will advance the state of the art in traffic understanding. Josh Mello, Chief Transportation Official of the City of Palo Alto has been the guide for this project. Together, in the fall of 2017, we will engage in an initial deployment of ~10 TrafficDots in the City of Palo Alto. When coupled with our prototype web dashboard, we will have the opportunity to more fully assess the impact this system could have.

**Web Links:** [http://ppms.cit.cmu.edu/projects/detail/14](http://ppms.cit.cmu.edu/projects/detail/14)

**Accomplishments**
The TrafficDot has been designed, prototyped and tested. We now have functional prototype devices ready for deployment in the City of Palo Alto. Each device consists of a hardened enclosure (milled polycarbonate) housing a circuit board with sensors (magnetometer, light sensor, humidity sensor) as well as three radio systems (LoRA, WiFi, and Bluetooth).
We have successfully demonstrated extraction of clean magnetometer traces from the sensors and have built two prototype versions of signal classifiers. We’ve conducted structured experiments on a closed airfield (under the auspices of the US Naval Postgraduate School) with a variety of vehicle types and speeds, and have produced a labeled training- and test-set for researchers interested in using magnetometer data to classify cars.
We have deployed a test LP-WAN network in the City of Palo Alto and we have conducted extensive field strength studies in and around the target deployment area. We have demonstrated that the network is adequate for the intended deployment and that the propagation and coverage criteria set out at the beginning of the experiment are within the capabilities of the network.

We launched and are still conducting a study into the design of antennas for pavement-mounted sensors for traffic measurement. It is our belief that this work will be applicable across a variety of smart city sensing applications.

We have built and tested a web user interface that allows us to both visualize traffic flows from our sensors and to perform basic health checks of the deployed sensor devices.

**Sharing Connected Vehicle Infrastructure for Safety Applications, Smart City and Internet Access**

Principal Investigator: Jon Peha <peha@cmu.edu>

**Research Outcomes**

Our research will enable leaders in government and industry to make informed decisions related to “connected vehicles” on several issues. First, we have already shown that vehicular networks using DSRC technology can provide a more cost-effective way to provide Internet access to mobile users than today’s cellular systems in some cases, e.g. where population (and automobile) density is sufficiently high, while still improving safety on our roads. We anticipate learning more about where this is the case, and how soon. Second, the cost of deploying these systems will be considerable. We anticipate learning more about how governments and commercial ISPs can share infrastructure to reduce the cost to tax-payers of improving safety using this technology, and perhaps also reduce the cost of making Internet available. Third, we anticipate providing valuable information to the Federal Communications Commission and other spectrum regulators on how to devise spectrum rules for intelligent transportation systems that promote safety as well as use this valuable and limited resource to maximum benefit for all. Funding permitting, we would do even more.

**Impacts**

Based on results presented for the first time at the IEEE Vehicular Technology Conference in June 2017, we find that federal, state and local governments could save on the order of 20% of the estimated $4 billion cost of deploying the roadside infrastructure that is required under the plan proposed by the U.S. Department of Transportation by working with commercial actors in entirely new ways. Should those proposed plans continue to move forward, we hope that our work will lead to consideration of public-private partnerships.

Our work to date has also shown that there are benefits to sharing some (but not all) of the spectrum allocation for intelligent transportation systems (ITS) with unlicensed devices, and that those who want better performance for ITS might do better by asking for more ITS spectrum that is shared rather than asking that the ITS spectrum that they have not be shared. However, our results are preliminary, and only apply in a limited range of scenarios. We need further research to determine whether these results are true more generally. If so, then this could be the basis for a different decision on ITS spectrum from the Federal Communications Commission.

**Did research results confirm or change practice?**

Our research results to date support a change in current practice in several ways. This includes using DSRC technology for a wider range of applications and traffic types than many in the field anticipate (including Internet access). It includes collaborations between government and commercial ISPs to build infrastructure, where it is current practice for those entities to work entirely separately. It includes new approaches to spectrum allocation for ITS.

**Web Links** [https://users.ece.cmu.edu/~peha/papers.html#Vehicular](https://users.ece.cmu.edu/~peha/papers.html#Vehicular)

**Accomplishments**

We have published two papers in two peer-reviewed conferences this year, one on infrastructure sharing issues and one on spectrum sharing issues. The PI was also the keynote speaker at a conference in Harrisburg PA for senior municipal officials, where he spoke for an hour about emerging wireless technology, and how this technology can help meet community needs such as transportation. The PI has
also met with senior government officials, including the new Chairman of the U.S. Federal Communications Commission and many staff experts, to present our results and discuss the opportunities and challenges in vehicular networks.

**Bystander Interactions with Failing Vehicle Autonomy**
Principal Investigator: Aaron Steinfeld <steinfeld@cmu.edu>

**Research Outcomes**
Bystander concerns: This work will help identify issues that bystanders care about when encountering autonomous vehicles (AVs), both during normal operation and failure states. This will include identification of biasing factors that influence these concerns.

Opportunities for conveying AV information to bystanders: This work will reveal factors that developers, designers, and researchers can leverage towards better interactions between bystanders and AVs.

**Expected Impacts**
Insights on these outcomes will help inform research, development, and policy regarding how AVs and associated systems convey failure and status.

**Web Links** [http://ppms.cit.cmu.edu/projects/detail/26](http://ppms.cit.cmu.edu/projects/detail/26)

**Accomplishments**
During this reporting period the team developed an experiment protocol for gathering bystander input about AVs. This protocol development effort defined interview and survey questions and a data collection plan. Team members waited in areas of Pittsburgh where Uber AVs frequently pass through. After such an occurrence, team members would intercept participants and ask them the protocol questions. This work was done in collaboration with Jodi Forlizzi. The next reporting window will describe this data collection effort and findings drawn from the fieldwork.

**Non-Intrusive Driver Distraction Monitoring Using Vehicle Vibration Sensing**
Principal Investigator: Hae Young Noh <noh@cmu.edu>

**Research Outcomes**
In this project, we will use inertial sensors embedded in the vehicle seat for recognizing driver’s distraction states. These includes physical distractions (such as texting and tuning the radio) and cognitive distractions (including stress, fatigue, etc.). Advantages of the inertial sensor based driver monitoring system come from its simple and non-intrusive nature (i.e. no need for drivers to wear a device).

- Currently, we have already built a sensing platform that can capture the micro-motion; (heart-beat, posture, and breathing-rate) from the occupant of the vehicle.
- Preliminary data are collected using multiple sensors with vehicle under various driving conditions, including highway, local, parking-lot, stop and go.
- Data collected from passengers of the vehicle while speaking, moving, and generally sitting in the car.

Moving forward, we will focus our effort on developing data processing methods to extract detailed heart rate variability (for stress detection, etc.), and distraction related movement of drivers (for phone usage detection, etc.). The main challenge resides in high noise due to moving vehicles and sensing location constraints. To address these challenges, we plan to utilize multiple sensor nodes, high-resolution and high frequency data with hybrid modeling approach to minimize uncertainties in signal processing and obtain reliable information through modeling of data as well as vehicle and human responses. We will experiment in real-vehicles during driving conditions to ensure real-world applicability of our system.

**Expected Impacts**
The results from this project will lead to understanding the drivers physiological states including distraction, which will lead to safer vehicles and safer roads. In particular, as self-driving cars become more prevalent, such information becomes more important to pass control between driverless and driver-operated modes. Driver distraction is responsible for more than a quarter of the 1.3 million deaths and 50 million injuries from road traffic accidents. It is the leading cause of death for the young. With the advent of mobile devices and mobile entertainment, this trend is only projected to increase. To reduce the distraction, the vehicle must first understand the distraction level of a user. In the past, many single-point
on-body sensors and camera systems have been proposed to measure in car driver status (such as sleep, etc.) but these approaches are often limited to certain environments or require intrusive sensors on drivers that are difficult to deploy in reality.

**Did research results confirm or change practice?**

Preliminary data confirmed that micromotion can be used to extract heart-rate under different occupant and vehicle scenarios. Most importantly, the results confirmed that the occasional time-variant noise the data experiences caused by large movements can be identified and removed. The results also suggest that the sensors are much more sensitive to the micro-motion than first anticipated. Thus, talking and radio noise was incorporated in the testing scenarios to determine the interference with the heart-rate signals. Separating these signals could require sensor fusion with microphone inputs in the audio environment.

**Web Links** [http://ppms.cit.cmu.edu/projects/detail/47](http://ppms.cit.cmu.edu/projects/detail/47)

**Accomplishments**

- We have built a sensing platform that can capture the micromotion; (heart-beat, posture, and breathing-rate) from the occupant of the vehicle.
- Preliminary data are collected using multiple sensors with vehicle under various driving conditions, including highway, local, parking-lot, stop and go.
- Data collected from passengers of the vehicle while speaking, moving, and generally sitting in the car.
  1. Two PhD students (both female) have been supported by this funding.
  2. The technology was demoed at the 2017 Cyber-Physical Systems Week held in Pittsburgh
  3. A demo abstract is published at the 2017 Cyber-Physical Systems Week
  4. The technology has been pitched to companies, such as Intel, Google to promote industry collaborations and potential commercialization.
  5. The work is presented through multiple invited seminars at Stanford, CalTech, Princeton, Georgia Tech, etc. to promote collaboration and expansion of the work.
  6. The developed hardware has been used as a data acquisition platform in graduate level project courses at CMU to promote student interest in safe transportation systems.
  7. We are currently preparing a submission of a paper to 2018 HotMobile workshop.

**Building an accessible, low-stress, safe, and sustainable, bicycle infrastructure network for the City of Pittsburgh**

Principal Investigator: Sean Qian <seanqian@cmu.edu>

**Research Outcomes**

For all road segments in the City of Pittsburgh, we conduct data analytics by analyzing the following four factors: safety, traffic flow volume and speed, ride easiness, and bus coverage. Those factors, along with customizable preferences, altogether create bikability scores for the City of Pittsburgh. We further developed a web application to incorporate, visualize and analyze the bikability scores, allowing user interfaces, queries and map-based visualization.

**Impacts**

This web application has been presented to both public agencies and private sector, such as Department of Mobility and Infrastructure at the City of Pittsburgh, PennDOT, Port Authority of Allegheny County, Southwest Pennsylvania Commissions, and Healthy Ride Pittsburgh.

This tool holds great potential to be commercialized with substantial market, impact travelers’ daily choices to promote cycling, and ultimately achieve sustainable and safe transportation.

This research has trained two undergraduate students and one doctoral students for the interdisciplinary research on computer science, data analytics and engineering. Those students are interested in a transportation-related career in the future.

**Did research results confirm or change practice?**

The bikability has the potential to change long-term transportation planning process, as cycling can be quantitatively considered as performance metrics for planning projects.
The bikability has the potential to impact cyclists’ traveling behavior to better protect them from accidents and stress both psychologically and physically.


**Up-to-date city maps for modeling, planning, and assistive technologies**

Principal Investigator: Christoph Mertz <cmertz@andrew.cmu.edu>

**Research Outcomes**

We anticipate several systems developed that can detect, classify, and measure parts of the road infrastructure.

**Expected Impacts**

The long term goal is to have a complete, detailed, and up-to-date map of all objects and structures visible from a vehicle. This information can be used for inventory and assessment of road infrastructure and as input for driver assistant systems and autonomous vehicles. It will provide data to significantly improve road asset maintenance and management as well as improve the robustness and performance of intelligent vehicles.

**Did research results confirm or change practice?**

This research has the potential to significantly change the practice of road maintenance. Up-to-date data on road damage could enable the maintenance department to do frequent preventive maintenance which is much more cost effective than waiting for roads to fail.


**Impact**

The startup RoadBotics was founded in 2016 with the technology of earlier work of this project.

**Analysis of Effects of Tire Tread Deterioration on Safety Impacts from Analysis of Inspection Data**

Principal Investigator: H. Scott Matthews <hsm@cmu.edu>

**Research Outcomes**

Over the course of this one year project, we anticipate developing vehicle-level deterioration rates for vehicles. We have developed algorithms and data analytics that can be shared with various stakeholders, and to develop messaging for consumers that educates them on the issues of safety as related to tires. We seek to:

* Estimate the deterioration rates of tire tread in all passenger vehicles in Pennsylvania over the past 10 years.
* Estimate the percent of vehicles in the fleet that are driving with unsafe tires (as defined by the inspection threshold of 2/3 at time periods after the most recent inspection
* Estimate the percent of vehicles that wait all the way until the next annual inspection to get tires replaced.

The results will be created through data analytic methods, using Python and R programming.

**Impacts**

We have been prioritizing work on the methods, but have shared results with several stakeholder groups to date. We have already presented interim results to attendees at national and PA conferences since May 2017 (see presentation details below).

We also seek, when done, to open a dialogue with PennDOT officials about altering the tire tread depth thresholds given modern use of vehicles (10k VMT per year) and given the knowledge of sizable fractions of the fleet driving with unsafe tires. We hope to help them consider modifications of the current thresholds which anticipate consumer behavior.

Web Links [http://ppms.cit.cmu.edu/projects/detail/16](http://ppms.cit.cmu.edu/projects/detail/16)

**Accomplishments**

We have already created initial estimates of the deterioration rates of tire tread in all passenger vehicles in Pennsylvania over the past 10 years. We estimate that the rate is 0.2 inches per 1000 miles, or 2/3; per 10,000 VMT.
We have also begun to create the policy model; that considers the risk associated with the current tire tread inspection threshold of 2/3, to be able to consider the percentage of vehicles that meet the tread depth requirement at the time of inspection, but that would be expected to fail an inspection; before the next annual inspection. Our current estimates are that about 25% of vehicles fall into this category. Further, we have created initial estimates of the percentages of vehicles with questionable tires that wait until the time of inspection to replace their old tires, which causes serious safety issues in PA.

**Safer Roads in Snow Storms and for Pedestrians and Bicyclists**  
Principal Investigator: Srinivas Narasimhan <srinivas@cs.cmu.edu>  
**Research Outcomes**  
Development of cutting edge algorithms for snow removal and estimation, and detection of pedestrians and bicyclists. Integration with our smart headlight prototypes that are installed in a vehicle. Road testing of algorithms.  
**Expected Impacts**  
Demonstration of improved visibility of pedestrians and bicyclists in snowy environments.  
**Did research results confirm or change practice?**  
No one else is addressing this challenging problem.  
**Web Links**  
**Accomplishments**  
Many demos to visitors of NREC, UTC, industry, and academics. Presenting work at Ford’s Advanced Lighting Expo and will give presentation at the University Technology Showcase during the 3 Rivers Venture Fair.

**Monitoring and Predicting Pedestrian Behavior Using Traffic Cameras**  
Principal Investigator: Luis E. Navarro-Serment <lenscmu@ri.cmu.edu>  
**Research Outcomes**  
We anticipate the creation of a vision-based pedestrian detection, tracking, and prediction capable of running in real time, where the location of all pedestrians in or near the intersection is determined using calibrated monocular cameras. Additionally, we anticipate the creation of techniques to increase the robustness of vision-based detectors for different illumination conditions.  
**Expected Impacts**  
The approaches developed in this effort move us closer to provide traffic intersections with the ability to monitor pedestrian activity. Most traffic intersections currently lack awareness of pedestrian traffic: their perception abilities—when available—are usually limited to the detection of vehicles at very specific places. Video cameras can be used to monitor pedestrian traffic in a setting where a static camera that has an unobstructed view of the road is used to detect and track pedestrians. Typically, a single camera cannot cover the entire area, so multiple cameras are used at each intersection. However, simply detecting pedestrians is not enough: it is also necessary to accurately determine their location within the area surrounding the intersection. The work done in 2016 is key to determine locations using the monocular cameras used for traffic monitoring. We anticipate that our research will have an impact on adaptive traffic light control systems, which currently operate entirely based on information pertaining vehicular traffic. Our work will alleviate the need for timely and accurate information about pedestrian traffic. This is particularly important at locations where it is not uncommon to find more pedestrians than vehicles during certain times of the day.  
**Did research results confirm or change practice?**  
To support the calibration approach and the methodology for person location within the intersection, we designed and constructed a low-cost 3D scanner. This scanner, built around a low-cost 2D laser range finder, allows us to obtain three-dimensional models of traffic intersections quickly and accurately, but at a fraction of the cost of more expensive scanners commercially available. We plan to make our design (i.e. mechanical design and accompanying software) freely available to other researchers in the near future. This will facilitate the adoption of our camera calibration methodology by other agencies.
Accomplishments
We have developed a video processing pipeline to detect people from images, which is customized for operation with the type of cameras currently used to monitor vehicular traffic. We have also developed an approach to calibrate traffic cameras on-site, which is inexpensive in terms of time and logistics; does not require expensive instruments or software packages; uses a low cost custom-made laser scanner; and can be performed by personnel with minimal training.

Using these elements, we have created a software framework that allows us to further develop the algorithms for pedestrian detection and tracking.

Additionally, we have applied concepts from Inverse Reinforcement Learning to construct predictive models of how pedestrians traverse an environment in the presence of certain features. These models allow us to forecast the paths that pedestrians may follow near the intersection. Similarly, since the predictive models do not consider the influence of other pedestrians (this is a highly complex problem) we developed a heuristic approach based on the analysis of potential interactions in the direction of motion, which is capable of dealing with environments involving multiple pedestrians and runs in real time. These algorithms were implemented as a software program.

Transitioning Roadways to Accommodate Connected and Automated Vehicles: A Pennsylvania Case Study
Principal Investigator: Costa Samaras <csamaras@cmu.edu>

Research Outcomes
• Straightforward method to evaluate feasibility of testing lane on limited access highways
• Conference presentations
• Meetings with stakeholders
• Peer-reviewed research paper

Impacts
• Provide the Pennsylvania Turnpike Commission potential consideration of a test area for automated vehicles on the Pennsylvania Turnpike.
• Input to policymaker and regulator decision-making

Web Links http://ppms.cit.cmu.edu/projects/detail/23

Accomplishments
Our first Ph.D. student studying automated vehicles, Dr. Corey Harper, successfully defended his Ph.D. dissertation in August of 2017. He is a future leader in the transportation field and represents CMU’s commitment to developing excellent researchers who can conduct systems analysis for the transition to automated vehicles.

In addition, this project has generated over this period:
• 9 research presentations
• 2 meetings with policymakers & regulators
• 2 presentation to industry groups
• 1 research paper submitted for publication
• 1 Ph.D. dissertation
• 2 panel presentations to media
• 1 op-ed article
• Several media mentions

Speed Gun App – Increasing Awareness of Urban Speeding
Principal Investigator: Bernardo Pires <bpires@cmu.edu>

Research Outcomes
The primary anticipated research outcome is the development of new techniques for speed estimation from monocular video recorded using a hand-held device such as a smartphone. Preliminary techniques under development include license plate tracking on a video that has been stabilized using the information from
the device’s accelerometer and gyroscope as well as visual estimates of background motion. The speed estimation shall be confirmed by comparing with outputs from a traditional speed gun.

**Expected Impacts**
The main anticipated impact is the creation of a vision-based approximate speed measurement app and its deployment to a select group of users (including city officials).

**Did research results confirm or change practice?**
Current results seem to indicate that it is possible to estimate vehicle speed using the sensing capabilities of a regular cell phone. This has the potential to change practice in many situations where stakeholders need to obtain course estimations of vehicle speed (which are currently obtained via more expensive traditional speed gun devices).

**Web Links**

**Accomplishments**
In the short time since the project has started, the team has already developed a working app prototype, which the team expects to refine and deploy until the end of the project.

**Sensors Know When to, What to, and How to Interact With Human in Vehicles**
Principal Investigator: Anind Dey <anind@cs.cmu.edu>

**Research Outcomes**
- Presents an example system that helps drivers become aware of and understand their aggressive driving behaviors
- Presents a prototype machine learning (ML) and visual analytic system that leverages ML applications for sensor-based time-series data collected during naturalistic driving tasks
- Presents study results in a human-subject based field-driving experiment that incorporates sensor-based technologies to predict expected duration of drivers’ in-situ interruptibility during naturalistic driving contexts.

**Expected Impacts**
Leverage the development of a working prototype that incorporates sensor-based technologies to assess real-time cognitive load, driver interruptibility and driver experience
Expected to address the issues of ubiquitous HCI in cars and the intelligibility of system behavior in naturalistic field driving situations
Expected research outcomes to be scalable to other application domains where computational aids proactively support users’ in-situ decision-making in situations of high uncertainty that include a potential cost of additional perception or cognition.

**Did research results confirm or change practice?**
We expect that it will change practice. We have a system that can present to drivers in real-time what behavior they just performed that our system detected as being aggressive. Obviously, you would not want to interrupt the driver with such information. So, identifying when to show that information is critical, and still to be worked out (at the next stop, when the driver is interruptible; at the end of a trip; at the end of the day; etc.)
We have made progress on building our ML and visual system for using time-series driver-related data that should also change practice in how researchers understand and use such data.
We are still working on supporting a driving-aware system that contextually adjusts how and when the driver receives information. However, it is likely that this will now have to be done in the lab, and not in the field, with a combination of AR/VR-supported driving simulation equipment, given the reduced time schedule.

**Website Links** [http://ppms.cit.cmu.edu/projects/detail/24](http://ppms.cit.cmu.edu/projects/detail/24)

**Accomplishments**
- We have built up our infrastructure for performing car-based simulations
- it allows us to track similar sensor data as described in our proposal (wearable, and vehicle-mounted - steering wheel, seat, pedals)
- it allows us to collect eye tracking data from drivers
- we are ~33% complete in being able to deliver different kinds of interruptions/information to drivers. Several presentations have been given on how to leverage this time-series sensor data for driving, as part of a larger discussion of the value of such time-series-based behavioral data.

**Analyzing and Defending Cyberattacks on Electric, Hybrid, and AV Battery Systems**
Principal Investigator: Venkat Viswanathan <venkvis@cmu.edu>

**Research Outcomes**
1. Identification of the conditions when the Electric Vehicles are the most vulnerable to cyber attacks.
2. Taxonomy of the impact on EV battery packs due to cyber attacks involving auxiliary components.
3. Development of approaches to quantify the impact of cyber attacks.
4. Approaches to modeling cyber attacks and coupling these attack scenarios with robust battery pack models to capture the impact.
5. Understanding the large-scale implications of the cyber attacks in terms of the effect on long-term adoption plans for EVs and HEVs.
6. After the above-mentioned stipulations are accomplished, other segments of the EV infrastructure that can be compromised to cause damage to battery packs need to be explored.

**Impacts**
With our work, we pinpoint the conditions when EVs are likely to be attacked and what the subsequent impact would be, particularly on the battery pack. These results would also aid in shifting the current paradigm of automotive cybersecurity in the context of EVs, to raise attention on developing not only robust but also secure battery management systems.

**Did research results confirm or change practice?**
Results highlight the importance of focusing on automotive cybersecurity in the context of EVs. Current narratives rarely assess cybersecurity risks for EVs, these results will emphasize the need to do so. We identified the critical parameters like temperature, state-of-charge, size of the battery, etc., which can significantly change the impact of a cyber attack. Although the effect of each of the parameters was found to be different in the context of EV security, compared to the well-known effects of these parameters on battery degradation, one example of such a parameter is the ambient temperature. State-of-charge was seen to be one of the critical parameters with the parametric analysis conducted to assess attack scenarios. Similarly, several other parameters were identified for each kind of impact/ cyber attack we assess.

**Web Links** [http://ppms.cit.cmu.edu/projects/detail/9](http://ppms.cit.cmu.edu/projects/detail/9)

**Accomplishments**
We have compiled the first-leg of the studies in a manuscript where we establish the details of the short-term and long-term impact of cyber attacks. This manuscript will also state the future paths that need to be taken in terms of inclusion of the charging infrastructure, autonomous driving, etc., and how compromising such an infrastructure would also lead to similar or greater impact than the results we will recently report in our manuscript for cyber attacks involving auxiliary components.

**Infrastructure Monitoring for Gradual Damage Detection Form an In-service Light Rail Vehicle**
Principal Investigator: Jacobo Bielak <jbielak@cmu.edu>

**Research Outcomes**
We have developed a statistical algorithm for indirect structural health monitoring of railway bridges and other similar rail transit structures that is capable of detecting a gradual change of structural integrity. Our approach is able to extract reliable indicators of damage from acceleration signals recorded onboard a vehicle moving over the bridge. Beyond introducing this novel and breakthrough approach, we expect to contribute to the scientific literature in this domain by providing a physics-based explanation for the effectiveness of our statistical method, as well as by providing simulation and experimental observations to corroborate these findings and validate the performance of the algorithm.
For this first outcome, we expect to submit and publish our findings in a top academic journal (e.g., Mechanical Systems and Signal Processing), as well as through oral presentations at conferences and other professional gatherings.
We will then focus our attention towards larger-scale structures and testbeds including vehicular and train bridges in the city of Pittsburgh, to refine and test the applicability of our approach in realistic settings.

Expected Impacts
The key distinguishing aspect of our approach in contrast with other indirect monitoring approaches for bridges is that rather than pre-define the features we extract from the sensor acceleration signals, the features we use are automatically defined by the algorithm during the training process, and thus does make assumptions about the generalized applicability of any pre-defined feature to different structural/environmental settings. We anticipate that our approach will open a new research direction for advancing the practice of indirect structural health monitoring, and could finally allow for the implementation and use of these approaches in practice.

Did research results confirm or change practice?
Our results have the potential of radically changing the way railway bridges and other related rail transportation structures are inspected and monitored.

Web Links http://ppms.cit.cmu.edu/projects/detail/10

Accomplishments
1. Demonstrated state-of-the-art breakthrough results on unsupervised gradual damage detection and estimation algorithm for vehicle-based bridge and rail track damage diagnosis
2. Presented our work at PIANC this Fall
3. Engaged in discussions with Arup and Union Pacific for follow-on funding opportunities. In discussion to submit a proposal to other agencies such as FRA and TRB
4. Drafted a journal paper on unsupervised damage diagnosis, to be submitted Fall 2017
5. Drafted a journal paper on the light rail train response data collected from the indirect monitoring system we developed through the collaboration with the Port Authority of Allegheny County
6. The project has been introduced and utilized for a graduate level project course on sensing and data mining for smart structures and systems. This project provided hands-on experience to the students and helped with engaging/inspiring them in transportation safety-related projects.
7. The work is presented through multiple invited seminars at Stanford, CalTech, Princeton, Georgia Tech, etc. to promote collaboration and expansion of the work.

The remaining challenges to be addressed in the following project period include
1. expanding and validating our approach to be robust to various levels and types of noise. For this purpose, we plan to utilize both numerical simulations and laboratory experiments
2. testing the sensitivity of our approach to the intensity and type of damage.
3. large-scale evaluation with the field data collected from the Pittsburgh light rail system that we already installed through previous years funding.

Low-distraction Intersection
Principal Investigator: John Shen <john.shen@sv.cmu.edu>

Research Outcomes
We Intend to show that environment and driver-aware interactive systems reducing cognitive load compared to state-of-the art Human-Machine-Interaction as performed in devices in vehicles today. Although any interaction in the vehicle will increase the cognitive load of the driver, our belief is that by supporting Human-like interaction in a dynamic and situational manner we can reduce distractions to a minimal amount.

Expected Impacts
We believe this research will help guide vehicle manufacturers, infotainment developers and Human-Machine-Interaction designers to develop safer voice-based interactive systems in vehicles.

Did research results confirm or change practice?
At the preliminary stage the research has yet to change practice. However initial results have demonstrated that the research direction has the potential for developing safer voice-based interactive systems in vehicles.

Web Links http://ppms.cit.cmu.edu/projects/detail/15
Accomplishments
We have analyzed and validated that Human-To-Human interaction in vehicles is dramatically different from current in-vehicle platforms that support Human-Machine-Interaction. By analyzing the timing, type and stages of interaction between a driver and a human co-pilot for three tasks (navigation, scheduling, search). Our analysis shows interesting trends relating physical situation to dialog behavior, specific examples include minimizing interaction at intersections or in busy driving conditions, adapting the speed and complexity of the interaction based on the quality of driving (or perceived performance of the driver), and supporting of situated interaction, especially during clarification. During navigation tasks drivers often clarified directions on-the-fly with under-specified clarifications questions which no currently deployed infotainment or navigation system supports.

EDUCATION AND WORKFORCE
Objectives: To educate a diverse and cross-disciplinary workforce in research, policies, and practices to improve real world safety deployments through a robust, sector-crossing efforts where our research is transferred.

Accomplishments:
• Welcomed our incoming fall 2017 Women in Transportation Fellow, Sarah Cho, and our first Diversity in Transportation Fellowship to Allante Whitmore an incoming fall 2017 CMU College of Engineering student. These two fellows will work closely with Mobility21 staff, be involved in technology transfer, collaboration, education and workforce programs and gain exposure to our national network.
• TSET hosted faculty seminars. These seminars reach our UTC campus communities, government and community partners as well as the public at large though live-streaming, recording and being added to our Learning Channel:
  ▪ Connected and Automated Vehicles in PA, Demonstrations and Public Policy Challenges, Chris Hendrickson, 9/29/17.
• Participated on the Advisory Group of CMU Air Quality Emission Capstone Class and held the final presentation on 5/2/17.

Impacts:
• Spoke on a Technology and Ethics panel to at the Pittsburgh Young Professional’s Technology and Ethics, to educate the audience about the importance of equity in transportation to young tech industry audience on 8/22/17.
• Presented at the PA Bar Association a Connected/Automated Vehicle Course to legal professionals, exposing them to the policies that are expected to impact their industry on 6/27/17.
• Presented at the Western PA Bar Association about the impacts of a connected/automated vehicle future to the legal industry on 6/16/17.
• Presented to a continuing education class at Carnegie Mellon University on 5/30/17. The class was mostly retired people concerned with how CAVs would affect their access to individual transportation.
• Hosted students from Chatham’s University Sustainable Course on a tour of CMU technology labs to increase their understanding of automated vehicle research and its potential environmental impact.
• Student graduate capstone course conducted a study US General Services Administration and presented it in Washington DC on 5/5/17 highlighting impacts on vehicle automation on the future federal workforce.
• Hosted National Association of County Officials for a CMU Technology Lab tour on 5/4/17 to educate these local officials about emerging transportation safety technology.
• Presented to National Robotics Engineering Center on 4/19/17, informing roboticists about their potential research and careers in transportation.
Presented a PDH-certified lecture to the Butler Chapter of the PA Society of Professional Engineers on 4/18/17, over 45 professional engineers received credit from the lecture which focused on the connected and automated future and impacts on safety.

TECHNOLOGY TRANSFER

Objectives: To educate a diverse and cross-disciplinary workforce in research, policies, and practices to improve real world mobility deployments through a robust, sector-crossing efforts where our research is transferred.

Accomplishments:

• Participated in the Greater Pittsburgh Chamber of Commerce legislative reception with stakeholders and regional policy makers to help strengthen relationships with region’s business community and elected officials on 5/8/17.

Impacts:

• TSET UTC Director Raj Rajkumar keynoted the Future Vehicles World Conference on 5/4/17 in Australia speaking to a global audience of executives advising on how to adapt business models to respond to the rapidly evolving transportation industry transformation.

• Provided technical and policy guidance to industry, DOT and congressional staff in BMW Group Roundtable discussion in Washington DC to transfer technology on mobility and safety implications of autonomous vehicles on 5/9/17.

• Faculty Costa Samaras presented to the ITS Berkeley professional industry chapter on Bending the Energy, Environmental, and Safety Curves through Transportation Automation and Electrification on 5/17/17.

• Presented to the Pennsylvania House Transportation Committee members on TSET research and impacts when they visited CMU on 5/18/17.

• Faculty Scott Matthews presented two discussions at the Inspection and Maintenance 2017 Conference on Data Driven Analyses of Safety Inspections and Data Driven Analyses of Emissions Inspections to a professional audience on 5/23/17.

• Consulted to the US Senate Committee on Commerce, Science, and Transportation Subcommittee on Consumer Protection, Product Safety, Insurance, and Data Security staff about the implications of vehicle automation on 5/24/17.

• TSET UTC’s Raj Rajkumar spoke about his automated vehicle research as a panelist to the American Association of State Highway and Transportation Officials’ (AASHTO) Subcommittee on Traffic Engineering at the annual meeting in Pittsburgh. The panel discussion on connected and autonomous vehicles included representatives from Uber and Delphi, among others on 6/26/17.

• Faculty Costa Samaras presented his research at the Society of Collision Repair Specialists Meeting on the Impact of Automation on Collision Industry on July 1, 2017.

• The 2017 Northeast Association of State Transportation Officials (NASTO) Conference was held in Philadelphia on July 10th-12th, and featured a plenary session on Automated Vehicles with TSET UTC Director Raj Rajkumar presenting his research.

• Faculty Costa Samaras was an on-stage discussant for 45-minute panel for Pittsburgh Post-Gazette Live Energy Forum Panel, “The Future of Transportation”, 7/10/17 presenting his findings. [http://promo.postgazette.com/energy2017](http://promo.postgazette.com/energy2017)

• Faculty Costa Samaras presented Transportation Automation and Implications for Municipal Decision-making to Washington D.C. City Department of Economic Development’s Autonomous Vehicle Working Group about his research on 7/27/17.

• Faculty John Peha keynoted the Pennsylvania State Association of Boroughs Conference on 8/10/17 speaking to a professional audience of borough managers about his research in Wireless Communication and Municipal Governments – Looking Forward.
• Faculty Costa Samaras presented his research to Hon. Leslie Richards, Secretary of Transportation for Pennsylvania on Transitioning to Autonomous Vehicles: Implications for PennDOT on 9/13/17.

• Faculty Scott Matthews gave the Keynote Talk to Association of Automotive Service Professionals (AASP) on his research – Data Flows to Support Inspection Programs in Pennsylvania on 9/23/17 to a professional audience.

1C Dissemination of Results
• Distributed the Smart Transportation Dispatch, a weekly newsletter that highlights TSET research and efforts in the news as well as industry news. With over 1,800 subscribers, the readership represents a wide range of interests.
• Promoted various TSET research news articles in the blog and newsletter
• All TSET sponsored seminars are on the website for the general public to access.
• TSET efforts and researchers are frequently mentioned in the news. Below is a short list of pertinent articles.
   April 12, 2017 - Harrisburg Street Lights to Get Smarter, Collect Data on Anything from Traffic to Trash
   April 27, 2017 - CMU: The Birthplace of Driverless Tech
   May 10, 2017 - The Link Between Autonomous Vehicles and Fuel Efficiency Efforts
   May 17, 2017 – RoadBotics Takes Aim at Roadway Maintenance
   June 26, 2017 - PennDesign's Erick Guerra Seeks to Improve Transportation Safety, Efficiency and Access
   July 24, 2017 - Bikes May Have To Talk To Self-Driving Cars For Safety's Sake
   August 9, 2017 - These Headlights Can Assist Drivers See through Snow, Rain
   August 28, 2017 - Smart Signals are Part of a $30 Million Plan to Beat Traffic Jams in Pittsburgh
   September 6, 2017 – PBS Newshour: How Pittsburgh is Test Driving Tech to Make your Commute Smarter
   September 14, 2017 - Education is what will keep us moving

1D Planned Accomplishments under Goals for the Next Reporting Period
• Our fall seminar series will kick off in September.
• We are working with faculty to ensure that they are focusing on the impacts of their research and preparing final reports for the close-out of the grant.
• We continue to promote TSET work through seminars, partner development, education, workforce development initiatives, however we will begin doing this in tandem with our new National UTC, Mobility21, a USDOT University Transportation Center for the Mobility of People and Goods.

2. PRODUCTS:

Publications, conference papers, and academic presentations

Throughput and Cost-Effectiveness of Vehicular Mesh Networks for Internet Access, Jon Peha, IEEE Vehicular Technology Conference, June 5, 2017


Structures as Sensors: Indirect Monitoring of Humans and Surrounding, Jacobo Bielak, Academic Seminar, April 22, 2017


Smartphone based monitoring of river infrastructure, Christoph Mertz, Smart Rivers Conference on Sept. 18, 2017.

Road Infrastructure Assessment with Smartphones in Vehicles, Christoph Mertz, 11th University Transportation Center (UTC) Spotlight Conference: Rebuilding and Retrofitting the Transportation Infrastructure on Sept 26, 2017.


Website(s) or other Internet site(s)
http://www.utc.ices.cmu.edu/utc/, http://ppms.cit.cmu.edu/

3. PARTICIPANTS & COLLABORATING ORGANIZATIONS: Who has been involved?

What organizations have been involved as partners?
Collaborative Research partners are integral to testing and deploying our research in the real world. Below is a list collaborative research partners working directly with TSET researchers on their projects.

- City of Philadelphia
- City of Pittsburgh
- City of Pittsburgh, Department of Mobility and Infrastructure
- City of Pittsburgh, Mayor’s Office
- Compuspections, LLC
- Delaware Valley Regional Planning Commission
- Ford
- GM
- Honda
• Port Authority of Allegheny County
• Renault
• Toyota
• Uber ATC
• Volkswagen

4. IMPACTS
In this report Section 4 - Impacts has been combined with Section 1 - Accomplishments to clearly demonstrate transition from accomplishments to impacts under research, education/workforce development and technology transfer. Please see pages 2-17 of this report for Impacts.

5. CHANGES/PROBLEMS
Nothing to report

Additional information regarding Products and Impacts
Nothing to report

6. SPECIAL REPORTING REQUIREMENTS
Nothing to report