A U.S. DOT UNIVERSITY TRANSPORTATION CENTER

Carnegie Mellon University

University of Pennsylvania

Program Progress Performance Report for University Transportation Centers

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Major Goals and Objectives of the Program

1) Research, Development and Deployment by the T-SET UTC

The CMU-Penn T-SET UTC focuses on research, development and ultimately deployment of technologies for safe and efficient transportation. The thrusts of the T-SET UTC are structured along 5 core areas: In-Vehicle Technologies, Infrastructure Technologies, Human-Vehicle Interactions, Mobility/Data Analytics and Policy. Each of the 16 research projects has identified Year 1 and Year 2 desired outcomes and metrics.

Metrics:

Number of publications and citations of faculty work in transportation-related areas
Number of new hires, new research initiatives, and special projects that build on intellectual leadership in fields related to the mission of the UTC.
Research collaborations in related fields
Quantified impact of technology deployments and transfers

2) Education and Workforce Development

Education and workforce development are important complements of the T-SET research program.

Metrics:

Number of institutional educational partnerships
Number of participants in workforce and educational programs
Number of related degrees awarded at our institutions
Number of new educational programs established
Number of job placements through workforce development programs

3) Technology Transfer

The CMU-Penn UTC will fully use the resources and 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:

Number of conferences and formal discussions focused on end users of ITS
Number of patent applications filed
Number of startups created
Number of technology licenses issued

4) Collaboration

Collaboration is the heart of the entire T-SET program. Carnegie Mellon and the University of Pennsylvania seek to ensure our research and development program leads to deployment of technologies in the transportation systems serving our communities and state, providing pilots 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 the T-SET Consortium
Number and impact of deployments achieved through collaboration

5) Diversity

T-SET projects will focus on transportation users in both rural and center cities, on suburban commuters and on residents of small communities with limited transportation options.

Metrics:

Participation by students and faculty of color and women in UTC research projects
Projects focused on rural, city, and suburban residents
Number of projects targeted at aging populations and persons with disabilities

Accomplishments Under Major Goals

Research, Development and Deployment

See **Appendix A** for specific research project accomplishments

Below is a listing of outreach efforts T-SET staff and management personnel have engaged in over the past six months in support of advancing Research Development and Deployment projects (outlined in Appendix A):

- ITS America Leadership Circle Conference
- ITS America DC Fly-in Technology Showcase
- Attended DOT Connected Vehicle Pilot Program Public Meeting in DC
- Attended New Cities Foundation Urban Mobility Conference, Mountain View, California
- Hosted Fuel Freedom Foundation Natural Gas to Liquid Fuels project kick off
- Meeting at the U.S. Conference of Mayors
- Meeting at the National League of Cities
- Attended TRB Executive Committee Meeting
- Attended NRC Committee on Assessment of Federal Railroad Administration Research
- Ongoing meetings with Barry Schoch, Secretary of PennDOT, for Vision 2040 Autonomous Vehicle Research
- Met with Beth's Barricades to discuss Mobility Analytics Center
- Met with Lyft to discuss research partnership possibilities
- Met with Ellen McLean New Executive Director of the Port Authority of Allegheny County to discuss Mobility Analytics Center
- Met with Lenore Williams of the Baum Center Corridor Coalition to discuss Surtrac expansion
- Met with Janet Scullion of Bloomfield Citizen Council to discuss Surtrac expansion
- Visit the CATT Lab at the University of Maryland to discuss the Mobility Analytics Center
- Met with Allegheny County Deputy Manager Barbara Parees to discuss Road Surface Monitoring
- Met with Jeff Adler from Open Roads Consulting to discuss Mobility Analytics Center
- Presented to Monique Evans at Turner Fairbank Research Center
- Takata visit to campus to discuss connected vehicles
- Met with City of Pittsburgh Chief Innovation Officer Debra Lam
- Met with Red Light Enforcement Camera Company
- Participated in CMU Smart Infrastructure Incubator Symposium
- TrafficVision visit to CMU to discuss Mobility Analytics Center
- Met with Mayor of Pittsburgh's Chief of Staff Kevin Acklin to discuss SURTRAC
- Met with Chuck DiPietro from the Southwestern Pennsylvania Commission to discuss Mobility Analytics Center

Education and Workforce Development

Gave presentation on the keys to effective implementation of transport R&D results at a EU-US symposium in Paris and participated in deliberations and recommendations of 50-member group of researchers and practitioners.

Participated as a member of a panel advising on a training program for Michigan DOT engineers. The program is broad-based and includes ITS components, freight logistics and multi-modal integration. Some of the T-SET UTC research helps provide input for the training components.

We held three seminars as part of our Faculty Seminar Series that presents research to the CMU student body. These seminars are webcast and made available to Consortium members and the general public, if they are interested.

Below is a listing of the additional efforts that T-SET has been engaged in over the past six months:

- Interviewed on “Our Region's Business”– a Sunday morning business affairs television program
- Selected First Women in Transportation Fellow
- Guest lecture on T-SET at Carlow College: Intro to Public Policy
- Guest lecture on T-SET at CMU: Civil and Environmental Engineering class, Introduction to Transportation Engineering
- Hosted two meetings of the newly established Student Transportation Club
- Participated as a member of a business roundtable to offer ideas and guidance for making the Community College of Westmoreland County business program relevant to current needs.
- Gave a presentation to an international group of 50 Bosch managers who were having an educational workshop at CMU.
- Participated in a monthly research sharing and program coordination meeting with the faculty researchers involved in the T-SET UTC.
- CMU hosted Pittsburgh City Councilwoman Natalia Rudiak’s Open Data Seminar that supports CMU’s Mobility Analytics Center
- Participated as a member of an Advisory Board providing guidance to students in a Masters Systems Synthesis class addressing transportation impacts of a major new development.
- Attended the Washington DC annual meetings of the Transportation Research Board and the Council of University Transportation Centers (CUTC). CMU PhD student George Lederman received one of the CUTC Student Awards, which was presented by RITA Administrator Gregory Winfree.
- Met with Dr. Curtiss Porter, City of Pittsburgh Chief Education Officer, to discuss City Year
- Met with Kate DiSimone, City of Pittsburgh Law Department to discuss a data sharing agreement
- Presented to Pennsylvania Highway Information Association, televised on PCN
- Attended the Pennsylvania Governor's School for the Sciences Opening Ceremony
- Gave T-SET briefing to visitors from Grenoble France
- Meeting with Egils Milbergs from the Center for Accelerating Innovation

Technology Transfer

Participated in two-day event in Washington, DC to give members of Congress rides in CMU's autonomous vehicle. The event included a press conference hosted by T&I Chairman Bill Shuster and included remarks by USDOT Undersecretary Peter Rogoff (designate) and NSF Deputy Executive Director Cora Marret.

Participated in a press conference with Pittsburgh Mayor Peduto and Council Members Gillman and Gross to announce the expansion of the Surtrac adaptive signal test beds from 24 intersections to 49 intersections. When operational toward the end of 2014 or early 2015, CMU will have a large test bed that also includes connected vehicle communication components.

Below is a listing of the many technology transfer efforts that T-SET has been engaged in over the past six months:

- Met with Pitt Ohio trucking company CEO Chuck Hammel III to understand the current state of the art of trucking communication data systems as well as continuing challenges that might be opportunities for PennDOT to consider as part of CMU's commissioned project to prepare PennDOT for a connected/automated vehicle future.
- Led a meeting with Turnpike Executive Director Mark Compton and his Chief Engineer to describe CMU's research capabilities and potential research projects of interest to the Pennsylvania Turnpike. A meeting followed this with the traffic engineering staff at the Turnpike to discuss research details.
- Attended PennDOT SHRP2 Capability Self Assessment Workshop
- Pittsburgh/Philadelphia Chambers of Commerce Joint Legislative Reception in Harrisburg
- ITSA Annual Reception in DC
- Presented at the Pennsylvania Safety Symposium in Harrisburg
- Participated in the Mayor's Transportation Sustainability Committee
- Attended Chamber meeting with PA House Majority Leader Mike Turzai
- Attended Chamber Meeting with Mayor's Chief of Staff Kevin Acklin

- Presented T-SET research at the Annual Meeting of the Pennsylvania Highway Information Association in Harrisburg. This was also filmed on PCN TV.

Collaboration

Participated in a one-day meeting in Ann Arbor, MI of researchers from CMU and the University of Michigan Transportation Institute to explore research collaboration opportunities in the fields of autonomous vehicle policy, cyber security, and connected corridors.

Participated in the ITS America Leadership Circle meeting in Phoenix, AZ. This group of academic, non-profit and industry representatives serves as a think tank generating topics to advance implementation of transportation technology. Strategies were developed to accelerate utility and use of ITS technology

Hosted a meeting with USDOT and TRB Committee representatives to plan for a Fall 2014 Safety Conference that CMU will host.

Held T-SET Consortium Meeting in Philadelphia at the University of Pennsylvania

Below is a listing of the additional collaboration efforts that T-SET has been engaged in over the past six months:

- Participated on panel offering ideas to the Urban Land Institute on improved use of technology for Port Authority of Allegheny County. ULI was hired by PAAC to recommend strategic ways to enhance their transit service and operations.
- Participated in the University of Pittsburgh Institute of Politics Infrastructure Committee
- Participated in a workshop with faculty and researchers of Heinz College, the College of Engineering and representatives of other universities and cities to explore a new initiative involving broad urban systems research -- a subset of which would be transportation.
- Met with Jim Sloss, City of Pittsburgh to discuss LED street light project
- Participated in the CMU Urban Systems Symposium
- Met with Southwestern Pennsylvania Commission Regional Operations Planning Committee to discuss SURTRAC
- Met with East Liberty Development Inc to discuss Dynamic Pricing for Parking
- Participated in the Pittsburgh Chamber Benchmarking Trip to Denver with focus on transportation.
- Summer Meetings of UTC and CUTC in Lincoln
- ASCE Sustainable Infrastructure Conference Steering Committee
- Led a meeting with PennDOT Barry Schoch and a group of Penn DOT managers to discuss ideas for future research projects
- Attended TRB Special Projects Committee Meeting
- Met with Parsons Brinkerhoff to discuss consortium opportunities
- Met with Penn State Pittsburgh Office
- City of Pittsburgh Sustainability Director Grant Ervin to discuss developing a model similar to University of Oregon's Sustainable Cities Initiative.
- Met with Dave Roger President of the Hillman Foundation
- Presented at CUTC conference in Lincoln

Diversity

T-SET supported a team of high school girls from the WTS Philadelphia chapter to the WTS Transportation YOU Summit in DC

Below is a listing of the additional efforts that T-SET has been engaged in over the past six months:

- Attended Womens Transportation Seminar Annual Conference
- Met with Girls of Steel at CMU to discuss working with their high school girl members on transportation related projects
- Hired an intern to fast track the formation of the Women's Transportation Seminar Pittsburgh Chapter

Plans for Next Reporting Period
T-SET will host a National Safety Workshop inviting other Safety UTCs and from DOT.
T-SET will expand SURTRAC adaptive traffic signal deployment from 13 intersections to 49 intersections.
T-SET will attend ITS World Congress.
T-SET will host a Consortium Meeting in Pittsburgh at CMU.

2. PRODUCTS

See **Appendix A** for specific research project products including publications, technologies, and inventions.

General Program Products

- **Weekly distribution of T-SET newsletter with 992 subscribers and an above industry average open rate**
- **Presence on social media, 332 followers on Twitter**

T-SET in the Media
Efforts have been made to promote T-SET UTC activities through the media. Below are some examples of T-SET media exposure from January – July 2013. Click on hyperlink to view articles
Articles:

'Performance parking' can lower average parking rates while raising more money for Pittsburgh Pittsburgh Post-Gazette

Capitol Hill gets a front-seat look at driverless car, new push for roads The Washington Times

Shuster praises driverless car after second ride, in D.C. Public Opinion

Driverless Car: Congress Gets Taken for a Ride and Loves It Newsmax

Demonstrating a driverless future: Promise of driverless cars Science Daily

Members of Congress Channel Their Inner George Jetson on Unique Ride ABC NEWS

City extends smart traffic technology in the East End Pittsburgh Business Times

Pothole complaints top 6,100 in Pittsburgh Mayor hopes to direct more money into infrastructure improvement Pittsburgh Post-Gazette

City expands use of high-tech traffic signals, Officials, CMU students team up again to reduce red-light wait times Pittsburgh Post-Gazette

City extends smart traffic technology in the East End Pittsburgh Business Times

More 'smart' intersections coming to Pittsburgh

CMU technology helping to ease traffic congestion WTAE

4 Innovation Trends That Could Change The Way We Design Roads By 2020 Forbes

Variable Meter Parking Rates Coming To Pittsburgh CBS Pittsburgh

Participants and Other Collaborating Organizations
In February, T-SET hosted it's Consortium meeting at the University of Pennsylvania. The Consortium continues to grow and has over 45 members.

Appendix A –

THRUST AREA #1: IN-VEHICLE SAFETY TECHNOLOGIES

Smart Headlights Lead, Srinivasa G. Narasimhan

Other Collaborators: Takeo Kanade (Robotics, CMU) Anthony Rowe (ECE, CMU) Mei Chen (Intel) Eriko Nurvitadhi (Intel)
University: CMU
Other publications, conference papers and presentations: *Programmable Automotive Headlights* Robert Tamburo, Eriko Nurvitadhi, Abhishek Chugh, Mei Chen, Anthony Rowe, Takeo Kanade and Srinivasa G. Narasimhan Accepted to appear, European Conference of Computer Vision (ECCV), 2014.
DMDs for Smart Headlights (invited talk and paper), Robert Tamburo, Srinivasa G. Narasimhan, Anthony Rowe, Takeo Kanade, Eriko Nurvitadhi, Mei Chen, Emerging Digital Micromirror Device Based Systems and Applications VI, SPIE 2014.
Other Dissemination Activities: Programmable Automotive Headlights Robert Tamburo, Eriko Nurvitadhi, Abhishek Chugh, Mei Chen, Anthony Rowe, Takeo Kanade and Srinivasa G. Narasimhan
Accepted to appear, European Conference of Computer Vision (ECCV), 2014.
DMDs for Smart Headlights (invited talk and paper), Robert Tamburo, Srinivasa G. Narasimhan, Anthony Rowe, Takeo Kanade, Eriko Nurvitadhi, Mei Chen, Emerging Digital Micromirror Device Based Systems and Applications VI, SPIE 2014.
Website:http://www.cs.cmu.edu/~ILIM/projects/IL/smartHeadlight/](http://www.cs.cmu.edu/%7EILIM/projects/IL/smartHeadlight/)
Other Products Associated: Instruments or equipment, We built a prototype headlight with off-the-shelf components that consist of a camera, a digital projector and simple beam splitter optics. This prototype is controlled using a computer.
Impact: The PI proposes a significant departure from current headlight technology to improve safety of driving. With a single design, the proposed headlights allow high-beam use without glaring anyone on the road, highlight lanes when there are no markings visible, highlight obstacles such as pedestrians or deer as well as traffic signs, and improve visibility on the road in harsh weather conditions due to snow, fog, rain, etc. This design is hoped to enhance safety when driving at night by reducing driver stress and fatigue leading to significantly reduced accidents on the road.
Impact in Other Disciplines: The idea of creating a reactive illumination system using a camera and a light source is novel even in the fields of computer vision and displays. Applications such as low cost high speed imaging with efficient lighting, intelligent and programmable stage/theater lighting, are a few of the possibilities enabled by the same research.

Automatic Understanding of the Driving Environment Lead, Martial Hebert
University: CMU
Website: http://www.andrew.cmu.edu/user/luisn/arudedf.htm
Technology / Techniques: We are in the process of developing a proof-of-concept system of a driver assistant using an embedded computer, which uses information from street maps and images collected from a vehicle to understand the environment and to assess potential risks.
Impact: We expect that our work will potentially impact road safety by effectively incorporating technologies currently found on experimental autonomous vehicles only to ordinary cars and trucks, which are still operated by humans. This is a difficult problem, since the typical sensors used in autonomous vehicles cost several thousand dollars. Our system compensates the lack of expensive sensors by using information from external sources.
Impact in Other Disciplines: Our methods for incorporating information from external sources can potentially be used to improve the accuracy of algorithms for pattern recognition and scene interpretation.

Automated Object Detection with Rear Camera Lead, Prof V. Bhagavatula
University: CMU
Other Collaborators: General Motors
Progress: Percent Complete: 0 We are still waiting for a new post-doc (hired for this project) to join CMU. His visa is expected to be approved by mid July and he will join by end of July. Project progress will start at that time.
Website: http://users.ece.cmu.edu/~kumar/
Impact: Automatic detection of objects in the reverse camera views will provide alerts to the drivers reversing their vehicles, potentially reducing the probably of backover accidents.
Impact in Other Disciplines: Object detection technologies to be developed as part of this project may prove to be of broader applicability in the computer vision research field.

Bus-Turn Detection and Pedestrian Warning System Leads, CJ Taylor and Daniel Lee
University: UPenn
Participant Organizations: Southeastern Pennsylvania Transit Authority **(**SEPTA) SEPTA has been an occasional collaborator throughout the duration of our project, and has assisted us on the following fronts:
1) To better understand the needs and priorities of transit authorities in the United States;
2) To provide practical feedback and expertise throughout the system design process in order to ensure that test systems in the lab are feasible in a real-world setting;

3) To offer specific insight into features and capabilities of our system that would be desirable to all stakeholders in transit agencies, including bus operators, pedestrians, and members of the agency itself.
Future collaboration with SEPTA is forthcoming as development progress continues, and will proceed on the front of real-world testing and pilot implementation of our system prototypes onto SEPTA's fleet of buses conservatively within the next 3 years.
Other Collaborators: Alex Burka (an ESE PhD student under Daniel Lee) and summer interns Marcus Pan and Justin Aird. Away from the project for a summer internship is Alaric Qin, an undergraduate ESE student. Previous students that have worked on various aspects of the project include Yida Zhang, Rahul Bhan, Nikhil Karnik, Jordan Parker, Vaibhav Wardhen (ESE), and Thomas Boutin (CIS).
Other Dissemination Activities: Presented a poster at the UTC Consortium meeting at the University of Pennsylvania Singh Center, 2/11/14.
Presented a poster and demonstration at the ITS America meeting at the Cannon House office building in Washington, DC on 6/25/14.
Website: http://alexburka.com/penn/septaudio.php
Technologies / Techniques: Major technologies that we have applied in this research include real time position tracking using GPS, IMU (inertial measurement unit) and a Kalman Filter; accurate obstacle detection and ranging using a laser rangefinder, and especially directional audio, using an array of small ultrasonic emitters to broadcast audible sound within a narrow, steerable cone.
Impact: This is primarily a systems integration project. We are applying a combination existing technologies in novel ways to solve a real-world problem. Therefore, the biggest impacts may be considered to be outside the field of electrical engineering, so please see the next section.
Impact in Other Disciplines: Since the motivation for our research is the extensive number of bus and pedestrian collisions that occur in urban areas, the primary impact of our research is to minimize such occurrences, thereby saving lives and the costly consequences of litigation and claims.
While there are a fairly large number of systems that are designed to prevent bus-pedestrian collisions at intersections, ours has two primary innovations that, to the best of our knowledge, have not been previously incorporated into such systems. Our system is an (1) externally mounted, cost-effective, low-maintenance device that (2) uses a proprietary ultrasonic parametric speaker to direct sound only to where it is needed, thereby reducing irritating noise pollution to nearby areas.
With respect to (1), our research has indicated that currently extant systems are costly and require disassembly of the bus for successful installation. Our system reduces installation complexity because it can be installed entirely on a bus exterior, resulting in cost and maintenance savings. An additional goal relevant to (1) is to minimize the internal complexity of the system by using inexpensive, off-the-shelf components in combination with advanced algorithms to reduce the overall cost of the system.
Innovation (2), importantly, allows for an audible warning to reach only the ears of an otherwise inattentive pedestrian or bus driver, while minimizing the amount of sound that goes into the neighborhood. Previous bus-pedestrian warning systems, while effective, have seen a strong public backlash due to the frequency and amount of noise emitted from such systems during a transit system's normal operation. Our innovation on this front allows us to avoid such problems, allowing for greater safety while minimizing noise and public disturbance.
In conclusion, the impact of our research is the creation and eventual availability of a low-cost, low-noise bus-pedestrian safety system that is inexpensive enough to be within the reach of every transit agency in the United States.

In-Situ Monitoring of Driver Workload Lead, SuengJun Kim
University: CMU
Participant Organizations: General Motors, UNIST, Interactions Lab, South Korea (director: Prof. Ian Oakley) will provide an in-kind support – developing a sensing steering wheel (currently, in the prototyping stage)
Other Collaborators: Prof. Anind K. Dey and Dr. Jaemin Chun (CMU, HCII, UbiComp Lab) Prof. Aaron Steinfeld (CMU, RI) Prof. Ian Oakley (UNIST, Interactions Lab, South Korea) Prof. Vincent Aleven (CMU, HCII, LearnLab)
Journal Publications: (peer-reviewed article) SeungJun Kim, Vincent Aleven, and Anind K. Dey "Understanding Expert-Novice Differences in Geometry Problem-Solving Tasks: A Sensor-based Approach," in CHI '14 Extended Abstracts on Human Factors in Computing Systems (Toronto, Canada, April 26 – May 1, 2014). CHI EA '14\. ACM, New York, NY. Note: GM matching fund of our project has supported this publication. The study topic and application domain are not directly related to our UTC project; however, the study includes the core sensor technology that has been employed in our project (= sensor-based assessment of a user's workload state in a near time).
Other publications, conference papers and presentations: Poster session in ACM CHI '14 Extended Abstracts on Human Factors in Computing Systems (Toronto, Canada, April 26 – May 1, 2014).
Other Dissemination Activities: Internally invited talks for industry visitors 1) CBD Brilliant (Jan 28, 2014) – Topic: "Cognitive Load Assessment in Human-Vehicle Interaction Projects" 2). LG Electronics and National Rehabilitation Center (Jan 24 - 25, 2014): Topic 1: "Quality of Life and HCI (Interaction Techniques for Elder Drivers", Topic 2 – "Human-Vehicle Interaction Projects in Quality of Life Technology Center"

Website: http://utc.ices.cmu.edu/utc/projectitem.asp?ID=92
Technologies / Techniques: 1) Data processing technology - helping feature extraction from sensor data streams collected in field driving (e.g., motion data of a driver's body elements, a driver's psycho-physiological responses, on-board-diagnostics car state data, etc.).
2). Video-based semi-automated annotation technique (w.r.t. a driver's in-car peripheral interaction activities).
Note: The data collected in this project have been used in another project that explores the development of a 'Usable Machine Learning Tool' (See a screenshot below – Gimlets, a prototype usable machine learning tool, provides a user-interactive visualization for driver/traffic videos, experiment session time information, time-stamped annotation data for a driver's in-car activities, and time-series sensor data for the driver's hands, foot, head motions, and psycho-physiological responses).
Other Products Associated: Audio / Video; Databases; Data & Research Material; Physical Collections; Software / Netware
Impact: • Presents a sensor-based experience sampling method (ESM) that helps us detect and track higher-rate variations in driver and driving states in an objective way (compared to conventional questionnaire-based ESMs).
• Presents a database that contains real-time driver motion (i.e., hands, head, and foot) and psycho-physiological responses (i.e., heart rate, breathing rate, ECG, etc.), as well as video records and OBD data, during naturalistic driving (See a figure below).
Impact in Other Disciplines: • Has an impact in ubiquitous computing domain, especially on 'interruption' research.
Our project explores a compatible solution aiming to identify appropriate interruption timings that a driver is available to safely split his/her visual attention and manage cognitive demand in a mobile context. Most of interruption research has explored screen-based tasks mediated with desktop computers and/or mobile devices; therefore, it's hard to replicate findings and approaches in those studies for more attention-risky situations where users must not to fully take off their engagement in the primary task while attending a dual-task demand that is intervened in an interruptive way (e.g., attending a navigation display while driving a car).

Detecting Driver Distraction Lead, Dr. Maxine Eskenazi and Prof Black
University: CMU
Participant Organizations: Yahoo InMind
Other Collaborators: Alan Black
Progress: So far we have investigated 10 different driving simulators and have just made our choice and set up most of the course that the subjects will drive. We are now working on the Wizard of Oz (WoZ) setup.
Website: http://www.utc.ices.cmu.edu/utc/projectitem.asp?ID=97

Smartphone-based Weather & Infrastructure Monitoring Lead, Christopher Mertz
University: CMU
Other Collaborators: University of Karlsruhe (Germany) and The University of Alcalá (Spain), developing joint proposal to EU and US to use the road monitoring techniques and ideas on a much larger scale for general infrastructure inventory and monitoring. PennDOT is funding a project with us to use the road monitoring techniques to detect snow cover on roads to determine road conditions live from snowplows.
Other publications, conference papers and presentations: Srivatsan Varadharajan, Sobhagya Jose, Karan Sharma, Lars Wander, and Christoph Mertz, "Vision for Road Inspection," Proceedings of WACV 2014: IEEE Winter Conference on Applications of Computer Vision, , March, 2014
Christoph Mertz, Srivatsan Varadharajan, Sobhagya Jose, Karan Sharma, Lars Wander, and Jina Wang, "CITY-WIDE ROAD DISTRESS MONITORING WITH SMARTPHONES", ITS World Congress 2014, paper accepted for publication.
Other Dissemination Activities: 1) Talk at CMU UTC seminar: ADDRESSING THE POTHOLE SITUATION IN PITTSBURGH, Christoph Mertz, March 18, 2014. 2) Presentation of work to PA Turnpike Commission
Website: http://www.ri.cmu.edu/person.html?person_id=670 and https://bitbucket.org/lwander/snowcam
Technologies and Techniques: The two main technologies and techniques we have developed are 1. Data collection system for android smartphones and 2. Image analysis algorithm to detect cracks in roads.
1) Is shared with the public through an open source repository website. 2) Image analysis algorithm is shared through a conference paper publication.
In the very near future more code will be made public through open source repository
Invention / Patent applications / Licenses: Open source license for some of our software.
Other Products Associated: Audio / Video; Databases; Software / Netware, The UTC seminar was recorded and the video is available online. We are continuously collecting more road data to develop and test our system.
Impact: Within the discipline of Robotics and computer vision: Expand the field to include transportation research, expose students to transportation research. On the reverse, computer vision is being introduced into the field of transportation and maintenance. With the arrival of smartphones it has become easy and cost effective to collect large amounts of images and tag them with GPS and other information. Up to now only a few companies with

large financial resources were able to create citywide databases of images (e.g. Google Streetview). With such databases new “big data” research will be possible in the fields of computer vision and transportation.

THRUST #2: CONNECTED VEHICLE SAFETY TECHNOLOGIES

Safety Assessment of Connected Vehicles Lead, Chris Hendrickson
University: CMU
Other Collaborators: Costa Samaras
Progress: Percent Complete: 30
Journal Publications: Papers being prepared for submission
Other publications, conference papers, and presentations: 2014 Automated Vehicle Symposium … **cutoff response**
Task List: Preparing analysis papers
Goals and Timelines: Expect to submit papers by the end of… **cutoff response**

Connected Technology for Bicycle Safety Lead, Anthony Rowe
University: CMU
Other Collaborators: Bruno Sinopoli, Ali Momeni
Website: http://cychic.io and http://wise.ece.cmu.edu/redmine/projects/safebike/wiki
Technologies / Techniques: Use of raw data from low-cost GPS and wireless communication as a mechanism to do ad-hoc differential positioning between moving vehicles.
Other Products Associated: Software / Netware, We have designed a plug-and-play architecture for linking on bicycle devices to aid in data collection and extending rider perception with sensors.

Vehicle Trust Management for Connected Vehicles Lead, Insup Lee
University: UPenn
Other Collaborators: Dr. Nicola Bezzo, post doc researcher and Yanwei Du, Programmer
Other publications, conference papers and presentations: "Attack Resilient State Estimation for Autonomous Robotic System" by Nicola Bezzo, James Weimer, Miroslav Pajic, Oleg Sokolsky, George J. Pappas, Insup Lee To appear in IEEE/RSJ International Conference on Intelligent Robots and Systems, Interactive Session, Chicago, IL, September 2014
Website: http://precise.seas.upenn.edu/research/automotive-cyber-physical-systems/v2v/ and http://www.seas.upenn.edu/~nicbezzo/UTC.html
Technologies / Techniques: We have proposed an adaptive recursive estimator which uses a filter approach to estimate the state while reducing the malicious effects introduced by an attacker. Our recursive algorithm is motivated by the results found in the Linear Quadratic Regulator implementation with some modifications to accommodate the possible presence of an attack in one of the sensors of a vehicle. If an attack is present and such that one of the measurements is corrupted, the goal is to remove it or mitigate its effect. Since the attack vector is generally unknown, the strategy we implement changes the covariance matrix associated with the measurement error in order to increase the uncertainty where the measurement is different from the predicted state estimate. The developed technique was applied to an adaptive cruise control case study on a wheeled ground robot. We have also started to investigate the effects of malicious attacks on V2V networks (urban and highway scenarios).
Impact: Improve the security and safety of modern vehicular systems. Support and train graduate students and postdoctoral researcher. Release software experiment platform to support further research.

V2V for Safe Intersections Leads, Vijay Kumar, George Pappas, Kostas Daniilidis
University: UPenn
Other publications, conference papers, and seminars: Roberto Tron and Kostas Daniilidis
“An Optimization Approach to Bearing-Only Visual Homing with Applications to a 2-D Unicycle Model”
IEEE International Conference on Robotics and Automation, 2014
Roberto Tron, Justin Thomas, Giuseppe Loianno, Joe Polin, Vijay Kumar, and Kostas Daniilidis,
“Vision-based formation control of aerial vehicles”
RSS Workshop on Distributed Control and Estimation for Robotic Vehicle Networks, 2014
Other Dissemination Activities: Internal seminars
Website: https://fling.seas.upenn.edu/~tron/cgi-bin/ http://www.jtwebs.net/ https://www.grasp.upenn.edu/
Technologies/Techniques: Robust vision-based teammate detection for formation control. Consensus-based filtering of distance information for formation scale estimation.
Other Products Associated: Audio, Video**,** We prepared a video illustrating the experiments performed in the GRASP UAV Test bed. These involve a formation of three quadrotors performing tasks such as following a leader or changing the formation scale and shape. The video can be found on the provided websites.

Impact: We believe that our algorithms and experiments impact both the theory and practice in the field of robotics. On the theoretical side, we advanced the field by subsuming many of the merits of existing algorithms while avoiding many of their drawbacks. For instance, our technique can work using exclusively line-of-sight measurements between vehicles, the agents can achieve the desired formation from any starting configuration, and the size and organization of the group of vehicles are almost unconstrained. On the practical side, this work shows the feasibility of implementing the theory on a formation of agents using low-power on-board processing and limited V2V communication. In the future, this technology will enable practical goals such as collision avoidance in convoys, platooning, and cooperative load transportation.
Task List: [x] Develop control law for a single agent with linear dynamics using bearing-only measurements [x] Extension of this law to a single agent with non-linear dynamics [x] Extend the control algorithm to consider a formation of agents [x] Consider the added information of distance measurements
[x] Visual detection of teammates [x] Implementation on real test bed with on-board low-power computations [ ] Adapt control law for vehicles of different dynamics [ ] Consider field of view and trajectory (road) constraints [ ] Provide collision avoidance guarantees while changing configurations [ ] Application to negotiating traffic at intersections
Goals and Timelines: Adapt control law for vehicles of different dynamics (September 2014)
Consider field of view constraints (December 2014), Provide collision avoidance guarantees while changing configurations, and consider trajectory (road) constraints (March 2015), Applications to negotiating traffic at intersections (June 2015) We also plan to use our current and future results for journal and conference publications.

ProtoDrive: An Experimental Platform for Electric Vehicle Energy Scheduling and Control Lead, Rahul Mangharam
University: UPenn
Other publications, conference papers and presentations: Y. Pant, T. Nghiem and R. Mangharam. “Peak Power Reduction in Hybrid Energy Systems with Limited Load Forecasts”. American Control Conference (ACC). June 2014
Other Dissemination Activities: Invited talks at Cornell, Drexel, UIUC, UC Irvine, UCLA, USC, UCSD, UC Berkeley, Kansas State University and University of Kansas.
Website: http://mlab.seas.upenn.edu/protodrive/
Technologies / Techniques: The focus of this project is to ensure safe and efficient hybrid energy storage systems for future vehicle architectures. The project is developing control and scheduling algorithms to ensure battery systems are safe by minimizing peak current draw. This is achieved by using a super capacitor to buffer charge and flatten peak current draws from the battery. The result is an extension in the lifetime of the battery and operation in the safe power density regime. We are developing the circuits, system models and control/scheduling algorithms that require minimal drive cycle information.
We are developing Protodrive, an experimental platform enabling rapid prototyping and simulation of electric vehicle powertrains. The powertrain is modeled at the small-scale in hardware, making it low-cost and compact enough to fit on a desk. It consists of a physical model of an electric vehicle powertrain coupled to an active dynamometer, making it possible to run the powertrain through its full speed and torque range. The fact that this system has been constructed in hardware allows it to capture intricacies in vehicle operation that may be missed by simulation in software alone.
Other Products associated: Audio / Video; Software / Netware, We are developing open-source software for prototyping hybrid energy storage architectures for electric vehicles. Demo video: http://youtube/ZWIuTwJ4Npk
Impact: In the past few months, ProtoDrive won the 3rd Prize in 11th World Embedded Systems Competition, Seoul, Korea. It won the Distinguished Recognition Award at the Intel/Cornell Embedded Systems Competition. The ProtoDrive team demonstrated at the ITS Showcase in DC on June 26, 2013.
In President Obama's, Jan 2011 State of Union Address, he mentioned - "We can replace our dependence on oil with biofuels and become the first country to have a million electric vehicles on the road by 2015." Electric Vehicles (EVs) have had a recent resurgence in popularity and are showing promise as a future mainstream means of transportation. However, the low energy density, high cost and long recharging time of batteries are formidable obstacles to mass consumer acceptance. There are a number of things that can be done to increase the viability of EVs, such as:
• Powertrain system optimization to extract the maximum range
• Development of better tools to predict range and reduce “range anxiety”
• Optimal fuel control and driver behavior influence to increase range
An electric vehicle powertrain consists of all the components necessary to deliver power to the wheels. This typically consists of a battery, motor controller, motor, gearbox and differential. Currently, EV powertrains are modeled and simulated in software and then prototyped and tested in a full-scale vehicle. While software can provide decently accurate predictions of performance, it may fail to miss some of the detailed intricacies of a real system. Full-scale models obviously demonstrate all real problems, however, iterating on a full-scale vehicle is time consuming and expensive.

Protodrive is a small-scale electric vehicle prototyping platform that attempts to find a middle ground between simulating purely in software, and prototyping at full scale. It is a real hardware system, representative of a real powertrain, however, it is implemented at a scale small enough to fit on a desktop. The hope is that it will allow the quick and cost effective characteristic of simulating in software, while still being able to capture the intricacies of real hardware performance.
Impact in Other Disciplines: Hybrid energy storage architectures developed here are relevant to building controls and smart grid applications for peak power minimization.

THRUST #3: INFRASTRUCTURE TECHNOLOGIES FOR SAFETY

Safety and Efficiency in Multi-modal Traffic Flows Lead, Stephen F. Smith
University: CMU
Other Collaborators: K. Larry Head and Yeheng Feng, University of Arizona - collaborative development of a joint route choice and traffic signal control model
Journal Publications: Xie, X-F, Y. Feng, S.F. Smith, and K.L. Head, "A Unified Route Choice Framework: Specification and Application to Urban Traffic Control", Journal of the Transportation Research Board, Accepted for publication, 2014.
Other publications, conference papers and presentations:
Xie, X-F, S.F. Smith, G.J. Barlow and T-W. Chen, "Coping with Real-World Uncertainty in Real-Time Traffic Control", Proceedings 93rd Transportation Research Board (TRB) Annual Meeting, Washington DC, January 2014.
Xie, X-F., Y. Feng, S.F. Smith and K.L. Head, "A Unified Route Choice Framework and Empirical Study in an Urban Traffic Control Environment", Proceedings 93rd Transportation Research Board (TRB) Annual Meeting, Washington DC, January 2014.
A. Mahendran, M. Hebert and S.F. Smith, "Ensemble of Exemplar SVMs - A Convex Relaxation of a Latent SVM", Poster Paper, International Workshop on Large-Scale Visual Recognition and Retrieval (CVPR BigVision), Columbus, Ohio, June 2014
Barlow, G.J., S.F. Smith, X-F Xie and Z.B. Rubinstein, "Real-Time Traffic Control for Urban Environments: Expanding the Surtrac Testbed Network", 2014 World Congress on Intelligent Transportation Systems, Detroit, MI, to appear, September 2014.
Other Dissemination Activities: S.F. Smith, The Future is Now: Innovative Intelligent Transportation Research and Deployment, Institute of Traffic Engineers Webinar, June 5, 2014.
Website: http://www.surtrac.net
Technologies / Techniques : Extensions have been developed to the Surtrac adaptive signal control system to give more active attention to pedestrian traffic. A coordination protocol based on exchange of phase information among neighbor intersections has been added, which allows earlier servicing of waiting pedestrians at intersections upstream of blocking intersections. Maximum pedestrian wait time constraints are also now enforceable, and experimental results show significant decrease in overall pedestrian wait times.
Invention / Patent applications / Licenses: Patent Application - "Smart and Scalable Urban Signal Networks: Methods and Systems for Adaptive Traffic Signal Control", Attorney Docket Number: 279430.139_NP, filed, filed June 18, 2014.
Impact: The techniques that have been developed for multi-modal traffic optimization provide new opportunities for effectively exploiting real-time adaptive traffic signal control into urban settings. Through experimental analysis carried out in both microscopic simulation and in actual operation in the East Liberty pilot system, results indicate potential for significant performance benefit. During the next period we will attempt to lessen the current constraint that pedestrians must push the pedestrian button to trigger pedestrian friendly behavior.

Structural Health Monitoring of Bridges Lead, Jacobo Bielak
University: CMU
Participant Organizations: National Science Foundation, Arlington, VA. Through grant 1130616, "Indirect Bridge Health Monitoring Using Moving Vehicles," NSF funded laboratory and field experiments. These experiments provided the data, which we are analyzing with the UTC funding. And Port Authority of Allegheny County: we have instrumented a light rail vehicle, and have been meeting with them on a weekly basis for the last 9 months.
Other Collaborators: Civil and Environmental Engineering (Faculty: Bielak, Noh, Garrett; Students: Cerda, Lederman, Wang) and Biomedical Engineering and Electrical and Computer Engineering (Faculty: Kovacevic; Student: Chen). Christoph Mertz from the Robotics Institute. This collaboration has allowed us to use state of the art robots in order to collect field data (dynamic response) from a parking garage structure on campus. Dr. Mertz is himself involved in other projects with the UTC. Piervincenzo Rizzo from the University of Pittsburgh Department of Civil and Environmental Engineering. Our project has benefited from Dr. Rizzo's expertise in Structural Health Monitoring. Yoshinobu Oshima, an Associate Professor from Kyoto University in Japan. As a

current visiting researcher at Carnegie Mellon, he will assist in analyzing the data we have collected from the Port Authority Project.
Journal Publications: S. Chen, F. Cerda, P. Rizzo, J. Bielak, J. H. Garrett, and J. Kovačević, "Semi-supervised multiresolution classification using adaptive graph filtering with application to indirect bridge structural health monitoring," IEEE Trans. Signal Process. 62, 2879-2893, 2014. Published. Federal Fund Acknowledged.
F. Cerda, S. Chen, J. Bielak, J. H. Garrett, P. Rizzo, and J. Kovačević, "Indirect structural health monitoring of a simplified laboratory-scale bridge model," Int. J. Smart Struct. Syst., sp. iss. Challenge on bridge health monitoring utilizing vehicle-induced vibrations, July 2014. Published. Federal Funding Acknowledged.
Other publications, conference papers, and publications: G. Lederman, Z. Wang, J. Bielak, H. Noh, J. H. Garrett, S. Chen, J. Kovačević, F. Cerda, and P. Rizzo, " Damage quantification and localization algorithms for indirect SHM of bridges," Proc. Int. Conf. Bridge Maint. Safety Manag., Shanghai, China, July 2014 (fully reviewed and accepted before publication). Federal Funding Acknowledged.
S. Chen, A. Sandryhaila, G. Lederman, Z. Wang, J. M. F. Moura, P. Rizzo, J. Bielak, J. H. Garrett, and J. Kovačević, "Signal inpainting on graphs via total variation minimization," In Proc. IEEE Int. Conf. Acoust., Speech Signal Process., Florence, May 2014 (fully reviewed before publication). Deliver. Federal Funding Acknowledged.
Website: http://jelena.ece.cmu.edu/repository/conferences/14_07_LWBNGCKFR.pdf
Technologies / Techniques: In the last semester we have made the greatest progress on three fronts. First, we have improved our data collection with the Port Authority; now raw data can be automatically processed and entered into our database. This includes extracting the vibration signal from a geographical point of interest and storing it along with relevant information like weather data, which we query from a national database. Second, we have developed a new signal-conditioning framework based on convolution, where the frequencies associated with the infrastructure can be more easily extracted. This leads to a better identification of the characteristic system features; we expect this will result in improved classification capabilities. And third, we have continued to develop graphs for signal processing, as demonstrated by the most recent paper published in the IEEE Transactions on Signal Processing. This activity, too, leads to improved classification capabilities.
Other Products Associated: Databases, through our collaboration with the Port Authority of Allegheny country, we have been recording the dynamic response of a light rail vehicle for the last 9 months. We have created a large MySQL database with the data, which we plan to make public when we publish our results.
Impact: The impact of this program is two-fold. First this grant has allowed us to investigate new signal processing techniques, which have advanced the sophisticated yet economical structural health monitoring technique our group has been developing. Second, this grant has helped train civil engineering students to learn more about signal processing, while encouraging signal processing students, to examine applications in infrastructure.
This reporting period, we have advanced both our theoretical understanding of signal processing for infrastructure assessment, and we have collected a large dataset from an operational system so we can begin to test these theories on real-world data. As expected, we have found the real data to be complicated to analyze. However, based on our previous experience, we are making progress to decode these signals.
We have been collecting data from a vehicle on the light rail system with hopes of monitoring the track and track structures. One of the challenges in working with these signals is that each day the temperature, speed, and car conditions might be slightly different; before looking for damage, we have to understand which parts of the signal change in a benign way due to environmental variability. We believe that graphs for signal processing may offer a promising route; each signal can be viewed as a node, and the similarities between them can be represented as edges. An anomalous signal will then be one, which exhibits strange behavior for its particular location within the graph.
If our work is successful, we hope to create an economical infrastructure assessment tool, which can be mounted on in-service vehicles. We will provide continuous inspection, which will compliment more infrequent visual inspections for a safer overall system. In addition, we hope to provide information on track and crosstie condition, which could benefit the operations deports of railroads.
Impact in Other Disciplines: The signal processing techniques researched under this grant were recently presented at a prominent signal processing conference (ICASSP), and have been published in the IEEE transactions in Signal Processing, one of the premier journals in the field. Signal processing within the civil engineering discipline is a nascent field. We are both applying proven techniques from signal processing to Structural Health Monitoring, as well as developing processing techniques which are novel even within the signal processing community.

Remote Diagnostics and Safety Verification Lead, Rahul Mangharam
University: UPenn
Other publications, conference papers and presentations: Y. Pant, T. Nghiem and R. Mangharam. “Peak Power Reduction in Hybrid Energy Systems with Limited Load Forecasts”. American Control Conference (ACC). June 2014
Other Dissemination Activities: Invited talks at Cornell, UIUC, U. Kansas, UC Irvine, UCLA, USC, UCSD, Drexel and Hong Kong Polytechnic University.

Website: http://www.seas.upenn.edu/~rahulm
Technologies / Techniques: We are developing AutoPlug, an automotive Electronic Controller Unit (ECU) test-bed to diagnose, test, update and verify controls software in a vehicle. AutoPlug consists of multiple ECUs interconnected by a CAN bus, a vehicle driving simulator which behaves as the plant model and a vehicle controls monitor in Matlab. As the ECUs drive the simulated vehicle, the physics-based simulation provides feedback to the controllers in terms of acceleration, yaw, friction and vehicle stability. This closed-loop platform is then used to evaluate multiple vehicle control software modules such as traction, stability and cruise control. With this test-bed we are aim to develop ECU software diagnosis and testing to evaluate the effect on the stability and performance of the vehicle. Code updates can be executed via a smart phone so drivers may remotely "patch" their vehicle. This closed-loop automotive control test-bed allows the automotive research community to explore the capabilities and challenges of safe and secure remote code updates for vehicle recalls management.
In the current year, we are extending AutoPlug to include Adaptive Cruise Control (ACC) – (for details see http://autoplug.blogspot.com/) to evaluate control algorithms and security attacks on ECUs. We will demonstrate the effect of sensor noise, limited field of view and other non-idealities on the performance of ACC.
Other Products Associated: Software / Netware, We are developing an open-source software for hardware-in-loop control system testing and remote diagnostics for automotive systems.
Impact: In 2010, over 20.3 Million cars were recalled. An increasing percentage of the recalls are due to two reasons: (a) For the 100 million lines of software code and over 60 microprocessors in each car, software bugs for traction control, stability control, anti-lock brakes and cruise control have accounted for over 13% of recalls, and are increasing rapidly; (b) With more stringent emissions standards, recalls due to malfunctioning exhaust systems have been escalating and vehicles must be disabled when in violation of emissions guidelines. The focus of this collaborative effort between Penn and GM is to develop automotive telematics architecture for diagnostics and control from a Remote Diagnostics Center (RDC). This will enable remote testing of vehicle software and emissions compliance, trigger perturbations to safely adapt the system, help with preemptive root cause analysis and assist the service center in resolving the problem with minimum waste. We will focus on the car and cloud architecture, communications protocols and remote diagnostics methodologies for diesel aftertreatment systems.
Impact in Other Disciplines: With the regulatory requirement of Super Ultra-Low Emissions Vehicles (SULEV) starting to roll out by 2016, the Nitrogen oxides (NOx) and particulate matter will be 10 times lower than current standards. With today's diesel aftertreatment systems, this will result in a significant recall of vehicles violating the new emissions standards. The proposed research will develop both the control systems mechanisms in the vehicle and at the RDC to rapidly detect a problem and trigger remote control signals between the engine and emissions control systems for the vehicle to adapt and remedy the problem. If successful, the proposed research will demonstrate the value of cloud-based control services for automotive warranty management and serve as a model caretaker of our environment.

Determinants of Roadway Accident Rates Lead John Landis
University: UPenn
Nothing to Report

THRUST #4: VEHICLE AUTOMATION FOR SAFETY

Proving Autonomous Vehicle & Advanced Driver Assistance Systems Safety Lead, Andre Platzer
University: CMU
Other Collaborators: Nikos Arechiga, Collaborator Education Nathan Fulton, Junior student, Education Sarah M. Loos, Co-author, Verification of wireless V2V communication Stefan Mitsch, Co-author, DL simulation, collaborative verification, co-author on research paper
Collaborators in other departments:
Bruce Krogh, Carnegie Mellon University School of Engineering, Collaborative research David Garlan, Carnegie Mellon University School of Computer Science (Institute for Software Research), Collaborative research Bradley Schmerl, Carnegie Mellon University School of Computer Science, Collaborative research
International Collaborators:
Grant Olney Passmore, Cambridge and LFCS, Edinburgh, 15 JJ Thomson Avenue, Cambridge, UK. Werner Retschitzegger, Wieland Schwinger, and Andreas Mueller. Department of Cooperative Information Systems, Johannes Kepler University. Contact for traffic center situation awareness
Journal Publications: André Platzer. Logical Analysis of Hybrid Systems: A Complete Answer to a Complexity Challenge. Journal of Automata, Languages and Combinatorics, 17(2-4), pages 265-275. 2012.
Other publications, conference papers, and publications: Stefan Mitsch, Grant Olney Passmore, André Platzer: Collaborative Verification-Driven Engineering of Hybrid Systems. Mathematics in Computer Science, 8(1), pages 71-97, 2014.
Stefan Mitsch, Jan-David Quesel, André Platzer: Refactoring, Refinement and Reasoning: A Logical Characterization of Hybrid Systems. In Cliff B. Jones, Pekka Pihlajasaari and Jun Sun, editors, 19th International Symposium on Formal Methods, FM, Singapore, Proceedings, volume 8442 of LNCS, pages 481-496.

Other Dissemination Activities: Stefan Mitsch: Safe Next-Generation Transportation Systems, ITS America's Annual Capitol Hill Transportation Technology Showcase & Reception, 2014, Washington DC, USA
Khalil Ghorbal: Abstracting algebraic differential equations by differential radical invariants, CMACS/AVACS Workshop at Carnegie Mellon University, 2014 Pittsburgh, PA, USA
Khalil Ghorbal: Characterizing invariant algebraic sets for algebraic differential equations, Abstract Interpretation Group Seminars, 2014, École Normale Supérieur, Paris, France
Khalil Ghorbal: Caractérisation des variétés affines invariantes pour les équations différentielles algébriques, Static Analysis Lab Seminars, 2014, Commissariat à l'Énergie Atomique, CEA LIST, Saclay, France
André Platzer and Sarah Loos: Logic of Dynamical Systems, Ens de Lyon, Lyon, France
André Platzer, Sarah Loos, João Martins: Logic of Dynamical Systems, Universidade do Minho, Braga, Portugal
Website: http://symbolaris.com/
Other Products Associated: Models Educational aids or curricula; Software / Netware, KeYmaera. The KeYmaera tool is freely available with a user friendly, web-start version. KeYmaera is a hybrid verification tool for hybrid systems that combines deductive, real algebraic, and computer algebraic prover technologies. It is an automated and interactive theorem prover for a natural specification and verification logic for hybrid systems. KeYmaera is continually being improved with added functionality to keep up with growing research needs. We are also developing an intensive tutorial and course curricula for KeYmaera to keep up with growing demand for the tool. http://symbolaris.com/info/KeYmaera.html
dL simulation The dL simulation toolkit translates hybrid programs into executable Mathematica. The simulation environment is integrated into KeYmaera. It enables users of these tools to gain an intuition about the modeled system behavior.
SPHINX is a freely available modeling environment for verification-driven engineering. The environment supports model refactoring and corresponding proof adaptation for CPSs. In particular, SPHINX addresses the following research questions:
* How to support modeling of CPSs and evolution of these models with recurring refactorings in a way that is amenable to proof adaptation?
* How to determine different kinds of refactoring operations that may occur in models of CPSs, and their impact on verification?
* How to properly adapt proofs according to model refactorings?
http://www.cs.cmu.edu/~smitsch/tools.html#sphinx
Foundations of Cyber-Physical Systems Course "Foundations of cyber-physical systems" is an undergraduate course on the formal verification of cyber-physical systems. The course introduces formal verification techniques and hybrid system modeling, with a special focus on autonomous robots as a running example throughout the course. The course materials include a syllabus, complete lecture notes, homework assignments, lab assignments, and associated KeYmaera source code. http://symbolaris.com/course/fcps13.html
Impact: Safety-critical traffic and automotive systems are becoming increasingly dependent on complex interactions with computers. Safety systems, such as adaptive cruise control, emergency braking and collision mitigation are becoming household terms, as family cars are equipped and sold with these devices. However, with this increased complexity, it is far more challenging to ensure the safe and accurate functioning of these devices, especially as an increasing number of them begin to interact on our roadways in a wide range of situations. Our research focuses on ensuring that these and other systems operate safely in all situations, even in those that are not conceived by the designers of the systems. To tackle this issue, we apply formal verification techniques, which allow us to either produce a conclusive proof that the systems is safe in all situations, or provide a counter example. However, these methods are only useful if they are powerful and robust enough to verify the computers, which actually control our cars. To this end, we have developed several collaborations with people outside our field to ensure that the methods and tools we develop are increasingly applicable and useful. One such collaboration is with researchers in the Engineering department at Carnegie Mellon University. Together we are investigating how to create the right abstractions to translate systems, which are currently too complex to prove directly into provably safe systems, without lessening the strength of our safety guarantees on the original system.
Despite the remarkable progress in automating formal verification of hybrid systems, the construction of proofs of complex systems often requires nontrivial human guidance, since hybrid systems verification tools solve undecidable problems. It is, thus, not uncommon for development and verification teams to consist of many players with diverse expertise. We introduced a verification-driven engineering toolset that makes it easier to tackle large-scale verification tasks.
In order to ultimately enable domain experts, such as traffic engineers, to ensure safety by formal verification, we develop user-friendly modeling and verification tools including tutorial and course material. The KeYmaera tool is a freely available, hybrid verification tool for hybrid systems that combines deductive, real algebraic, and computer algebraic prover technologies. System models for KeYmaera can be created with Sphinx, a freely available modeling tool for hybrid programs. Through Sphinx, domain experts can create graphical and textual models of hybrid systems that are suitable for formal verification in KeYmaera (details in J. Mathematics in

Computer Science). In this effort, we collaborated with Grant Olney Passmore. KeYmaera and Sphinx support simulation of those models to help domain experts gain intuition about the behavior of their models.
Proper safe developments of transportation system designs are accompanied by a proof of correctness. Since the inherent complexities of those systems practically mandate iterative development, frequent changes of models are standard practice, but require re-verification of the resulting models after every change. To overcome this issue, we developed proof-aware refactorings that transform system models and maintain correctness proofs.
We developed and taught "Foundations of cyber-physical systems" (FCPS), an undergraduate course on the formal verification of cyber-physical systems. The course introduces formal verification techniques and hybrid system modeling, with a special focus on autonomous robots as a running example throughout the course. The course was offered during the Fall 2013 term, and is offered again in the Fall 2014 term.
The course material includes lecture notes, lab assignments, homework assignments, and YouTube demonstrations for new KeYmaera users. In addition to completing the publicly available course material, Carnegie Mellon FCPS students completed an end-of-term verification project. Three of these end-of-term projects were presented at Carnegie Mellon's Undergraduate Research Symposium, resulting in one award. Short versions of this course were presented to graduate students and faculty at Universidade do Minho and Ens de Lyon.
Impact in other Disciplines: Much of our research has resulted from cross-disciplinary collaborations. We have developed several collaborations with people outside our field to ensure that the methods and tools we develop are increasingly applicable and useful. One such collaboration is with researchers in the Engineering department at Carnegie Mellon University on abstraction and translation of complex systems into provably safe systems. Another collaboration is with Johannes Kepler University Linz, Department of Cooperative Information Systems. In this collaboration, we investigate how to integrate safe traffic control measures into an intermodal traffic situational awareness software framework for traffic control centers. These efforts are expected to contribute to traffic information system engineering, in order to increase safety and trustworthiness of information systems in the traffic control domain.

Sensing and Planning Under Uncertainty for Increased Driving Safety Lead, John Dolan
The project has not begun yet.
Website: http://www.ri.cmu.edu/research_project_detail.html?project_id=651&menu_id=261

Planning for Autonomous Vehicles Lead, Erick Guerra
University: UPenn
Participating Organizations: Delaware Valley Regional Planning Association
During interviews, several additional MPOs have expressed interest in participating in the project
Other Collaborators: Megan Ryerson, Assistant Professor of City and Regional Planning, UPenn, Zachary Billet, Master's student, Chi Zhang, Master's student
Dissemination: Accepted for presentation at 2014 conference of the Association of Collegiate Schools of Planning, Proposal submitted for Transportation Research Board 2015 annual meeting.
Website: http://utc.ices.cmu.edu/utc/

THRUST #5: MOBILITY ANALYTICS

Tiramisu: Live Bus Occupancy Data Feeds Lead, Aaron Steinfeld
University: CMU
Dissemination Activities: Team members routinely interact with interested stakeholders from industry, transit agencies, other government entities, and the general public. This ranges from meetings to discuss specific aspects of transit rider information systems all the way to acting as a resource for members of the public.
Website: http://www.tiramisutransit.com
Technologies / Techniques: The team is currently focused on using intelligent software techniques to link unstructured Twitter postings about transit service to specific routes, bus stops, and vehicle trips. We are using natural language processing techniques for this effort. The team started this project late in the reporting window due to internal personnel schedules, so we expect to have more details in later reports.
Impact in Other Disciplines: Aaron Steinfeld continues to serve on the National Academies of Science, Transportation Research Board, Standing Committee on Accessible Transportation and Mobility (ABE60). He was appointed this year to be Co- Chair of the Technology subcommittee.
https://www.mytrb.org/CommitteeDetails.aspx?CMTID=1164

Mobility Analytics Center Lead, Sean Qian
University: CMU

Dissemination Activities: We have demonstrated and presented this project to a variety of agencies, such as PennDOT, PA Turnpike, Port Authority, Benedum Foundation, City of Pittsburgh, Parking Authority etc.
Website: http://utc.ices.cmu.edu/utc/projectitem.asp?ID=96
Other Products Associated: Databases; Software / Netware, We have established a comprehensive database that integrates various types of transportation data, which include GIS, counts, travel time, speed, cameras, transit, parking, incidents, weather, electric vehicle charging stations, and social media data. We have by far built a template website to provide those archived traffic data, as well as to visualize the data.
Impact: A mobility data analytics center is necessary to accommodate needs of data fusion and analytics. The ultimate objective of mobility data analytics center is to,
• Provide archived and real-time traffic data of every element of multi-modal transportation systems
• Reveal the behavior information for both passenger transportation and freight transportation
• Serve as a key managerial instrument for legislators, transportation planners, researchers, and engineers
• Serve as a key information platform for individual travelers and transportation industries.

Automated Video-based Traffic Count Analysis Lead, Camillo J. Taylor
University: UPenn
Participant Organizations: Delaware Valley Regional Planning Commission
Other publications, conference papers and presentations: T. Furuya and C. J. Taylor, “Road intersection monitoring from video with large perspective deformation,” in 21st World Congress on Intelligent Transport Systems, September 2014.
Other Dissemination Activities: Project code made freely available to the public on the website below
Website: https://github.com/takfuruya/DVRPC
Technologies / Techniques: In this work we have developed an approach to vehicle tracking that handles many of the challenges associated with the video data acquired from non-nadir view. More specifically we have developed an approach that extracts feature trajectories from the images, then compensates for perspective distortion and performs grouping into individual vehicles. This approach allows us to overcome the non-linearities associated with perspective and the problems associated with shadows.
Other Products Associated: Software / Netware, We have developed a C implementation of our approach on top of the OpenCV library and have made the code available to the public.
Impact: We have published our research results and conclusions and made the system public so that other implementers can take advantage of the lessons that we learned.

AutoMatrix: A Large Scale Traffic Congestion Modeling Tool to Investigate Anytime Algorithms for Multi-core Computer Lead, Rahul Mangharam
University: UPenn
Journal Publications: R. Mangharam and M. Pajic. “Distributed Control for Cyber-Physical Systems” Journal of the Indian Institute of Science, Special Issue on Cyber-Physical Systems, Vol.93, No.3. September 2013.
Other publications, conference papers and presentations: Truong X. Nghiem, Yash V. Pant and Rahul Mangharam, "Robust Model Predictive Control with Anytime Estimation", IEEE Control and Decision Conference, Dec 2014. (under review)
Other Dissemination Activities: Invited talks at Cornell, UIUC, U. Kansas, UC Irvine, UCLA, USC, UCSD, Drexel and Hong Kong Polytechnic University.
Website: http://www.seas.upenn.edu/~rahulm
Technologies / Techniques: Developed an approach for Robust Model Predictive Control with Anytime Estimation. With an increasing autonomy in modern control systems comes an increasing amount of sensor data to be processed, leading to overloaded computation and communication in the systems. For example, a vision-based robot controller processes large image data from cameras at high frequency to observe the robot's state in the surrounding environment, which is used to compute control commands. In real-time control systems where large volume of data is processed for feedback control, the data-dependent state estimation can become a computation and communication bottleneck, resulting in potentially degraded control performance. Anytime algorithms, which offer a trade-off between execution time and accuracy of computation, can be leveraged in such systems. We present a Robust Model Predictive Control approach with an Anytime State Estimation Algorithm, which computes both the optimal control signal for the plant and the (time-varying) deadline/accuracy constraint for the anytime estimator. Our approach improves the system's performance (concerning both the control performance and the estimation cost) over conventional controllers, which are designed for and operate at a fixed computation time/accuracy setting. We numerically evaluate our approach in an idealized motion model for navigation with both state and control constraints.
Other Products Associated: Software / Netware, Anytime Computation Toolbox for Self-driving Vehicles is being developed and will be release as open-source software at the end of the year.
Impact: In the current year, we are extending the traffic modeling to semi-autonomous driving systems. Anytime Algorithms for Autonomous Vehicles. In semi-autonomous vehicles, algorithms for trajectory control, obstacle avoidance and path planning/navigation are very compute-intensive and require a lot of processing. These

algorithms must run in an on-line and real-time manner within the closed-loop context of the moving vehicle. Currently, the computer vision-processing bottleneck for sensor data capture (by cameras, position sensors and laser range finders) is the bottleneck and restricts fast vehicle responsiveness and faster velocities.
This project is focused on the development of approximate and imprecise computation algorithms that take the large amount of data generated by these sensors and provide the best possible answer within the deadline, so the vehicle is always safe and responsive. We are developing this architecture to run on graphics processors (GPUs) and will demonstrate the safety and efficacy on both modeled vehicles and full-scale vehicles. This project has large impact in making low-cost sensing more viable by ensuring the processing is more effective and appropriate for the situation the vehicle is in.
Impact in Other Disciplines: The research in anytime controls and computation is widely applicable to data-driven problems where the systems are overloaded with sensor streams but have to make decisions by a deadline.

Enhancing the Safety of Visually Impaired Travelers in and around Transit Stations Lead, M. Bernadine Dias
University: CMU
Participant Organizations: Western Pennsylvania School for Blind Children (WPSBC)
PWPSBC provides connections to research participants; support needs assessment, technology testing, and end user feedback; provide general and specific information of relevance to the motivation and purpose of the project; provide further opportunities for dissemination and outreach activities.
Partner makes personnel available for project discussions and facilities available for testing and outreach activities. Project staff members are able to conduct needs assessment and test aspects of the project on-site with partner permission. Partner makes personnel available for project discussions and facilities available for testing and outreach activities. Project staff members are able to conduct needs assessment and test aspects of the project on-site with partner permission.
Other Collaborators: From the University of Pittsburgh- Dr. George Zimmerman from the School of Education Vision Studies Program, Dr. Hassan Karimi from the School of Information Sciences Geoinformatics Laboratory, Dr. Jonathan Pearlman from Human Engineering Research Labs.
Other Dissemination Activities: On February 25, PI M. Bernardine Dias presented at a meeting organized by the Oakland Business Innovation District, and hosted by the University of Pittsburgh to discuss avenues for deploying assistive navigation technology tools in the Oakland and greater Pittsburgh community. Local foundations, local industry representatives, and stakeholders from the local visually impaired community as well as organizations that serve this community attended the presentation.
On May 5, TechBridgeWorld students Ming Wu, Alekhya Jonnalagedda and Lucy Pei presented outcomes from their joint independent study entitled "Assistive Navigation Technology for Visually Impaired Travelers" at Carnegie Mellon University's 2014 Meeting of the Minds (undergraduate research symposium).
Website: http://www.cs.cmu.edu/~navpal and http://www.techbridgeworld.org and http://us2.campaign-archive2.com/?u=400f29b8a21b7a09840086b91&id=5f748b5b34
Technologies / Techniques: The work to date has primarily focused on literature review and an initial needs assessment as described in the proposal for this work. Primary techniques used for the needs assessment are interviews, surveys, observations, and focus groups.
Other Products Associated: CMU undergraduate students Ming Wu, Alekhya Jonnalagedda and Lucy Pei conducted a joint independent study through TechBridgeWorld on the topic of technology enhancing how blind and visually impaired people navigate large indoor transit stations such as airports, train stations, bus depots, etc. The students submitted a final report, which includes a literature review to understand the current state of navigation assistance for visually impaired travelers as well as a needs assessment with relevant stakeholders to learn more about strategies and challenges. Drawing on these findings, the students included their design guidelines for developing relevant and accessible technology for visually impaired travelers as well as recommendations for technology solutions in the final report. They also conducted surveys, interviews, and observations to learn more about the needs and challenges associated with safe and independent navigation in and around transit stations. PI M. Bernardine Dias and TechBridgeWorld Project Manager Ermine Teves advised the students.
Impact: In the current year, we are extending the traffic modeling to semi-autonomous driving systems. Anytime Algorithms for Autonomous Vehicles. In semi-autonomous vehicles, algorithms for trajectory control, obstacle avoidance and path planning/navigation are very compute-intensive and require a lot of processing. These algorithms must run in an on-line and real-time manner within the closed-loop context of the moving vehicle. Currently, the computer vision-processing bottleneck for sensor data capture (by cameras, position sensors and laser range finders) is the bottleneck and restricts fast vehicle responsiveness and faster velocities.
This project is focused on the development of approximate and imprecise computation algorithms that take the large amount of data generated by these sensors and provide the best possible answer within the deadline, so the vehicle is always safe and responsive. We are developing this architecture to run on graphics processors (GPUs) and will demonstrate the safety and efficacy on both modeled vehicles and full-scale vehicles. This

project has large impact in making low-cost sensing more viable by ensuring the processing is more effective and appropriate for the situation the vehicle is in.

Impact in Other Disciplines: While our focus is in the discipline of robotics, and more specifically in assistive technology, the outcomes of this work will also have impact in the fields of orientation and mobility (the specialists who train blind and visually impaired people to navigate) and human-computer interaction. Orientation and mobility experts have shown interest in how our work can assist them to further enhance the independence and safety of blind and visually impaired people. Human-computer interaction researchers who focus on interface design are interested in what we learn about accessible interfaces to technology tools through our work.