Technologies for Safe and Efficient Transportation

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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1. Accomplishments

Major Goals and Objectives of the Program

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.

Education and Workforce Development

Education and workforce development are important compliments 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.

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 has already created startups in the past will serve as mentors to colleagues interested in this activity.

Metrics
Involvement of faculty in technology transfer activities.
- Number of conferences, meetings, and formal discussions that focus on end users of ITS
- Number of patent applications filed
- Number of startups created
- Number of technology licenses issued

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, educational partners and industry partners.

Metrics
- Number and diversity of members of the T-SET Consortium
- Number and impact of deployments achieved through collaboration

Diversity

T-SET projects will focus on transportation users in both rural areas and center cities, in 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 the Major Goals
See Appendix A for specific research project accomplishments.

Education and Workforce Development
In workforce development Carnegie Mellon’s efforts continue with the Pennsylvania Department of Transportation (PennDOT) and the Community College of Allegheny County. There have been discussions with PennDOT about specific opportunities to have T-SET faculty attend annual divisional training sessions and conduct a seminar on current and future applications of intelligent transportation systems (ITS). The goal is to increase the exposure and interest of PennDOT’s front line workers and mid level management in the potential of ITS safety and efficiency opportunities.

With the Community College of Allegheny County (CCAC) T-SET is discussing the development of a “train-the-trainers” program where T-SET faculty present their current research to CCAC faculty with the goal of increasing CCAC’s faculty and student exposure and interest in ITS. Currently CCAC offers the Pittsburgh Automotive Training Program which would be well suited for this effort.

Various T-SET personnel at CMU have been actively engaged in a campus wide effort to consider the development of an urban systems institute which would include intelligent transportation systems.

Below is a listing of specific additional Education and Workforce Development efforts T-SET personnel have engaged in over past six months:

- Met with University of Maryland’s Center for Advanced Transportation Technology to discuss possible collaborations.
- Participated in University Roundtable to discuss transportation careers for students.
- Met with group interested in an ITS project to coordinate and route school bus service across school districts.
- Gave overview of the T-SET research program to the research faculty of CMU's Institute for Complex Engineered Solutions.
- CMU faculty provided a guest lecture on autonomous vehicle research at a University of Pittsburgh transportation engineering course.
- Assisted in planning a 2013 transportation forum at the University of Pittsburgh.
- Discussions with the CMU’s Director of Remaking Cities and community representatives about a potential project.
- Attend Pittsburgh Chapter Meetings of the Young Professionals in Transportation.
- Attended an Organizing Meeting at New York University for the Center for Urban Science and Progress (CUSP) of which CMU is a partner.
- Conducted UTC Student of the Year Competition.
- Attended the Community College of Allegheny County’s “Robert Mill Lecture Series” where the keynote speaker was the Deputy Secretary of Transportation, John Porcari.
- Support CMU’s Heinz College spring student data analytics Systems Synthesis project for the Port Authority of Allegheny County.

Technology Transfer and Collaboration
Carnegie Mellon continues to work with the Pennsylvania Department of Transportation (PennDOT) in developing a master agreement and work plan of T-SET research projects that address real world transportation challenges of PennDOT utilize Pennsylvania as a test bed for ITS deployment.
In August 2012, T-SET personnel were actively engaged in the planning of the ITS Pennsylvania Annual Meeting which was held in Pittsburgh. One session highlighted the T-SET UTC where both CMU and Penn faculty presented UTC research.

In September 2012, Carnegie Mellon held a press conference to share the results of CMU's adaptive traffic signal network project, alongside Pittsburgh Mayor Luke Ravenstahl, Henry Hillman from the Hillman Foundation, and CMU President Jerr Cohon. This event marked an ideal example of technology transfer & deployment where the City of Pittsburgh allowed the piloting of a first of its kind decentralized adaptive traffic signal system. The city continues to utilize the system and CMU researchers are expanding from 9 to over 40 intersections with T-SET UTC support.

In October 2012, with the support of the Intelligent Transportation Society of America (ITSA), and Power of 32 Regional Visioning Initiative, T-SET personnel organized a Regional Traveler Information Charrette. This two-day event brought together national experts with local transportation agency and community representatives to explore the possibilities of developing and deploying a real time traveler information system for 32 counties surrounding Pittsburgh including Maryland, Ohio and West Virginia.

Below are additional Technology Transfer and Collaboration accomplishments and efforts:

- Met with cabinet advisors to the Emir of Qatar to discuss transportation research advances
- Met with the Director the Joint University of Pittsburgh, CMU and City of Pittsburgh “Power Up Initiative” to discuss transportation program and potential commercialization.
- Met with Takata to discuss potential sponsored research.
- Met with Iteris to discuss potential sponsored research.
- Met with PennDOT Secretary Schoch to discuss cooperative research between CMU and PennDOT.
- Met with venture capitalist regarding natural gas vehicle research.
- Met with 10,000 Friends of Pennsylvania to discuss collaboration on travel demand modeling.
- Attended the AASHTO Annual meeting; included discussions with Florida DOT to have the adaptive signal research presented to them in early 2013.
- Met with AASHTO and UC Berkeley PATH to discuss collaboration opportunities.
- Presentation of transportation research to Bosch representatives.
- Hosted the Local Government Academy for a tour of Nav Lab and met UTC faculty to discuss research deployments on local roads.
- Attended Pittsburgh Chapter Association of Unmanned Vehicle Systems International Membership Meetings.
- Participated in East Liberty Mobility (transportation planning) Session.
- Served on the Allegheny County Executive’s Transportation Visioning Committee.
- Met with the Southwestern Pennsylvania Commission and IndioGO (Indiana County Transit) to develop research and deployment proposal.
- Met with the CMU/University of Pittsburgh Quality of Life Technology Institute to discuss Technology Transfer Initiatives.
- Served on panel for Pittsburgh Mayor Ravenstahl to select innovative smart cities project to propose for the 2012 Bloomberg Mayors Challenge (CMU’s adaptive signal project was a finalist in Ravenstahl’s process.)
- Met with PennDOT Director of the Pittsburgh Traffic Management Center to discuss camera research.
- Met with PennDOT and CMU Researchers for Inspection and License Data.
- Met with Caterpillar and CMU Nav Lab Researchers.
- Attend Pittsburgh City Planning Charrette on the Green Boulevard Study.
- Bus Rapid Transit Stakeholders Meeting.
- In Harrisburg Attend Meeting of PennDOT Autonomous and Connected Vehicle Working Group and appointed to serve on that group.
Met with the Pittsburgh Parking Authority and CMU Researchers to develop a dynamic pricing project for street meters.

Hosted IBM Smarter Cities Challenge Team Meeting with faculty on campus.

Participated in Transportation in the Mon Valley steering committee meeting.

Attended committee meeting of the Steel City Codefest of Which Traffic21 is a sponsor.

Hosted Staff Campus Visit from PA Department of Community and Economic Development to Discuss T-SET Technology Transfer Efforts.

Met with researchers from Audi/VW.

Attended meeting of the PennDOT FHWA State Transportation Innovation Council. T-SET personnel serve as a committee member.

Met with the Port of Pittsburgh Commission to discuss potential research on the Wireless Waterways test bed.

Met with Pittsburgh City Planning and Developer, Walnut Capital, to discuss transportation sensing technology and associated data analytics.

Faculty presentation to RITA AERIS Connected Vehicle Working Group to present adaptive traffic signal research.

Presented T-SET research to Pittsburgh venture capital representatives.

Diversity

As mentioned above in the Education and Workforce section, discussions continue regarding the collaboration with the Community College of Allegheny County which with a 24% enrollment of ethnic minorities can be an opportunity for diversity outreach.

The UTC continues to work with Indiana University of Pennsylvania and the Indiana County Transit Authority to transfer UTC technology to transit serving rural populations in Pennsylvania.

Additional Diversity Outreach Activity

- Meeting of the Accessible Transportation and Workforce Interagency Cooperative.
- Meeting with the Pittsburgh region’s three Transportation Management Associations; Pittsburgh Downtown Partnership, Oakland Transportation Management Association, and the Airport Corridor Transportation Association to discuss research ideas for multi-modal transportation.
- Made UTC presentation to the Innovation Oakland Committee and discussed research for multi-modal way-finding.

Dissemination of Results

In addition to the outreach activities mentioned above and UTC researcher activity in Appendix A, UTC leadership personnel attended the following conferences and meetings to promote UTC research, technology transfer, education and workforce activities:

- Presented TSET research to the National Conference of State Legislatures at meeting in Chicago.
- Participated in workshop hosted by the American Public Transportation Association, Boston.
- Participated in Buhl Foundation session discussing transportation data for research purposes.
- Guest speaker at monthly meeting of the Airport Corridor Transportation Association.
- Presented T-SET research program to members of Pittsburgh City Council.
- Moderated a session at, and attended ITS World Congress in Vienna, Austria.
- Presented T-SET research to a visiting delegation from China.
- Discussions with various Pittsburgh foundations (e.g. Hillman, Heinz, Richard King Mellon, McCune) regarding funding support for to match the UTC.
- Presented T-SET program activity monthly at CMU’s Community Connection working group which promotes university outreach with the community.
- Interview with Pop City (Local Online Magazine) regarding UTC efforts.
- Host Senator Toomey’s staff for T-SET presentation on campus.
• Attend University of Pittsburgh Institute of Politics Elected Officials Retreat.
• Manage a video shoot for professional production of a promotional video for the T-SET and shown at the INFORMS Conference in Las Vegas.
• Attend ITS IPO Connected Vehicle Workshop in Chicago.
• WESA Radio in-studio interview on T-SET projects.
• Hosted on Campus the Mayor of Pittsburgh in the closing session of the IBM Smarter Cities Challenge Team 3-week visit to Pittsburgh.
• Hosted Chinese business and local government leader on campus for briefing on T-SET research project deployments.
• Served as moderator at the University of Pittsburgh Institute of Politics Infrastructure Forum.
• Met with IBM and the City of Pittsburgh to discuss potential Smarter Cities transportation research projects.
• Attended TRB/UTC Spotlight Conference on Sustainable Energy and Transportation (Student presented poster too.)
• Served on an Autonomous Vehicle Licensing Panel at the Penn State Transportation Safety and Engineering Conference in State College, PA.
• Attend Sustainable Pittsburgh’s, Smart Growth Conference featuring Keynote Speaker PennDOT Secretary Barry Schoch.
• Facilitated first bi-weekly interactive webinar between Carnegie Mellon and University of Pennsylvania faculty and students with research presentations.
• Attended Greater Pittsburgh Chamber of Commerce Elected Officials Reception.

Plans for Next Reporting Period

• Continue deployment progress on the research projects
• Hold a T-SET Consortium meeting at UPenn
• Plan a second T-SET Consortium Meeting in at CMU
• Update the T-SET web site
• Develop web-based process for research project tracking
• Continue individual follow-up with consortium members on education, workforce, diversity and technology transfer initiatives
• Hold a technology transfer symposium for UTC faculty and students involving campus affiliates and consortium members who provide technology transfer assistance
• Further develop STEM and diversity initiatives
• Continue media exposure of upcoming newsworthy research activity
• Begin research projects with PennDOT
• Design T-SET marketing publication and information for the website
• Higher T-SET Project Manager

2. Products

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

General Program Products
• UTC website www.utc.ices.cmu.edu
• 919 blog postings since January 2012
• Consistent weekly distribution of T-SET email newsletter, 662 subscribers
• New presence on social media, 11 fans on Facebook and 37 followers on Twitter
• Incorporated a webinar based systems of linking CMU and UPenn faculty and students for our bi-weekly T-SET meetings. Now a faculty member interactively presents their research at the beginning of each meeting.
• Updated custom web portal for UTC researchers to report progress
• Research Project Descriptions
Promotion of various CMU and Penn research news articles in the T-SET blog and newsletter

Feature article of the UTC in the CMU ICES quarterly magazine

T-SET Media

Efforts have been made to promote T-SET UTC activities through the media. Below are some examples of T-SET media exposure from July – December 2012. Click on hyperlink to view articles

- Tiramisu App Wins FCC Chairman’s Award
- PennDOT Secretary Schoch Highlights CMU and Autonomous Vehicles
- Virtual traffic lights help solve commuting hell
- CMU develops high-technology traffic signal timing system
- The New Frontier in Accessible Transportation
- Robert Hampshire selected to participate in Frontiers of Engineering symposium
- ITS Pennsylvania To Host Annual Meeting in Pittsburgh, August 13-14th
- Carnegie Mellon Researchers Develop Approach To Improve Emergency Medical Services in Developing Countries
- Carnegie Mellon Spinoff Tiramisu Transit Receives Funding To Commercialize Transit App

3. Participants and Other Collaborating Organizations

Collaborating Organizations

T-SET Advisory Council Inaugural Meeting
In October 2012 T-SET held its first meeting of the T-SET Advisory Council. Advisory Council members in attendance were Gerry Mooney (IBM), Jim Misener (Booz Allen Hamilton), Bill Millar (American Public Transportation Association), Jim Paige (Conference of Minority Transportation Officials), Doug Foy (Serrafix), Ray Betler (Wabtec), John Inglish (Utah Transit Authority) and Barry Schoch (PennDOT). The committee spent a day half with T-SET faculty and administrators learning about and providing feedback and guidance on research, education, workforce, technology transfer and diversity initiatives.

Please refer above to the “Accomplishments Section” under our Major Goal of Collaboration for specific examples of our general program collaborating organizations.

T-SET Consortium. We continue to actively work with our 31 T-SET Consortium members listed here http://utc.ices.cmu.edu/utc/consortium.asp and to deploy research and enhance education, workforce, diversity and technology transfer efforts.

Appendix A – Research Projects Accomplishments, Products and Participants

Thrust Area #1 In-Vehicle Technologies for Safety

V2V for Safe Intersections (DOT Goal: Safety; Topic: Technology-Related Research) Lead: Ozan Tonguz (CMU)


Websites The following website presents overall description and outcomes of the project http://utc.ices.cmu.edu/utc/Tonguz%20project%20description.pdf

**Products - Software:** Large-scale simulator based on a modified version of the SUMO simulator was developed to quantify the benefit of the proposed VTL scheme in the city of Pittsburgh during rush hours (both morning and evening rush hours). The simulator used is based on the open-source simulator SUMO (originally designed at ETH Zurich) with custom designed modules added to implement our VTL algorithm. The results obtained show that the average commute time of urban workers in Pittsburgh can be reduced by more than 35% which is quite significant. - **Video product:** A video clip that demonstrates benefits of this project has been prepared and aired in January 2013 by the Discovery Channel Canada. The video clip can be found at [http://watch.discoverychannel.ca/clip841424#clip841424](http://watch.discoverychannel.ca/clip841424#clip841424) - **Others:** The visibility of this project has increased substantially in the last 3-4 months. Below are some URLs reflecting the coverage and such the interest: [http://www.newscientist.com/blogs/onepercent/2012/11/virtual-traffic-lights-help-ke.html](http://www.newscientist.com/blogs/onepercent/2012/11/virtual-traffic-lights-help-ke.html), [http://www.gizmag.com/virtual-traffic-lights/24917/](http://www.gizmag.com/virtual-traffic-lights/24917/) New Scientist is a prestigious science journal published in London that reports ground breaking scientific inventions and discoveries. According to its web site, it has an audience of more than 900,000 (close to 1 million people). Similarly, GizMag is also a well-known technology magazine with high visibility. In addition to several articles featuring Virtual Traffic Lights in very visible magazines, several interviews have been given on Discover Channel Canada, a broadcast channel in Sydney, Australia, and Anadolu Agency in Turkey.

**Collaborators** - Wantanee Viriyasitavat, Research Scientist, Carnegie Mellon University - Apoorv Khandelwal, Masters student, Carnegie Mellon University

**Impact on Principal Discipline** Below, we briefly elaborate on these outcomes from the program and how they impact on the base of knowledge, theory, and research in the transportation research. 1-The impact of RF obstructions at the intersections on the proposed Virtual Traffic Light (VTL) scheme has been studied carefully and reported in the following ACM VANET paper: T. Neudecker, N. An, O.K. Tonguz, T. Gaugel, and J. Mittag, Feasibility of Virtual Traffic Lights in Non-Line-of-Sight Environments, in Proceedings of the 9th ACM International Workshop on Inter-vehicular networking, systems, and applications (VANET12), Low Wood Bay, Lake District, United Kingdom, pages 103-106, June 2012. The main finding of this paper is to show that while RF obstructions (such as highrises on the corners of intersections and other obstacles such as trees and foliage) are an important issue for the implementation of the proposed Virtual Traffic Lights scheme, the feasibility of Virtual Traffic Lights can be guaranteed with reasonable deceleration rates (with less than 3 m/seconds squared). It was also established that the leader election process should be established about 60 meters away from the intersection for safe and reliable operation of VTL. 2-The important issue of how to support priority management at intersections with the proposed VTL scheme has been studied and the results were reported in the following paper: W. Viriyasitavat and O.K. Tonguz, Priority Management at Intersections Using Virtual Traffic Control, in Proceedings of the IEEE Vehicular Technology Conference (VTC) Fall 2012, Quebec City, Canada, September 2012. The main findings of this paper is to show that by designing a new biologically inspired algorithm VTL can give priority to vehicles at intersections. This has 2 concrete applications: i) Emergency vehicles such as ambulances and fire trucks can be prioritized with the proposed VTL scheme. This can save lives in emergency situations such as traffic accidents or fires in buildings. ii) Mass transit vehicles (such as buses) can be prioritized at intersections during rush hours. This is a very desirable result since prioritizing mass transit vehicles at the intersections could reduce the commute time of a larger number of urban workers during rush hours. It is our belief that both of these applications are significant safety applications, which will enhance the appeal of the biologically-inspired scheme known as Virtual Traffic Lights. 3-Large-scale simulations based on a modified version of the SUMO simulator were run to quantify the benefit of the proposed VTL scheme in the city of Pittsburgh during rush hours (both morning and evening rush hours). The simulator used is based on the open-source simulator SUMO (originally designed at ETH Zurich) with custom designed modules added to implement our VTL algorithm. The results obtained show that the average commute time of urban workers in Pittsburgh can be reduced by more than 35% which is quite significant. 4-New work on showing how Virtual Traffic Lights fare with respect to congestion pricing has been finished and a report has been prepared. Part of this work will be submitted as a CMU patent through the Technology Transfer Office of CMU. The main finding here is to show that, contrary to common belief, Congestion Pricing cannot effectively mitigate or eliminate congestion. Conversely, it is shown that VTL is a much more effective scheme compared to Congestion Pricing. These findings should be of interest to the US Department of Transportation in addition to companies such as IBM who implement congestion pricing.
in cities like London in the U.K. and other companies such as Xerox who also are involved in congestion pricing in cities like Atlanta and Los Angeles.  

**Impact on Other Disciplines** Some of the work that was done in the context of Virtual Traffic Lights is also relevant for traffic control in railway transportation. Based on this synergy, new contacts have been established with Bombardier. There is a great deal of interest on the part of Bombardier to support my research and to license some of the patents we have filed on VTL and traffic control in railway transportation. In fact, effective January 2013 it has been agreed that Bombardier will sponsor my research for railway transportation. Some of the work that have done in this domain was reported in the following paper: C. Rico-Garcia and O.K. Tonguz, Maximizing the Safety and Efficiency of Rail Transport: A Biologically Inspired new Approach, in Proceedings of the IEEE International Conference on Communications 2012 (ICC 2012) Workshop on Intelligent Vehicular Networks, Ottawa, Canada, June 2012.

**Automatic Recognition and Understanding the Driving Environment for Driver Feedback (DOT Goal: Safety; Topic: Technology-Related Research)** - Lead: Marial Hebert and Luis E. Navarro-Serment (CMU)  

**Technologies and Techniques:** We have developed algorithms that use prior knowledge for scene understanding purposes. Specifically, our algorithms use external sources of information to build representations of the environment where the vehicle is operating. These representations provide contextual information that describe if and where certain objects are likely to occur in the scene. Basically, these representations can be used to obtain a prior on the set of possible object occurrences, object locations and scenes. The advantage of using prior distributions obtained from external sources of information is that they can be used to place constraints on the predictions generated by other scene understanding algorithms, thus improving the accuracy of their predictions. Additionally, we have completed the first implementation of software to extract information from external sources and generate prior distributions of objects and places in the vicinity of a vehicle. This software has allowed us to test algorithms developed during this period for automotive applications using data from real world situations. This software is not being shared at the moment, although we plan to make it available to the community in the future.

**Impact on the Development of the Principal Discipline:** Within the discipline of Robotics and Machine Learning: 1) Developed algorithms for scene understanding that use external sources of information for automotive applications. 2) Expose students to issues involved in the design of machine perception algorithms in the transportation domain.

**Other Collaborators Involved:** We have contacted researchers from Takata Corporation. We are currently discussing the possibility of using data from their Stereo Vision System (SVS) to evaluate our algorithms using this sensor. This would enable us to test our algorithms using a sensor that is tailored to vehicular applications. Similarly, Takata Corporation would explore the possibility of embedding our algorithms into the SVS to enhance its current capabilities. We will continue to pursue this collaboration.

**Sensory Augmentation for Increased Awareness of Driving Environment (DOT Goal: Safety; Topic: Technology-Related Research)** - Lead: Paul Rybski and John Dolan (CMU)  

**Publications:** Authors: Alok Sharma, John M. Dolan, Paul Rybski, Title: LIDAR-based perception for an autonomous car, Year: December 2012, Status: Accepted, Acknowledgement of federal support: no  

**Technologies and Techniques:** Near-automotive-grade LIDAR-based static and dynamic obstacle detection.  

**Other organizations that have been involved as partners:** GM R&D, Warren, Michigan.

**Impact on the Development of the Principal Discipline**  
Automated intent recognition for automotive applications has the potential to greatly improve safety systems in cars and on roadways. If a situation around the vehicle can be deemed potentially hazardous due to the driving conditions, actions of other drivers, the speed of the vehicles, and existence of blind spots, then automated systems can alert the driver to this before an unavoidable hazardous situation can occur. Automated Vehicle Type Recognition (DOT Goal: Safety; Topic: Technology-Related) - Lead: Kostas Danilidis (Penn)  

**Technologies and Techniques:** The goal of this project is to develop a visual navigation system for use in vehicles using Android tablets. Current vehicle navigation techniques rely solely on static road maps and noisy
GPS data. This approach is prone to errors where GPS information is not available, such as urban canyons. We propose to use a windshield mounted, Android tablet as a sensor platform for augmenting in-vehicle navigation. We begin by detecting and tracking salient features over time from the color camera images. Combined with the accelerometer and gyroscope data, we can distinguish between static (background) and dynamic (foreground) features in the images. The static features are then used to compute the visual odometry (motion of the vehicle) and produce a 3D model of the environment. This information can then be used to augment the navigation system with local, real-time information and overlays.

**Other Collaborators:** Dan Lee, Jordan Brindza, Teyvonia Thomas

**Impact on the Principal Discipline:** Ultimately we aim to create an Android application that helps to make drivers more aware of their environments and promotes safety and focus while driving. To this end, we are developing algorithms to carry out key operations which include detecting the road and lane markings, identifying other vehicles on the road, recognizing pedestrians and cyclists, and identifying important road features such as stop lights, stop signs, and speed limits. Using moving object detection and visual odometry, our application will compute and monitor distances to other vehicles, pedestrians and cyclists nearby. This information can in turn be used to alert the driver of a potentially hazardous situation such as an impending collision. Additionally, lane detection and vehicle egomotion estimation will be used to determine and issue warnings when unintended lane departure (drifting) occurs.

**Impact on Other Disciplines:** Android tablets well suited for this task because they are inexpensive, readily available and come with an array of useful sensors; including GPS, color cameras, accelerometer, gyroscope, and wireless capabilities. Unlike many of the current advanced safety features available in vehicles today, this project does not require any specialized hardware to be installed on the vehicle. The radar and LIDAR sensors, typically used in modern vehicles safety measures, can be expensive and any older vehicles would not benefit from these solutions. Our solution will not require any external hardware modification allowing for an immediate impact in both new and old vehicles.


**Technologies or Techniques:** We have developed AutoPlug, an automotive Electronic Controller Unit (ECU) test-bed to diagnose, test, update and verify controls software. 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 past year, we have extended AutoPlug to include Adaptive
Cruise Control (ACC) – (for details see http://autoplug.blogspot.com/) to evaluate control algorithms and security attacks on ECUs. We have been able to successfully demonstrate the effect of sensor noise, limited field of view and other non-idealities on the performance of ACC. We have demonstrated this to the U.S. Department of Transportation, Research and Innovative Technology Administration, John A. Volpe National Transportation Systems Center. We have also demonstrated this to Intel Corporation, Toyota Infotech Center, BOSCH Research and General Motors.

Website: http://www.autoplug.org/

Other Products: Hardware and Software for Test-bed available at http://www.autoplug.org

Other Collaborators: Kevin.Harnett@dot.gov (NHTSA Volpe Center) - Initial discussion on cyber-security approaches for automotive control systems with the AutoPlug project.

Awards: The AutoPlug project won the Grand Prize in the World Embedded Software Contest, Seoul, Korea in November 2010. The PI was awarded the Intel Early-Faculty Career Honor in November 2012 for his efforts on the AutoPlug project. The PI was selected as one among top 20 academics internationally ($40,000 award) The PI was selected by to National Academy of Engineers to speak at the US Frontiers of Engineering Symposium in September 2012. The talk was on “The Car and The Cloud: Automotive Architectures for 2020”. This honor is awarded to top 15 engineers under 45 years, nation-wide.

Pedestrian Collision Warning for Buses (DOT Goal: Safety; Topic: Technology) Lead: Daniel Lee (Penn)


Technologies or Techniques: Visual processing algorithms are open-source, and freely available.

Impact on the Development of the Principal Discipline: Vision techniques being developed for traffic tracking will lead to overall developments in efficient computational algorithms for use in embedded devices such as smartphones and tablets. This prevalence will only increase in the future, and the algorithms being developed could become widely disseminated and shared.

Impact on Other Disciplines: Other disciplines that are impacted include robotics and artificial intelligence. In general, this UTC project is a great test bed for real-world applications of more intelligent vision algorithms on embedded devices.

Other Organizations Involved as Partners: Collaboration with Intel Science and Technology Center as well as visiting students from Seoul National University in Korea

Website: Article online about Penn UTC activities: http://www.upenn.edu/pennnews/current/2013-01-17/latest-news/penn-drives-transportation-research-forward

Thrust Area #2 Smart Infrastructure

Smart Parking (DOT Goal: Livable Communities; Topic: Land-Use Planning) - Lead: Robert Hampshire (CMU)

Publications: Type of publication: Journal, Authors: Robert Hampshire, Tayo Fabusuyi, Title: Decision Analytics for Parking Availability in Downtown Pittsburgh, Journal: Interfaces, Status of publication: Under review, Acknowledgement of federal support: Yes

Type of publication: Conference paper, Authors: Tayo Fabusuyi; Robert Hampshire; Victoria Hil, Title: Evaluation of a Smart Parking System, Journal: Transportation Research Board of the National Academies of Engineering, January 2013, Status of publication: Accepted, Acknowledgement of federal support: Yes

Type of publication: Conference paper, Authors: A. Millard-Ball, R. Weinberger and R.C. Hampshire, Title: Is the glass 85% full or 15% empty? Assessing the efficacy of San Francisco’s parking experiment, Journal: Transportation Research Board of the National Academies of Engineering, January 2013, Status of publication: Accepted, Acknowledgement of federal support: Yes.

Other Organizations Involved as Partners: Numeritics LLC, ALCO Parking Corp, Deeplocal LLC

**Impact on the development of the principal discipline of the program:** Our predictive parking availability platform, parkpgh.org, is first of a kind. It has received awards from trade organizations, such as ITS America, and popular press conference including WIRED magazine. Our team has briefed officials in several cities, including San Jose CA, on the development of smart parking systems.

**Website:** [www.parkpgh.org](http://www.parkpgh.org)

**Continuous Road Surface Distress Detection (DOT Goal: State of Good Repair; Topic: Infrastructure Monitoring Research) - Lead: Christoph Mertz (CMU)**

**Technologies or Techniques:** The technologies that are being developed in this research activity are data collection with a smartphone, analysis of collected images and other data, display of the data to the user and software to automate the whole process. The current status is that we can collect and download data from a smartphone with a few clicks on icons and run one script in the central server to produce the display. We also have initial image analysis software. This is research in progress and besides mentioning them in reports and presentations they are not yet being shared.

**Partner Organizations:** City of Pittsburgh, Department of Public Works. We have meetings with their maintenance division to study their work practices and get feedback on our results. They tell us how they plan and conduct road inspections, how the findings are entered into their database and how that data is used. We discuss with them if our data collection methods are practical, how our system can replace some of their processes, and how we need to format our results to be entered into their system.

**Impact on the Development of the Principal Discipline:** 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.

**Website:** [http://utc.ices.cmu.edu/utc/Mertz%20project%20description.pdf](http://utc.ices.cmu.edu/utc/Mertz%20project%20description.pdf)

**Other Products:** Research Database: Road images tagged with GPS, time, and acceleration in the City of Pittsburgh. Research Hardware/Software: Smartphone based data collection.

**Bridge Monitoring (DOT Goal: State of Good Repair; Topic: Infrastructure Monitoring) - Lead: Jacobo Bielak (CMU)**

**Publications:** **Type of publication:** Conference Paper, **Authors:** Siheng Chen, Fernando Cerda, Jia Guo, Joel B Harley, Qing Shi, Piervincenzo Rizzo, Jacobo Bielak, James H Garrett and Jelena Kovacevic, **Title:** Multiresolution Classification with Semi-Supervised Learning for Indirect Bridge Structural Health Monitoring Conference: 38th International Conference on Acoustics, Speech, and Signal Processing (ICASSP), **Status of publication:** Abstract Accepted, Final Paper Submitted, **Acknowledgement of federal support:** Yes.

**Type of publication:** Conference Paper, **Authors:** Siheng Chen, George Lederman, Zihao Wang, Fernando Cerda, James Garrett, Piervincenzo Rizzo, Jelena Kovacevic and Jacobo Bielak, **Title:** Field Experiments for Structural Health Monitoring, Conference: 2013 ASCE International Workshop on Computing in Civil Engineering (IWCCE), **Status of publication:** Abstract Accepted, **Acknowledgement of federal support:** Yes.

**Type of publication:** Conference Paper, **Authors:** Zihao Wang, Siheng Chen, George Lederman, Fernando Cerda, Jacobo Bielak, James Garrett, Piervincenzo Rizzo and Jelena Kovacevic, **Title:** Indirect SHM by Means of Sparse Representation, Conference: 2013 Structure Congress, **Status of publication:** Abstract Accepted, **Acknowledgement of federal support:** Yes.

**Type of publication:** Conference Paper, **Authors:** F. Cerda, J. Garrett, J. Bielak, P. Rizzo, J. A. Barrera, Z. Zhang, S. Chen, M. McCann, and J. Kovacević, **Title:** Indirect structural health monitoring in bridges: scale
experiments Conference: 6th International Conference on Bridge Maintenance, Safety and Management, Status of publication: Published in Conference Proceedings, Acknowledgement of federal support: No, the work was done just prior to receiving the UTC funds, but is the type of publication that this funding will help to support.

Type of publication: Journal Article, Authors: Fernando Cerda, Siheng Chen, Jacobo Bielak, James Garrett, Piervincenzo Rizzo and Jelena Kovacevic, Title: Indirect structural health monitoring of a simplified laboratory-scale bridge model, Journal: Smart Structures and Systems, Status of publication: Accepted, Acknowledgement of federal support: No, the work was done just prior to receiving the UTC funds, but is the type of publication that this funding will help to support.

Technologies and Techniques: This funding has allowed us to further explore new signal processing approaches for determining if a bridge is healthy or damaged, and a number of new techniques have been developed. One such technique has occurred through our unique interdisciplinary team combining biomedical imaging experts with structural health monitoring experts. Recently, we have found that multi-resolution classifiers, a well-known biomedical signal processing technique, renders exceptionally high results for damage classification in a laboratory bridge model and a simple full scale bridge. To the best of our knowledge this framework had not been tried previously in Indirect Structural Health Monitoring. These results are being communicated both at the 2013 ASCE International Workshop on Computing in Civil Engineering (IWCCE) and at the 38th International Conference on Acoustics, Speech, and Signal Processing (ICASSP).

Partnering Organizations: University of Pittsburgh, Pittsburgh PA. through collaborator Piervincenzo Rizzo, a faculty member in the Civil and Environmental Engineering Department. (2) In kind support (thermal camera) (4) Collaborative research; 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. (1) Financial Support.

Other Collaborators: At the core of this project, we have collaborated between Civil and Environmental Engineering (Faculty: Bielak, Garrett; Students: Cerda, Lederman, Wang) and Biomedical Engineering and Electrical and Computer Engineering (Faculty: Kovacevic; Student: Chen). We have also collaborated with 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. Lastly we have collaborated with 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. Dr. Rizzo has also lent our project his Thermal Camera. This piece of equipment allowed us to record the temperature distribution within a bridge model in the laboratory while collecting the datasets we are now analyzing with the UTC funding.

Impact on the Development of the Principal Discipline: 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. The need for new structural health monitoring techniques is clear. As our national infrastructure ages, decision makers need the best possible information on the state of each structure. This information can ensure public safety while facilitating more efficient maintenance programs, and more effective capital replacement projects. While significant progress has already been made in the field of structural health monitoring, proven technologies remain elusive and expensive, often requiring capital intensive installation processes, and time consuming maintenance programs. Our group has been working on an “indirect” approach where a vehicle records the dynamic response of the bridge as it crosses over the structures. Since many modern vehicles already have accelerometers and computers on board, implementing such an approach would require little capital. However, because less data is collected in the indirect approach and the data is noisier (as it is farther from the source), data analysis plays a crucial role. Therefore, with this funding we have investigated the application of advanced signal processing techniques and machine learning techniques to analyze the data. The goal of data analysis is to analyze patterns of various damage types and label each observation into a predefined class. In data analysis for SHM, we aim at detecting the presence or absence of damage, or to go one step further and detect the severity, location and type of
damage. These tasks are signal processing problems known as classification. A classification system often has two core components, a feature extractor and a classifier. The feature extractor extracts numerical features from the data with the aim of discriminating classes based on those features. The task of the classifier is to label each observation into a predefined class based on those features. So far, we have tried several different feature extractors and classifiers to (1) study the potential power of each algorithm, (2) find suitable situations in which to use each algorithm, (3) study the complexity of the classification problem and (4) upgrade our classification system to achieve better results. We have found that the best feature extractors depend on how well the data is labeled (i.e. how well the state of the structure is known when the data was collected). When the data is well labeled, we have found that Local Fisher Discriminant Analysis is the most powerful feature extractor. When there are fewer labels, Sparse Representation is the most powerful approach. We have found that when the data is well labeled, the best classifier is a Support Vector Machine, and when the data is not well labeled, a semi-supervised machine learning approach is the most effective. The general framework we found to be the most powerful is the multi-resolution classification framework. The overall impact of our findings is that we now know which algorithms among those we have tested can most accurately classify the state of the structure for a given condition. To date, we have dealt only with bridge models in the laboratory and with simple actual structures, such as girders in a parking garage. This knowledge contributes to our ultimate goal of someday determining if a bridge is safe or unsafe with high confidence by using cumulative data from vehicles driving over the bridge. This research is pushing the boundaries in terms of the sophistication of bridge structural health monitoring. It heralds a new era, where traditional visual bridge inspections will be complemented by objective, data driven evaluations of the structures. And this research is contributing to make this new era a reality by giving young engineers the advanced technical skills to lead the complex national infrastructure monitoring programs of the future.

Impact on Other Disciplines: The signal processing techniques researched under this grant are being presented at a prominent signal processing conference (ICASSP). Signal processing within the civil engineering discipline is a nascent field, and even though the techniques we are applying are new for this type of Indirect Structural Health monitoring, they have been proven in other areas of signal processing. We expect this project will generate more interest within the signal processing community for studying structural health monitoring and other infrastructure-related applications. New approaches in signal processing have been at the heart of some of the most impressive technological advances of the last decade, in fields such as wireless communication, biomedical imaging and speech recognition. Based on our current results, we can foresee that the application of signal processing techniques to civil engineering will play an important role in providing safer, smarter infrastructure networks for future generations.

Smart Camera Infrastructure (DOT Goal: Safety; Topic: Technology) - Lead: C.J. Taylor (Penn)

Technologies and Techniques: The goal of this effort is to develop software that could be used to automate the tedious task of analyzing video data to produce traffic counts. Existing commercial systems like Miovision offer solutions but they are expensive and can be somewhat cumbersome. The aim is to develop software that would be freely available to practitioners to reduce the cost of deploying video based traffic analysis systems.

Other Organizations Involved as Partners: Delaware Valley Regional Planning Commission (DVRPC)

Impact on the Development of the Principal Discipline: A successful software package would substantially reduce the cost and time required to gather accurate data about traffic flows. More information could be used to better plan improvements or make the best use of existing resources.

Other Products: At present we have an initial prototype that provides real time traffic counts and turn analysis. The system has been implemented using the OpenCV library and the current implementation runs comfortably on a standard laptop. Our approach to count analysis attempts to produce a virtual equivalent of a network of pneumatic tubes and then analyzes the trip counts and timings to decide on the vehicle traffic patterns.

SEPTA GIS: Visualization and Analysis of Railway Safety Incidents (DOT Goal: Safety; Topic: Technology-Related) - Lead: C.J. Taylor (Penn)

Technologies and Techniques: The Southeastern Pennsylvania Transportation Authority (SEPTA) is one of the largest metropolitan transit systems in the world, with an annual ridership of nearly 340 million. A major
concern with such a large transportation system is safety: each year, many safety incidents occur on SEPTA transit systems, particularly the Regional Rail Lines. Our work focuses on the implementation of a Geographic Information System (GIS) to be used by SEPTA to analyze this data.

**Other Organizations Involved as Partners:** South East Pennsylvania Transit Authority (SEPTA)

**Impact on the Development of the Principal Discipline:** SEPTA is the nation’s sixth-largest commuter rail system. As with any large public transportation system, safety is a very high priority, particularly on regional rail. Regional Rail combines the high-speed danger of subway systems, with the easy, above ground access of bus and light rail systems into a dangerous safety risk. Regional Rail trains can travel up to 90 miles per hour, and are so massive that they are not able to stop except over a very long distance. Sadly, once a train conductor sees someone on the tracks, there is hardly anything they can do to stop it. In 2009, SEPTA regional rail trains were involved in seven fatalities; Amtrak trains have reported sixteen deaths on SEPTA tracks since 2006. The only way to mitigate these tragic incidents is by prevention: by awareness and education about the danger of railways. This is the problem our work is trying to fix. By arming SEPTA with knowledge, our project aims to decrease the number of fatalities on SEPTA regional rail lines.

**Other Products:** So far, our group has shown progress and completed the barebones functionality of the web application. After multiple back and forth communications with SEPTA’s safety department, SEPTA has compiled and sent past incident data to our group dating all the way back to 2002. Our group successfully plotted more than 3000 incidents on a map of the Greater Philadelphia Area. Building on to our achievements from the fall semester, we would like to provide analytical tools, more data for correlation, and live integration with SEPTA’s database.

**Thrust Area #3: Human-Vehicle Interactions for Safe Driving**

**Modeling, Verification and Validation of Transportation Safety (DOT Goal: Safety; Topic: Technology-Related Research) - Lead: Andre Platzer (CMU)**

**Publications: Type of Publication:** Presentation, **Author:** Stefan Mitsch, **Title:** A Brief Introduction to Modeling and Verification of Hybrid Systems in Differential Dynamic Logic, **Status of publication:** Presentation given at the Upper Austria University of Applied Sciences, School of Informatics, Communications, and Media, Hagenberg Campus, Austria, 12/2012, **Acknowledgment:** No.

**Website:** [http://symbolaris.com/info/DCCS.html](http://symbolaris.com/info/DCCS.html)

**Technologies and Techniques:** 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. KeYmaera can be downloaded or launched from this website: [http://symbolaris.com/info/KeYmaera.html](http://symbolaris.com/info/KeYmaera.html)

**Partner Organizations:** Carnegie Mellon University School of Computer Science

**Other Collaborators Involved:** Grant Olney Passmore Cambridge and LFCS, Edinburgh 15 JJ Thomson Avenue, Cambridge, UK Joint work on collaborative verification

**Impact on the Principal Discipline:** 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 conclusive proof that the system is safe in all situations, or provide a counterexample. 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.

Impact on 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 situation awareness software framework for traffic control centers. Domain knowledge about those traffic control measures is provided by “team Communication Technology Management GmbH” (contact to the Austrian highways agency ASFINAG) in another collaboration. 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.

Other Products: 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 proof 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 and to make knowledge about verification of hybrid systems and transportation systems available publicly. http://symbolaris.com/info/KeYmaera.html

Thrust Area #4: Large-Scale Mobility and Data Analytics

Social Networks in Transportation (DOT Goal: Livable Communities; Topic: Land Use Planning and Multi Modal Transportation Research) - Lead: Lavanya Marla and Ramayya Krishnan (CMU)

Publications

Type of publication: Journal paper, Authors: Marla, L., R. Krishnan and Y. Yue, Title: An Efficient Data-driven Approach to Resource Allocation and System Status Management for Emergency Medical Services, Status of publication: Under review at Management Science, Acknowledgement of federal support: Yes.

Type of publication: Journal paper, Authors: Hampshire, R., L. Marla and N. Eluru, Title: An Empirical Analysis of Bike Sharing Usage and Rebalancing - Explaining Trip generation and Attraction from Revealed Preference Data, Status of publication: Under second round of revision at EURO Journal of Transportation and Logistics. Acknowledgement of federal support: Yes.

Type of publication: Journal paper, Authors: Marla, L., C. Barnhart and V. Biyani, Title: A Decomposition Approach for Commodity Pickup and Delivery with Time-Windows Under Uncertainty. Status of publication: Final round of review at Journal of Scheduling, Acknowledgement of federal support: No.

Type of publication: Journal paper, Authors: Marla, L., B. Vaaben, C. Barnhart, Title: Integrated Disruption Management and Flight Planning to Trade off Delays and Fuel Burn, Status of publication: Third round of review at Transportation Science, Acknowledgement of federal support: No.

Other Collaborators: Prof. Naveen Eluru, Department of Civil Engineering at McGill University.

Distributed Transit Rider Messaging (DOT Goal: Livable Communities; Topic: Land Use Planning and Multi Modal Transportation Research) - Lead: Aaron Steinfeld (CMU)

Technologies and Techniques: In the last six months, the team has continued to develop SmartWrap, an extension of the Mixer system that focuses on the extraction of tables from the web. This work has involved a variety of tasks: test set development, interface development, algorithms development, implementation and testing. We are now at the stage of testing of SmartWrap for non-programmers. Testing involves the running of laboratory study, with associated training materials (videos), an experimental protocol, set of tasks to perform and metrics to measure, etc. Preparation for the study is almost complete. In addition to an in-laboratory study
(complete with video recording of user actions), our materials are designed to run experiments via Amazon Mechanical Turk. Under other funding, the team is also in the process of updating the Tiramisu system architecture, data model, and user interfaces to support rider and transit agency messaging. This pipeline will be used to transmit information obtained from relevant websites.

**Other Organizations Involved as Partners:** Tiramisu Transit LLC, the team's spinout company for commercializing Tiramisu, is working on a Phase I SBIR from US DOT. The company side of the team will continue to coordinate with university team members throughout the project. This SBIR is focused on commercialization and sustainability of the crowd sourced transit information system approach.

**Collaborators Involved:** Progress on SmartWrap and related technologies and methods are periodically discussed with IBM Research Japan. We have existing relationship, as two of our students have completed summer internships with the group.

**Impact on Other Disciplines:** The Tiramisu Transit system, which will act as the rider information interface for this work, received the FCC’s Chairman’s Awards for Advancement in Accessibility in the Geo-Location Services category.

**AutoMatrix:** A large-scale traffic congestion modeling tool to investigate Anytime Algorithms for Multi-core Computing Architectures - **Lead:** Rahul Mangharam (Penn)

**Technologies or Techniques:** *AutoMatrix:* Algorithms for traffic estimation, prediction and custom route assignment based on historic and real-time traffic data. We investigate this through the design of the AutoMatrix traffic simulator that is capable of simulating over 16 million vehicles on any US street map. *Philadelphia Traffic Signal Timing Optimization:* We are working with the Delaware Valley Regional Transportation Commission (DVRPC) to improve the traffic signal schedules in Philadelphia's Center City for more efficient flows during peak and off-peak hours. We have developed a tool to optimize traffic signal schedules, conduct automated sensitivity analysis and interface with industry standard traffic planning tools such as VISSUM/VISSIM. This work is done in collaboration with DVRPC and Penn DoT.

**Impact on the Principal Discipline:** *AutoMatrix:* A large-scale traffic congestion modeling tool to investigate Anytime Algorithms for Multi-core Computing Architectures. Our goal is to investigate the construction, instrumentation and scheduling of time-bounded and anytime algorithms on multi-core architectures such as graphics processing units (GPUs). Most algorithms are run-to-completion and provide one answer upon completion and no answer if interrupted before completion. On the other hand, anytime algorithms have a monotonically increasing utility with the length of execution time. Such imprecise and approximate computing has wide application in prediction algorithms in the domains of vehicle traffic congestion, stock price prediction and weather prediction where a large number of variables and dynamical states must be considered to periodically stream an output. Our investigation focuses on time-bounded anytime algorithms on GPUs for real-time vehicle traffic congestion prediction and route assignment. To explore this, we have designed AutoMatrix, a traffic congestion simulation platform on the Nvidia CUDA-enabled GPU. AutoMatrix is capable of simulating over 16 million vehicles on any US street map and executing traffic estimation, prediction and route assignment algorithms with high-throughput. This research has the potential to extend real-time scheduling on massively parallel GPU architectures to attack a variety of data-driven, interactive and dynamical algorithms with timely operation. We are now focusing on simulating large traffic networks for disaster response and evacuation. The goal is to evaluate evacuation approaches from traffic signal adaptation and with support of information dissemination using vehicle-to-vehicle networking. AutoMatrix now includes both simulation-based and optimization algorithms for vehicle traffic evacuation on real street maps. We are writing two papers, one on each project for Spring 2012. The software is open source and has been share with collaborators in Cornell University and University of Connecticut. The PI is also on the Organizing Committee for the Delaware Valley Regional Planning Commission for Disaster Response and Evacuation. The experience from this will contribute a real-world perspective on traffic evacuation to the project.


**Other Organizations Involved as Partners:** Delaware Valley Regional Transportation Commission (DVRPC) - Collaboration on Philadelphia Center City traffic signal scheduling
Other Collaborators: Emmanuel Anastasiadis - Initial discussion on traffic congestion information sharing for AutoMatrix Project. Dr Fang Yuan (fyyuan@dvrpc.org) at DVRPC - active collaborator Philadelphia Center City traffic signal timing modeling and optimization.

ProtoDrive: An Experimental Platform for Electric Vehicle Energy Scheduling and Control - Lead: Rahul Mangharam (Penn)


Technologies or Techniques: Protodrive is 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. This platform allows for development of scheduling and control algorithms for the battery and supercapacitor in electric vehicle powertrains to maximize range, improve battery lifetime and minimize peak current draw.

Impact on the Principal Discipline: ProtoDrive: An Experimental Platform for Electric Vehicle Energy Scheduling and Control 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. Protodrive has a number of interesting applications that will further EV development. These include: • Enabling rapid prototyping and evaluation of novel powertrain architectures • Simulating federal drive cycles to determine a vehicle’s fuel consumption and MPGe rating (Miles Per Gallon equivalent) • Predicting range, when coupled with elevation data from Google maps and a driver control strategy Protodrive is 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. Protodrive can be used for a wide range of simulation tasks, and presently the benefits of a battery/supercapacitor powertrain are being investigated. Protodrive runs a scaled version of an actual commute drive cycle with various battery/super capacitor charging/discharging schedules with the goal of maximizing the battery’s life time and the vehicle’s range. [http://protodrive.blogspot.com/2012/04/demo-day.html](http://protodrive.blogspot.com/2012/04/demo-day.html) To investigate battery-supercapacitor charge/discharge control and scheduling strategies for range maximization, peak current draw minimization and maintaining the battery temperature in the efficient operating region we begin with an energy-efficient hybrid system that comprises of both, the batteries and the supercapacitors connected through a DC/DC converter to achieve optimal performance. The inputs to the system are the EPA’s Federal Drive Cycle and real vehicle model information from the EPA, the U.S. Department of Energy (DoE) and the National Renewable Energy
Laboratory (NREL). Various power distribution schedules will be implemented over the drive cycle, enabling the comparison of a hybrid system to a battery-only system, and the comparison of various current distribution algorithms. The output will show the current load on the battery and the super capacitor, which can be used to determine the battery’s State of Charge and the efficiency of the vehicle. Ultimately, we aim to determine if a battery/supercapacitor system offers significant benefits over a battery-only system, by simulating real commuting routes in hardware.

Website: https://alliance.seas.upenn.edu/~mlabweb/dynamic/proto/

Other Products: Hardware and Software for Test-bed available at https://alliance.seas.upenn.edu/~mlabweb/dynamic/proto/

Awards ProtoDrive won the 3rd Prize in the World Embedded Software Contest, Seoul, Korea in November 2012. ProtoDrive has been selected as a finalist in the 2013 Intel-Cornell Embedded Systems Cup Competition.

Modeling Highway Accidents Using Spatially and Temporally Explicit Event Data: A Southeastern Pennsylvania Pilot Study (DOT Goal: Livable Communities; Topic: Land Use Planning and Multi Modal Transportation Research) Lead: John Landis (penn)

Impact on the Development of the Principal Discipline: There is a large and rich literature on the determinants of traffic accidents, most of which looks at accident frequencies in the aggregate. Using individual accident data and locations provided by PennDOT District VI (Southeastern Pennsylvania), this project will develop a statistical of location-specific accident probabilities based on lighting and weather conditions, traffic volumes and levels, roadway geometry, and to the extent possible, the characteristics of the drivers and vehicles involved.

Impact on Other Disciplines: These models will be used to calculate the expected accident frequency for each quarter-mile (or less) roadway segment, and the expected frequency, in turn will be compared to actual frequencies. The pattern of differences, or residuals, will be investigated to better identify the stochastic determinants of highway traffic accidents. The results will help highway planners and operations managers better anticipate traffic accidents, and hopefully, take steps to avoid them.

Collaborators Involved: Scott Weber

The Determinants of Metropolitan Congestion-Resilience (DOT Goal: Livable Communities; Topic: Land Use Planning and Multi Modal Transportation Research) - Lead: John Landis (Penn)

Impact on the Development of the Principal Discipline: The project will develop a statistical model comparing per capita, per GMP, and per VMT congestion levels in the 81 largest US metro areas (between 1990 and 2010) to household characteristics, highways and transit supply characteristics, and measures of the spatial density and pattern of population and employment centers. From this analysis, we expect to be able to identify those land use and transportation planning and investment programs that generate the greatest congestion-avoidance benefits.

Technologies or Techniques: Some U.S. metropolitan areas seem to be more congestion resilient (Defined as less than a unit change in congestion levels per unit change in population, economic activity, or vehicle-miles-of-travel)than others. Recent empirical studies of four representative US metro areas (Chicago, Houston, Los Angeles, and Washington DC) by Penn PhD Matthias Sweet points to the combination of transportation network geometry and the spatial structure of metropolitan job centers as the primary determinant of congestion resilience. This research will extend this line of inquiry to the 81 largest US metropolitan areas for which reliable congestion is available from the Texas Transportation Institute.

Other Organizations Involved as Partners: Texas Transportation Institute

Other Collaborators: Matthias Sweet, Penn PhD, 2012; Joshua Warner, Ph.D. student

How Real People Respond in Real Time to Real Congestion (DOT Goal: Livable Communities; Topic: Land Use Planning and Multi Modal Transportation Research) - Lead: John Landis (Penn)

Impact on the Development of the Principal Discipline: This app will make use of Inrix real-time travel volume data and real-time PennDOT photo and digital information on current congestion levels and compare it
to historical levels to calculate an “instant” estimate of expected travel time from work to home. In the second phase of this project, we will work with selected Philadelphia area office employers to conduct an experiment: We will deploy the app to see whether and how commuters change their behavior (e.g., time or route-shifting) in response to having this custom-tailored information.

Technologies or Techniques: Much of the current wave of investments in distributed traffic information systems is predicated on the assumption that given the right information, travelers will individually adapt to congestion in ways that boost system performance. But what if this assumption isn’t true? This two-phase project will explore how commuters change their travel behavior in response to the availability of customized, real-time information regarding traffic congestion on their preferred travel route. In the first phase of this project, we will develop a desktop and smartphone application (or app) that provides real-time information to office workers regarding their expected travel time to return home from work.

Other Organizations Involved as Partners: PennDOT

Other Collaborators: Andrew Mondschein, Fern Braun, Ryan Sloan

Thrust Area 5: Policy & Guidance

Assessment of Information & Communication Technologies in Transportation (DOT Goal: Livable Communities; Topic: Livability Performance Measures) - Lead: Chris Hendrickson (CMU)


Impact on the Development of the Principal Discipline: New methods for economic and environmental analysis of transportation policies.

Impact on Other Disciplines: Methods developed can be used in multiple fields.

Quantitative Trust Management for V2V/V2I Networks (DOT Goal: Safety; Topic: Technology-Related Research) Lead: Insup Lee (Penn)

Publications: Authors: Cong Liao, Jian Chang, Insup Lee, and Krishna K. Venkatasubramanian, Title: A Trust Model for Vehicular Network-Based Incident Reports, Status of publication: Submitted, Acknowledgement of federal support: Yes.

Technologies or Techniques: We have proposed a novel trust management framework for ensuring trustworthy traffic accident report using Vehicle-to-Vehicle (V2V) networks. Accident report messages being received can be evaluated regarding their trustworthiness through explicit feedback mechanism or autocorrelation with authoritative dataset, with the benefit of hindsight. Such historical behavior information of message sender will be used to compute a trust value for trust decision making by the receivers of the message in real-time. Further, static information about the message sender such as vehicle maker, vehicle model, and spatial and temporal context information is also considered to reason about trust and to achieve trust decisions. For validating our scheme, we implemented a V2V/V2I trust simulator by extending an existing V2V simulator with trust management capabilities. Preliminary analysis of the model shows promising results.

Impact on the Development of the Principal Discipline: Improve the state-of-the-art of trust management in vehicular networks, poster presentation and academic paper submission at international conferences. Support and train graduate students. Develop software experiment platform to support further research.

Other Products: Software: A V2V/V2I trust simulator, which significantly extended based on an open-source hybrid-network simulator – GrooveNet. This simulator was not only to validate our current approach, but also provide an extendable platform for researchers to test and compare different trust modeling techniques. Once the development of the simulator is in a stable and mature stage, it will be released as open-source software.

Other Organizations Involved as Partners: Worcester Polytechnic Institute Worcester, Mass., USA Collaborative research: close collaboration for the research.

Website: Penn PRECISE center webpage: http://precise.seas.upenn.edu/research/automotive/v2v/