University
Transportation
Centers Program

UTC

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Office of the Assistant Secretary for Research and Technology
U.S. Department of Transportation
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ABSTRACT

This report outlines the new technology transfer (T2) plan and reporting requirement[1] to guide and strengthen the University Transportation Centers (UTCs) technology transfer activities. It discusses the Fixing America's Surface Transportation Act (FAST Act, 49 U.S.C. §5505 as amended by P.L. 114-94, Sec. 6016) requirement for a Regional Center to address transportation safety, congestion, connected vehicles (CV), connected infrastructure, and autonomous vehicles (AV). The report also highlights examples of ongoing or recently completed UTC research projects by each of the 32 Centers and summarizes UTC program-wide performance indicators used to measure productivity at individual UTCs.

INTRODUCTION

The UTC Program is a federal grant program that funds university-based transportation centers to conduct research, education and workforce development, and technology transfer activities. Grants are administered and managed by the United States Department of Transportation (USDOT) staff in the Office of the Assistant Secretary for Research and Technology (OST-R) in Washington, D.C.

The FAST Act provides long-term funding for surface transportation infrastructure planning and investment. Section 6016 of the FAST Act authorizes the Secretary of Transportation to establish and operate University Transportation Centers to advance transportation expertise, provide critical transportation outside the department, and to address critical workforce needs and educate the next generation of transportation professionals. The FAST Act authorized $72.5 million for fiscal year 2016, $75 million for fiscal years 2017 and 2018, and $77.5 million for fiscal years 2019 and 2020 for up to 35 competitive grants for UTCs. As part of its efforts to fulfill this mandate, USDOT administered a grant competition which resulted in the announcement of 32 of the 35 new UTCs in December 2016. A re-competition was held for UTC grants in Regions 1, 2, and 3, due to a lack of meritorious candidates in the initial FAST Act grant competition. To view the 2016 UTC Competition solicitation, visit https://www.transportation.gov/utc/fy-2016-grant-solicitation. The final three UTCs were awarded in June 2018. To view the 2017 Grant Solicitation for Regional Centers in Federal Regions 1, 2, and 3, visit https://www.transportation.gov/utc/utc-program-2017-grant-solicitation. The full list of the 35 FAST Act UTCs can be found on the UTC website, https://www.transportation.gov/utc/2016-utc-grantees.

The FAST Act includes a provision for the periodic review and evaluation of the UTC Program. This report assesses, among other things, 1) progress made to advance technological development, 2) selection of a Center to address connected infrastructure and automated vehicle research, 3) select UTC research projects addressing FAST Act research priorities along with non-exclusive topic areas, and 4) the reporting metrics used to assess the performance of FAST Act grantees.

- ***Technology Transfer:*** The Trump Administration is committed to advancing technological development and conducting research and development to promote emerging technologies, empower Americans to innovate, and defend American technologies abroad.[2] Within the past year, OST-R has led USDOT efforts to increase the effectiveness of T2 activity to promote transportation safety and efficiency. This report provides a discussion on USDOT's new requirement for UTCs to develop Technology Transfer Plans to advance technological development and research and development to facilitate the adoption and commercialization of market-ready transportation technologies.

[1] USDOT, Assistant Secretary for Research and Technology, Technology Transfer Plans Memorandum, April 16, 2018

[2] Office of Science and Technology Policy, Science & Technology Highlights in the First Year of the Trump Administration

- ***Focused Research:*** The FAST Act also requires that one of the Regional UTCs selected address the field of comprehensive transportation safety, congestion, CVs, connected infrastructure, and AVs [49 U.S.C. 55-5(c)(3)(E)]. The Regional UTC selected for funding is the Center for Connected Automated Transportation led by University of Michigan in Region 5. A discussion of this Center's focused research activity is included in this report.
- ***Project Description Examples Addressing Research Priorities:*** The FAST Act specified six research priorities that UTCs selected through the competition must address:
  - Improving Mobility of People and Goods;
  - Reducing Congestion;
  - Promoting Safety;
  - Improving the Durability and Extending the Life of Transportation Infrastructure;
  - Preserving the Environment; and
  - Preserving the Existing Transportation System.

  In addition, the Act charges the Secretary of Transportation with establishing nonexclusive candidate topic areas within these priorities. The nonexclusive topic areas were determined through a meeting of the USDOT Research, Development and Technology Planning Team and input from the FAST Act implementation groups. Included in this report is a table listing the six research priorities along with the nonexclusive topic areas within these priorities and detailed project descriptions submitted by most FAST Act grantees along with results to date for projects active during FY 2018.
- ***Performance Metrics:*** This report concludes with UTC Program-wide performance indicators used to measure productivity in meeting the research, technology transfer, education, and outreach goals at individual UTCs and for the UTC Program as a requirement of 49 U.S.C. 5505(b)(4)(B)(viii), as amended by the FAST Act.

REPORTING REQUIREMENTS

The FAST Act, which authorized funding for the current UTC program, requires a periodic review and evaluation of the UTC grant program. Section 5505(d)(2) of 49 U.S.C as amended by FAST Act specifies:

> "*Annual review and evaluation. Not less frequently than annually, and consistent with the plan developed under section 6503, the Secretary shall –*
>
> *(A) review and evaluate the programs carried out under this section by grant recipients; and*
>
> *(B) submit to the Committees on Transportation and Infrastructure and Science, Space, and Technology of the House of Representatives and the Committees on Environment and Public Works and Commerce, Science and Transportation of the Senate, a report describing that review and evaluation*."

BACKGROUND

Evolution of the UTC Program

The UTC Program has provided funding to a wide variety of university transportation centers since the late 1980s. USDOT initiated the UTC Program in 1988 as authorized by the Surface Transportation and Uniform Relocation Assistance Act of 1987 to fund transportation curricula and research at universities nationwide. The initial program included 10 competitively selected regional centers focused primarily on conducting research. The UTC Program has since changed significantly in size and scope, evolving to meet the shifting needs and interests of the transportation community.

Since its founding, the UTC Program has been renewed with each surface transportation authorization including:

- the Intermodal Surface Transportation Equity Act (ISTEA) of 1991;
- the Transportation Equity Act for the 21st Century (TEA-21) of 1998;
- the Safe, Accountable, Flexible, Efficient, Transportation Equity Act: A Legacy for Users (SAFETEA-LU) of 2005;
- the SAFETEA-LU Extension Act of 2011; Moving Ahead for Progress in the 21st Century (MAP-21) in 2012; and
- the Fixing America's Surface Transportation (FAST Act).

ISTEA continued the 10 competitive Regional UTCs and designated nine others. TEA-21 also continued the 10 competitive Regional UTCs and designated 23 centers. TEA-21 additionally required 17 of these designated UTCs to compete for continuation funding for only 10 UTCs, reducing the total number of centers during the 2002-2005 grant period from 33 to 20.

With SAFETEA-LU came an increase in the number of UTCs from 20 Centers to 60 during the 2005-2010 grant periods. The legislation designated an additional 40 centers and continued the existing 20 competitive UTCs. Another major change occurred in 2011 with the SAFETEA-LU extension, the introduction of a competitive process for awarding funds to all UTC groups rather than holding competitions only for Regional or existing centers. The 2011 grant competition reduced the number of centers to 22.

MAP-21 authorized funding for up to 35 centers, and OST-R established a detailed, transparent process for the competitive proposal solicitation, evaluation, and grantee selection. Applicants for grant funding were required to demonstrate a commitment to broadening participation and attracting new entrants to the transportation field in order to enhance diversity. They were also asked to describe planned outreach or activities designed to increase interest in science, technology, engineering, and mathematics disciplines, and raise awareness of transportation careers among underrepresented groups including women and minorities. Minority institutions were encouraged to apply as the lead institution for a center or to be part of a consortium as an institution of higher education whose enrollment of a single minority or a combination of minorities exceeds 50 percent of the total enrollment.

The FAST Act's authorization of the UTC Program both sustains existing and establishes new and vital initiatives in research, education and workforce development and technology transfer that have benefited the U.S. traveling public and its transportation system over the years. The FAST Act authorized funding for up to 35 Centers with emphasis on accelerating and better coordinating research and innovation across multimodal systems. The FAST Act required establishing nonexclusive candidate topics areas within the six research priorities supporting departmental goals and allowing for the full breadth of cross-modal research. One of the ten regional awards must be given to a center focusing its efforts in the field of comprehensive transportation safety, congestion, CVs, connected infrastructure, and AVs.

UTC Center Role and Objectives

The role of these Centers is to:

- Advance transportation expertise and technology in the varied disciplines that comprise the field of transportation through research, education and workforce development, and technology transfer activities;
- Provide for a critical transportation knowledge base outside the USDOT; and
- Address critical workforce needs and educate the next generation of transportation leaders.

The UTC Program and each individual Center share the following objectives:

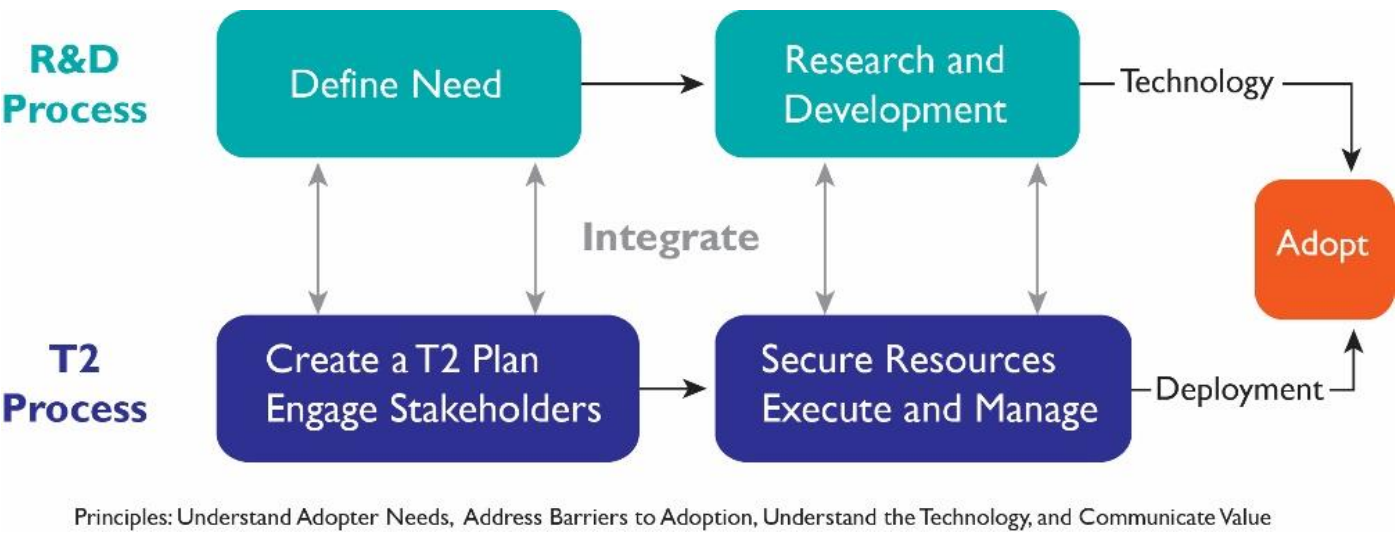
- **Research:** To conduct basic, advanced, and applied research, the products of which are judged by peers or other experts in the field of transportation to advance the body of knowledge in transportation.
- **Education and Workforce Development:** To provide an education program relating to transportation that includes multidisciplinary course work, participation in research and workforce development activities and programs to expand the workforce of transportation professionals.
- **Technology Transfer:** To deliver an ongoing program of technology transfer that makes transportation research results available to potential users in a form that can be implemented, utilized, commercialized, or otherwise applied.

TECHNOLOGY TRANSFER

To better integrate technology transfer into the transportation research process, the UTCs are now required to develop Technology Transfer Plans (referred to as T2 Plans). T2 Plans guide and strengthen the UTCs technology transfer efforts by making research results available to potential users in a form that can be implemented, utilized, commercialized, or otherwise applied. The change from an optional to a mandatory T2 Plan for each UTC was initially announced at the UTC Directors' meeting held during the Transportation Research Board Conference in January 2018, followed by an official memo[3] sent to 32 UTCs in April 2018. The 32 grant agreements that went into effect November 30, 2016, required development of T2 Plans outlining their steps toward improved technology transfer and deployment of research outcomes by July 31, 2018. The three newly awarded grants were to submit their T2 Plans by October 30, 2018. The annual review of UTC performance documents including the T2 Plan will determine if UTCs meet program requirements and the statutory mandate. Where there are instances of insufficient performance, USDOT can withhold additional funding or pursue suspension/termination of the federal award.

The 35 FAST Act UTCs' T2 Plans now describe the technology transfer activities. As shown in Figure 1 below, the UTCs will undertake to ensure the successful transfer of information and technology to those who can use it, especially transportation practitioners. Each plan must outline the people and organizations involved in implementing the T2 process along with identifying their roles, planned activities, and the desired outcomes that will increase the effectiveness of their technology transfer activity in transportation. Additionally, the T2 Plans must align with USDOT Strategic Plan FY 2018-2022 to increase production of USDOT-funded tangible research outputs as a performance measure. The strategic plan calls for the requirement of providing performance measures in terms of number of tangible research outputs, outcomes, and impacts for each UTC's technology transfer plan. Thus, the number of tangible research outputs will now be a required performance measure for each UTC's T2 Plan.

Figure 1: Integrating T2 and Research & Development (R&D)



Source: Building a Foundation for Effective Technology Transfer through Integration with the Research Process

[3] USDOT, Assistant Secretary for Research and Technology, Technology Transfer Plans Memorandum, April 16, 2018

At a minimum, a UTC's T2 Plan must:

- Identify and describe the involvement of stakeholders (including funding partners) in the research program;
- Assist stakeholders in implementing and deploying research outputs;
- Show the commercialization process of research outputs;
- Allow for the collection and use of licensing revenues to provide further support for research and technology transfer;
- Disseminate research results;
- Discuss how research outputs, outcomes, and impacts will be tracked and reported; and
- Describe how corporate research support will be increased.

UTCs must develop T2 goals and relevant performance metrics that they will use to measure the effectiveness of their T2 efforts. The Semi-Annual Progress Report combines the former Program Progress Performance Report and now serves as the foundation for the T2 Report that will be submitted semi-annually with the first report due April 30, 2019. The "Grant Deliverables and Reporting Requirements for 2016 University Transportation Centers" has been amended to reflect this new requirement.

Table 1. Research Terminology

Term	Definition
Research Output	Any new or improved process, practice, technology, software, training aid, or other tangible product resulting from R&D activities.
Research Outcome	Any changes made to the transportation system, or its regulatory, legislative, or policy framework resulting from R&D outputs. Examples include the full-scale adoption of a new technology technique, or practice, or the passing of a new policy, regulation, rulemaking, or legislation.
Research Impact	The impact of an R&D outcome on the transportation system, or society in general, such as reduced fatalities, decreased capital or operating costs, community impacts, or environmental benefits.

FOCUSED RESEARCH

The FAST Act required that one of the ten selected Regional UTCs must address the field of comprehensive transportation safety, congestion, connected vehicles, connected infrastructure, and autonomous vehicles.

The Center for Connected and Automated Transportation (CCAT) focuses its research efforts in those designated areas. CCAT is USDOT's Region 5 UTC. This consortium includes the University of Michigan at Ann Arbor in partnership with Purdue University, University of Illinois at Urbana-Champaign, University of Akron, Central State University and Washtenaw Community College.

CCAT emphasizes technology evaluation and deployments in realistic testing environments to address research questions in a comprehensive and accelerated manner. CCAT tests emerging technologies and concepts by leveraging the Ann Arbor Connected Vehicle Test Environment—a unique 'living laboratory' that has instrumented urban streets and highways, thousands of connected vehicles, motorcycles, bicycles, and smartphones. It also leverages Mcity, a state-of-the-art off-roadway facility for connected and autonomous vehicle testing and evaluation developed at the University of Michigan.

The Ann Arbor Connected Vehicle Test Environment aims to be the largest operational, real-world deployment of connected vehicles and infrastructure in the world. It has expanded to encompass the entire City of Ann Arbor – 29 square miles. It has 70 infrastructure sites to include three curve speed warning sites, four pedestrian crosswalks, eight freeway sites, one roundabout, five staging/testing sites, and 49 intersections that are instrumented. More than 2,650 cars, commercial trucks, and transit vehicles are equipped with global positioning systems and dedicated short-range communications. All devices pass industry certification testing and use production security.

Mcity is a simulated city providing safe, repeatable, off-roadway testing of advanced connected and automated technologies and system concepts. Occupying 32 acres on the University of Michigan Ann Arbor campus, the facility simulates a broad range of urban and suburban environments. This test environment includes four lane-miles or roads with intersections, roundabouts, roadway markings, simulated buildings, pedestrians and obstacles such as construction barriers that are designed to replicate the most challenging scenarios for connected and automated vehicles.

Mcity at University of Michigan Ann Arbor

The University of Michigan Transportation Research Institute in collaboration with the Michigan Department of Transportation, established the American Center for Mobility. Built on 335+ acres of existing infrastructure at Willow Run, and employing under-utilized state roadway infrastructure, it provides a comprehensive range of realistic road and weather scenarios in a concentrated and fully-instrumented and professionally-operated test facility.

CENTER PROJECT HIGHLIGHTS

The following are detailed descriptions of some of the research projects submitted by 32 of the 35 FAST Act grantees. The other three regions were re-competed due to a lack of meritorious candidates in the initial 2016 FAST Act competition for grants. Grants were not awarded for these regions until June 2018. Information is categorized by center type (National, Regional or Tier 1).

For each research project in this section, this report provides the project name, grantee name, Center's name, research priority, a detailed project description, outputs, outcomes, impacts, funding amount, and end date. Section 6503(c) of the FAST Act specifies six research priorities (Table 2, next page) that UTCs selected through the upcoming competition must address [improving mobility of people and goods, reducing congestion, promoting safety, improving the durability and extending the life of transportation infrastructure, preserving the environment, and preserving the existing transportation system].

In addition, the FAST Act charges the Secretary of Transportation with establishing nonexclusive candidate topic areas within these priorities. The research topics, listed under each priority area, were determined through a meeting of the USDOT Research, Development and Technology Planning Team, held on January 21, 2016 and input from the FAST Act implementation groups.[4] The foundation for the chosen topics is *Beyond Traffic – 2045: Trends and Choices* released in February 2015. This report is intended to support a continuing dialogue about the state of the U.S. transportation system, and to provide a framework that identifies both emerging and challenges to the system in coming years. The full report is available at https://www.transportation.gov/policy-initiatives/beyond-traffic-2045-final-report.

To coincide with the new technology transfer requirement, each Center project must focus on research outputs, outcomes, and impacts. Research outputs are used to improve the efficiency, effectiveness, and safety of transportation systems because of a new or improved process, practice, technology, software, training aid or other tangible product. Outcomes essentially are the application of outputs, such as changes made to the transportation system, or its regulatory, legislative, or policy framework resulting from research and development outputs. Examples of outcomes include:

- Increased understanding and awareness of transportation issues;
- Passage of new policies, regulation, rulemaking, or legislation;
- Increases in the body of knowledge;
- Improved processes, technologies, techniques and skills in addressing transportation issues;
- Enlargement of the pool of trained transportation professionals; and
- Adoption of new technologies, techniques or practices.

Impacts can sometimes take a significant amount of time to realize. Impacts are the effects of an outcome on the transportation system, or society in general, such as reduced fatalities, decreased capital or operating costs, community impacts, or environmental benefits.

Funding identified for each research project includes both federal and matching funds.

[4] USDOT, Assistant Secretary for Research and Technology, Action Memorandum to the Secretary on FAST Act Requirement: Secretarial Determination of Research Topics and Grant Amounts for the 2016 University Transportation Centers Program Competition, February 9, 2016.

Table 2. FAST Act Research Priorities[5]

Research Priority Areas	
1. Improving mobility of people and goods:	
• Increase access to opportunities that promote equity in connecting regions and communities, including urban and rural communities; • Smart cities; • Innovations to improve multi-modal connections, system integration, and security; Assistive technologies for those with physical or cognitive disabilities;	• Data modeling and analytical tools to optimize passenger and freight movements; • Innovations in multi-modal planning and modeling for high-growth regions; • Novel (non-traditional or alternative) modes of transport and shared use of infrastructure; and • Regional planning and setting of transportation priorities.
2. Reducing congestion:	
• Optimize the efficiency and reliability of travel for all transportation system users; • Improve operations, controls, and devices; • Urban logistics – last mile for both passengers and freight; • Land use and transportation planning;	• Novel (non-traditional or alternative) forms of freight movement; • Data Modeling and analytical tools to evaluate effects of shifting transit incentive structure; and • Ridesharing and alternative forms of transportation.
3. Promoting safety:	

• Vehicle and system automation across surface modes;
• Energy and hazardous material transport;
• Safety planning for all users:
  ○ Pedestrians and bicyclists;
  ○ Vehicular users; and
  ○ Integrated systems planning;
	• Application of transportation safety data and safety management systems;
	• Human factors and risk factor analysis;
	• Transportation worker safety:
	  ○ Construction zones;
	  ○ Emergency responders; and
	  ○ Trespass and vandalism.

4. Improving the durability and extending the life of transportation infrastructure:	

• Improving the durability and extending the life of transportation infrastructure;
• Application of new materials and technologies;
• Cyber and communications security;
• Condition monitoring, remote sensing and use of global positioning systems;
	• Asset management and performance management:
	  ○ Data accessibility and security, and
	  ○ Analytical tools;
	• Construction methodologies and management; and
	• Corrosion and aging infrastructure.

5. Preserving the environment:	

• Preserving the environment;
• Reduction of transportation system Greenhouse Gas emissions;
• Use of alternative fuels and energy technologies;
• Recycling infrastructure assets;
• Effects of new materials on the environment;
	• Environmentally responsible planning and construction:
	  ○ Multiple uses of existing infrastructure, and
	  ○ Noise and vibration reduction; and
	• Impacts of freight movement.

6. Preserving the existing transportation system:	
• Innovation in aligning transportation decision-making, funding sources, and mechanisms; • Data modeling and analytical tools to evaluate the effects of tolling and investment; • System response to disruptive events/resilience to disasters;	• Infrastructure preservation techniques and cost-effective maintenance practices; • Retrofitting and multiple uses of infrastructure to create efficiencies and reduce barriers to opportunity; • Workforce development and capacity building; and • Modal shifts.

[5] See Section 6503(c)(1).

Surtrac for the People: Upgrading the Surtrac Pittsburgh Deployment to Incorporate Pedestrian-Friendly Extensions and Remote Monitoring Advances

Grantee: Carnegie Mellon University

Center Name: Mobility 21, A National UTC for Improving Mobility of People and Goods

Research Priority: Improving Mobility of People and Goods

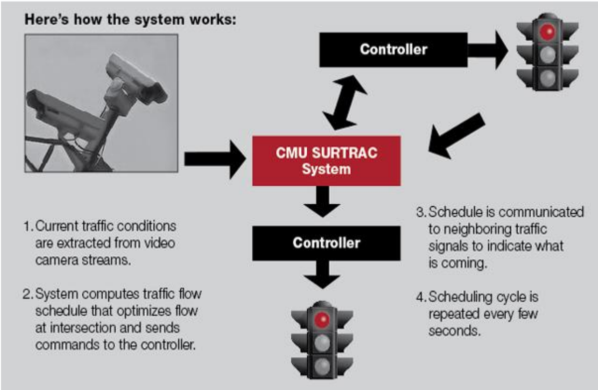
Research Project Funding: $154,696

Project End Date: June 30, 2019

Project Description: Partnering with the City of Pittsburgh and Rapid Flow Technologies, the commercial provider of the Scalable Urban Traffic Control (Surtrac) smart signal system, this project will upgrade and assess the Surtrac Pittsburgh deployment. This will include new coordination of traffic signals with pedestrian walk signals and assessing the upgrade to determine the impact on pedestrian crossing time at intersections, predictive modeling of traffic flows from detector information, and overall traffic flow optimization. The research focuses on the integration of new pedestrian detection capabilities to exploit vehicle-to-infrastructure (V2I) communication for smart transit priority and other vehicle expediting services, and providing pedestrians with disabilities improved technology for safe intersection crossing. The anticipated result of this project will allow for enhancing the existing technology to make intersections safer, incorporation of pedestrians, and improvement of vehicle throughput.

Outputs: Expected project outputs include preparation of the Surtrac network for further research, development, and deployment of new technologies, e.g., pedestrian detection capability, and for further expansion of the system. This includes the development of new algorithms for software applications and installation/integration of software at signalized intersections. This project will also assess the upgrades of the coordination of traffic signals with pedestrian walk signals, predictive modeling of traffic flows from detector information, improved mobility for all system users and overall traffic flow optimization.

Outcomes/Impacts: Expected project outcomes include (1) significantly greater amounts of walk time for pedestrian traffic (including pedestrians with disabilities—resulting in safer intersection crossing), and (2) further improvements to overall vehicle flows. Since 2012 the UTC has been supporting Surtrac deployment. Carnegie Mellon's lead principal investigator for Surtrac has worked with the City of Pittsburgh, the Southwestern Pennsylvania Commission, Pennsylvania DOT, University of Pittsburgh Medical Center, local foundations and neighborhood groups on a pilot deployment of Surtrac in Pittsburgh, PA. Deployment results showed a 40% reduction in vehicle wait time and a 20% reduction in emissions at nine intersections. Surtrac has expanded to 50 intersections and has now leveraged USDOT Advanced Transportation and Congestion Management Technologies Deployment grant and Pennsylvania DOT grants to support an additional 150 intersections in Pittsburgh. With two patents on this technology, the lead principal investigator spun off a Pittsburgh-based company, Rapid Flow Technologies, that has created eight jobs and currently has commercial deployments in Atlanta, Needham and Quincy, MA, and Portland, ME.



SURTRAC Adaptive Traffic Signal System

Land Use and Transportation Policies for a Sustainable Future with Autonomous Vehicles: Scenario Analysis with Simulations

Grantee: Portland State University

Center Name: National Institute for Transportation and Communities (NITC)

Research Priority: Improving Mobility of People and Goods

Research Project Funding: $173,779

Project End Date: November 14, 2019

Project Description: As AV technology matures in the coming decades, policymakers and the public face great uncertainties and challenges. How will we consider the potential impacts of AV on our communities and travel patterns to make effective long-term investment and policy decisions? On one hand, self-driving cars could increase the total amount of driving by effectively increasing roadway capacity and lowering costs of travel. On the other, they may reduce it by enabling more carsharing and ridesharing, improving access to transit, and reducing parking supply. Policymakers and researchers do not have a suitable conceptual framework or modeling tools to comprehensively assess the likely long-term effects of AV and how to preempt possible adverse effects with policies and investment. Building on an earlier NITC project that conducted a nationwide survey about the likely adoption of AV, this project investigates long-term travel and land use outcomes in response to the adoption of AV and then develops tools to help policymakers better understand the effectiveness of various policy scenarios.

Outputs: Survey results show that even though there are reservations about AV technology many survey respondents would shift to use it if the cost is low. Survey respondents also indicated an interest in ridesharing with others if it delivers sufficient cost savings. Findings will be used to develop a better travel demand model that will allow researchers and practitioners to create and run simulations that consider the impacts of AVs, ridesharing, carsharing, and new mobility options. This includes the methodology and outcomes of the scenario simulations used in the research. The model will be an open source software tool.

Outcomes/Impacts: Current transportation policies and investments are developed around personal vehicle ownership and do not account for the new mobility options such as ridesharing, carsharing, and the eventual proliferation of AV. AV adoption has the potential to increase driving, but carefully crafted policies may help address the negative effects of that increase.

This research will help agencies understand the long-term effects of AV on travel and communities. It will also help inform agencies on the policy and infrastructure investment decisions required—such as what needs to be built or what investments need to be made to accommodate these new mobility options.

Understanding how autonomous vehicles will affect travel demand and land use can help regions make master planning and investment decisions.

Local Government Pavement Improvement: Improving Expertise and Practice

Grantee: University of California, Davis

Center Name: National Center for Sustainable Transportation

Research Priority: Preserving the Environment

Research Project Funding: $209,843

Project End Date: August 15, 2018

Project Description: City and county governments bear responsibility for 80% of the roadway pavement lane-miles in California, carrying 45% of the vehicle miles traveled. However, these governments, facing a growing backlog of projects, need new approaches to reduce the costs of preservation, maintenance, rehabilitation, and reconstruction while also minimizing environmental impacts. Much of federal and state investments in pavement-related research, development, and implementation is focused on the problems and capabilities of state departments of transportation, as is much of the national effort to provide professional outreach and training in pavement technology. Some of the new technologies are also relevant to local governments, though this information is not making its way to cities and counties in a form that is useful to practitioners. Prior to this project, California and some other states did not have a systematic approach for delivering technical content to local governments to help them improve both cost and technical effectiveness. The need for implementation assistance is especially acute for permeable pavements, which offer benefits for flood control and stormwater quality, as well as active transportation. The project included a national workshop, sponsored by the National Pavement Contractors Association and others, the goal of which was to expand knowledge and remove communication barriers to further the adoption of permeable pavement of all types.

Outputs: A white paper, "*Local Government Pavement Research, Development and Implementation Organization in Several States*," provides a summary of best practices in other states and recommendations for California. Recommendations include the establishment of a center focused on local government pavement needs, with the mission of supporting the improvement of city and county pavement practices. The white paper and subsequent work with state associations for cities and for counties led to the creation of the City and County Pavement Improvement Center (CCPIC).

With limited initial funding, CCPIC has developed and facilitated initial trainings, produced technical briefs for best practices, and worked with the associations to set up a local government-controlled governance board. The permeable pavement workshop team identified gaps in knowledge and other barriers that were perceived to be holding back the full deployment of pavements that can simultaneously solve transportation, stormwater quality, and flood control problems. The workshop brought together a diverse group of stakeholders from the planning, stormwater quality, flood control, and pavement communities to listen to presentations, exchange ideas, and discuss unanswered questions identified by the group. The results of the workshop were used to produce a Permeable Pavement Road Map to fill the gaps in knowledge, processes, and guidance.

Permeable pavement testing equipment

Outcomes/Impacts: The County Engineers Association of California, California State Association of Counties and League of California Cities used the white paper to guide the creation of CCPIC in California. The roadmap is being used by the pavement industry to organize themselves with government, seek funding and move forward with the technology.

Completing the Picture of Traffic Injuries: Understanding Data Needs and Opportunities for Road Safety

Grantee: University of North Carolina, Chapel Hill (Lead); University of Tennessee, Knoxville; Florida Atlantic University; University of California, Berkeley

Center Name: Collaborative Sciences Center for Road Safety

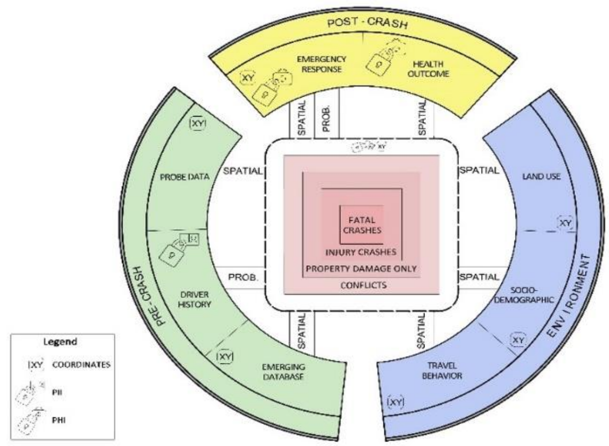
Research Priority: Promoting Safety

Research Project Funding: $220,000

Project End Date: November 30, 2018

Project Description: Police-recorded crash data has improved over time, but still fails to report all aspects of crashes that are important to developing a full understanding of crash mechanism, injury burden, pre-crash conditions, and ultimately total health and cost outcomes. This project aimed to map disparate data sets to inform questions surrounding crashes, build linkages between police-crash datasets and other datasets (i.e., incident-oriented data, spatial data, emerging datasets), and scale up data integration efforts to larger geographic areas. It provides background, rationale/motivation, and a thorough literature review of approaches to enhance integrated safety data and analytics. Five case studies illustrate how data linkage can aid in completing the picture for transport safety analysis. Each case study highlights different approaches and advantages to utilizing a subset of linked data. This work shows amore "complete picture" of crashes and injuries and enable researchers and practitioners to improve their applications of integrated data through modeling, policy-making, and data visualization. Ultimately, enhanced safety data integration will help tell more compelling safety stories to guide traffic safety improvements.

Outputs: This effort resulted in the development of a final research report on linked/integrated safety data systems, an appendix describing individual datasets and their linkage opportunities, and five case studies showcasing the importance of data integration. To date, six journal articles were produced and are under review; one has already been accepted for publication by *Accident Analysis and Prevention*. Three datasets, used to create the case studies, were also produced.



A complete picture of crashes can be conceptualized in this figure, where crash outcome data (e.g., police crash or near data) are improved by adding complementary pre-crash, environment and post-crash data sets

Outcomes/Impacts: While only recently completed, this study has informed traffic safety researchers and practitioners on core traffic safety data needs and linkage opportunities. It has spurred four follow up studies to further investigate and enhance data linkage between crash and post-crash data, vulnerable road user data, spatial data, and data regarding opioid use and transportation safety outcomes. The research has led to a conference session at the upcoming Safe Systems Summit, bringing together Federal and State agencies to discuss data integration, and has informed local safety data integration efforts by Vision Zero cities (including Durham, NC). Plans are underway to examine opportunities to integrate the findings from these research studies into practice by hosting a national conference related to traffic data, the National Travel Monitoring Exposition and Conference, in 2020.

Factors Surrounding Child Seat Usage in Ride Share Services

Grantee: Virginia Polytechnic Institute and State University

Center Name: Safety Through Disruption (Safe-D) National University Transportation Center

Research Priority: Promoting Safety

Research Project Funding: $160,366

Project End Date: August 30, 2019

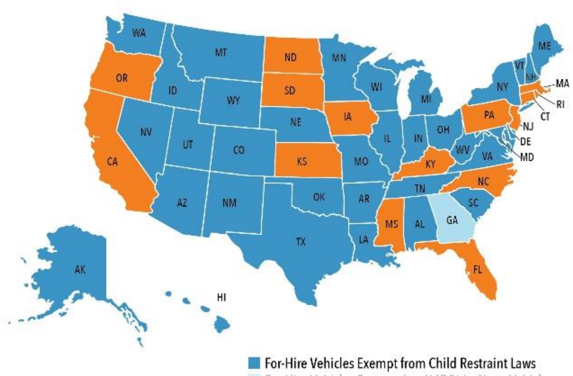
Project Description: Transporting children safely in ride-share vehicles has become a growing concern due to the increase in popularity of services such as Uber and Lyft, and the ongoing shift from owning a vehicle to using these services. In a research project funded by the Safe-D National UTC, researchers at the Virginia Tech and Texas A&M Transportation Institutes are collaborating to study the current state of child ridership and child safety seat use in ride-share vehicles.

The goal of this project is to understand how parents and caregivers currently transport children when using ride-share vehicles, how this behavior corresponds with child passenger safety laws across the United States, and how we can move the culture of child safety forward in this new era of ride-share transportation. The project consists of three core focus areas of data collection: a review of existing regulations surrounding child passenger transportation, a series of six focus groups conducted to gather in-depth information about caregivers' and rideshare drivers' attitudes and practices regarding child safety in ride-share vehicles, and an internet survey to understand rider and driver behaviors and attitudes more broadly using a national sample.

The data from these three data collection efforts are currently being combined into a final report and an outreach website described in the section below.

Outputs: An informational website that is being designed will serve as the primary public-facing output to present information about local regulations regarding child passenger safety in ride-share vehicles to riders and drivers, including hyperlinks to regulations for each state, along with guidance on general child passenger safety with links to other sites that focus on topics such as child seat selection and installation. The website will be highly accessible and easy to use across a broad population, including use on portable devices. The research partners are teaming with a popular ride-share service to publicize this website and plan to work with this service to highlight it through their social media presence and via direct driver contacts. In addition, a final report will be publicly available for interested parties.

Outcomes/Impacts: This project has several meaningful outcomes. First, it provides a comprehensive and in-depth overview of how parents and caregivers currently transport their children when using ride-share services, and how this aligns with legal requirements around the country. Second, it provides a valuable reference that parents, ride-share drivers, and others can use to identify child passenger regulations in their state in the form of a publicly-accessible website. The project highlights the shared responsibility of both driver and ride-share user while transporting children who are safest riding in child safety seats.



State-by-state exemptions for child seat restraint laws

Regional Centers

Performance Measurement & Management Using Connected & Automated Vehicle Data

Grantee: University of Florida

Center Name: Southeastern Transportation Research, Innovation, Development and Education Center

Research Priority: Reducing Congestion

Funding: $235,886

Project End Date: August 31, 2019

Project Description: Transportation system performance measurement is a key component in congestion management as well as in setting agency priorities and making policy decisions. Effective estimation of system performance requires detailed data from multiple sources combined with advanced data management and analytics. Emerging connected and automated vehicle technologies, shared autonomy, and shared mobility will significantly affect transportation system performance. They will also increase data quantity and quality and allow estimation of new performance measures (e.g., door-to-door travel times, queue locations, real-time safety risk assessment, etc.). This project investigates the estimation of currently used and new system performance measures based on data generated by the above mentioned emerging technologies fused with data from existing sources such as transportation agency sensors, private sector vendors, incident and work zone databases, weather data, signal controller data, and other data sources. The derived measures will provide critical information as input into public agency decisions.

Outputs: Products generated from this research include: 1) a methodological framework for estimating transportation system performance measurement using CV data for use by transportation agencies when investing in CV technology; 2) proof of concept to evaluate the effectiveness of utilizing CV data instead of or to supplement existing data sources to calculate currently used performance measures as part of agency decision making processes; and 3) demonstration of the use of CV data to estimate new mobility, reliability, safety, and environmental measures that cannot be estimated using currently available data to enhance long-term (off-line) and short-term (real-time) agency decisions.

Outcomes/Impacts: This project will provide an important framework and methods to enable transportation agencies to use connected vehicle data in their performance-based planning, design, planning for operations, and operations processes. In addition, this product from this project will allow the estimation of existing and new mobility, reliability, safety, and environmental measures that can be used to assess highway performance. These measurements will support congestion-reducing goals and objectives at the national, state, regional, and local levels; and will help operationalize performance management strategies.

Connected vehicles provide and receive a variety of information to and from other vehicles and the infrastructure

Connected Automated Vehicle Testing Scenario Design and Implementation Using Naturalistic Driving Data and Augmented Reality

Grantee: University of Michigan

Center Name: Center for Connected and Automated Transportation

Research Priority: Promoting Safety

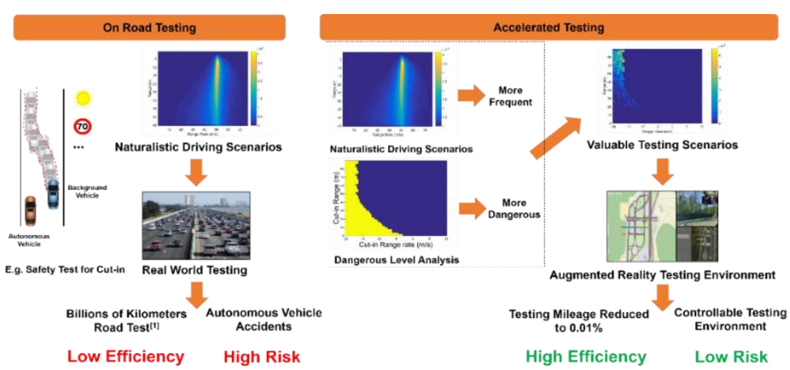
Research Project Funding: $131,015

Project End Date: March 29, 2019

Project Description: Testing and evaluation is a critical step in the development and deployment of connected and autonomous vehicles (CAVs), yet there is no systematic way to design representative scenarios for validating CAV systems. In this project, researchers investigated how to design representative testing scenarios for CAVs systematically by mining and examining crash and naturalistic driving databases. A hierarchical structure is proposed to describe scenarios, and three levels of scenarios are defined. A small set of critical scenarios were chosen from the entire scenario space to generate the scenario library, by considering both the difficulty level and frequency of the scenario occurring in the real-world. Furthermore, researchers also included CAV mobility into the evaluation framework, which is defined as whether a CAV can finish a driving task successfully and efficiently within a given time. An adaptive evaluation method was proposed to determine a CAV's mobility level. The proposed scenario generation framework was integrated within the augmented reality testing environment to provide a safe and cost-efficient way to evaluate CAVs.

Outputs: Four outputs will be delivered in this project: (1) a systematic procedure for defining CAV testing scenarios and identifying critical components; (2) establishment of a framework for generating a representative testing scenario library; (3) validation and evaluation of CAV safety and functionality by using the proposed procedure and framework; (4) a prototype system that includes a number of exemplary testing scenarios combining real CAV and the augmented reality testing environment in the Mcity test facility.

Outcomes/Impacts: The results of the project can be used as a guideline to create a comprehensive testing scenario library; thus, increasing the body of knowledge and understanding amongst lawmakers and transportation professionals as they develop CAV testing regulations and standards. The automakers can also utilize the library to accelerate their CAV testing procedure to ensure the safety and efficiency necessary to make driverless technology viable. Ultimately, the project lays a foundation for generating a complete and comprehensive set of scenarios that can systematically evaluate the "intelligence" of CAVs.



Cost Effective Methods to Retrofit Metal Culverts Using Composites

Grantee: Louisiana State University (Lead); University of New Mexico

Center Name: Transportation Consortium of Southcentral States

Research Priority: Improving the Durability and Extending the Life of Transportation Infrastructure

Research Project Funding: $188,000

Project End Date: August 31, 2019

Project Description: Metal culverts have served as a common element in the transportation infrastructure since the mid-1950s due to low initial cost, ease of fabrication, and simple construction methods. In the last decade, these culverts have experienced alarming levels of collapse and corrosion nationwide. This has led to limited operating life, service failures, and costly repairs. Furthermore, current repair techniques are also prone to corrosion and degradation. There is an immediate national need to develop a cost-effective, corrosion-free technique to retrofit corroding metal culverts.

This study proposes a cutting-edge method that uses Glass Fiber Reinforced Polymers (GFRP) as a fit-in liner for complete repair and rehabilitation of corroded metal culverts. GFRP is corrosion-free, lightweight, and does not require additional protective coatings or maintenance. This study partners with the New Mexico Department of Transportation to: (1) develop a state-wide culvert database; (2) conduct a series of laboratory tests to investigate bond characteristics between GFRP and corroded metal surfaces; (3) develop and select the most optimal GFRP liner technique; and (4) conduct a full-scale laboratory test of a GFRP-lined metal culvert to investigate field suitability.

Outputs: This study will produce a cost-effective, corrosion-free technique for retrofitting metal culverts using GFRP material. Specifically, a methodology is being developed to design (determining the required number of glass fibers, orientation, and thickness) and install (determining bonding methods, installation techniques) a GFRP liner to repair corroded metal culverts.

Outcomes/Impacts: The developed technique will significantly extend the service life of retrofitted metal culverts to beyond 75 years, more than doubling the current average operating life of 30 years. Furthermore, the technique is suitable for field installation and capable of nationwide adoption and implementation.

Full-scale laboratory testing of GFRP-lines metal culvert

Investigation and Development of a MASH Test Level 6, Cost-Effective, Barrier System for Containing Heavy Tractor Tank-Trailer Vehicles and Mitigating Catastrophic Crash Event

Grantee: University of Nebraska, Lincoln

Center Name: Mid-America Transportation Center

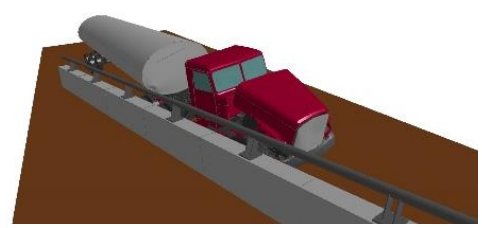
Research Priority: Promoting Safety

Research Project Funding: $210,886

Project End Date: September 30, 2018

Project Description: Large tanker trucks often transport hazardous and/or flammable chemicals through heavily-populated communities. Current barrier designs do not provide adequate protection in the event of a crash, leaving our communities and critical facilities, e.g., schools, hospitals, military bases, etc., vulnerable to the devastating and destructive effects of hazardous materials release. Although tractor-tank trailer crashes occur rarely, the effects of a crash can be catastrophic. To date, only one Test Level 6 vehicle containment system was successfully tested and evaluated according to National Cooperative Highway Research Report 230 that identifies safety performance criteria using a tractor-tank trailer vehicle. Unfortunately, the cost, height, and appearance of this Test Level 6 containment barrier have prevented its widespread implementation. Due to its current configuration, few Test Level 6 barriers have been utilized in the real-world thus far to prevent and mitigate situations such as: (1) cross median, opposing-traffic, vehicle crashes involving hazardous heavy tanker trucks along urban freeways and interstates and (2) tanker vehicle penetration or override of existing lower capacity, Test Level 4 or 5 barriers located on bridges, elevated road structures, or high volume roadways, which create potential catastrophic events near schools, malls, sports venues, concert arenas, military bases, international airports, critical government buildings, or other high-risk facilities.

A new, cost-effective, Test Level 6 vehicle containment system has been developed to prevent and/or mitigate the consequences of errant heavy tanker-truck vehicles striking opposing traffic on heavily-congested urban freeways and interstates as well as crashes into high-risk facilities or highly-populated areas. The new optimized barrier system provides adequate structural strength, investigate reduced heights, consider visual appeal for communities, implement height transitions for barrier ends, incorporate options for expansion/contraction joints, and remain safe for errant motorists operating light to heavy passenger vehicles.



Computer simulation of a tractor tank-trailer vehicle impacting a new prototype barrier.

Outputs: A new *Manual for Assessing Safety Hardware* (MASH) Test Level 6 containment barrier will be developed to contain errant tractor-tank trailer vehicles. The barrier will be evaluated using finite element analysis computer simulation, small-scale component and material testing, and full-scale crash testing. The final barrier safely contains and redirect vehicles ranging from 2,420-lb small passenger cars to 79,300-lb tractor tank trailers while also limiting vehicle climb, roll, and peak-impact forces in smaller cars and trucks. The barrier will be aesthetically pleasing while being economically competitive to existing Test Level 5 containment barriers.

Outcomes/Impacts: The newly developed, cost-effective MASH Test Level 6 containment barrier will improve the safety of our traveling public, protect those living and working in highly-populated areas or high-risk facilities, and mitigate the negative impacts of hazardous material spills on our nation’s infrastructure and economy.

Extending the Service Life of Older Bridges through Innovative Joint Design

Grantee: North Dakota State University (Lead); South Dakota State University

Center Name: Mountain-Plains Consortium

Research Priority: Preserving the Existing Transportation System

Funding: $160,000

Project End Date: July 31, 2018

Project Description: Due to age, rapid deterioration and increased traffic demands, many bridges on local highway systems throughout the region need replacement. A common issue among existing precast double tee (DT) bridges is the rapid deterioration of grouted longitudinal joints between adjacent girders. The grouted joint starts to crack after a few years in service, creating a path for water and deicing chemicals to reach and corrode the steel reinforcement. The design life of a typical precast DT bridge is expected to exceed 50 years. However, some bridges built less than 40 years ago are already in need of replacement. The conventional joint detailing of a precast DT bridge calls for a two-inch wide grouted joint with discrete welded connections. The new design developed in this project calls for a four-inch wide grouted joint with continuous overlapping steel mesh. The performance of the conventional and newly developed joint designs was examined through laboratory testing of two full-scale DT bridge specimens under fatigue and monotonic loading. A finite element model was used to verify the experimental results. The improved design was shown to mitigate water seepage and eliminate stiffness degradation under fatigue loading.

Outputs: The project resulted in a new joint design for precast DT bridges which has been adopted by the South Dakota Department of Transportation for new and replacement bridges. A detailed Mountain Plains Consortium report compares the performance of conventional and new joint designs and provides a handy reference for transportation practitioners.

Outcomes/Impacts: The new joint design can extend the service life of a DT precast girder bridge from less than 50 years to more than 75 years. The improved joints can be constructed with relative ease and at reasonable cost, making them ideal for new and replacement construction. The new design can be used in other precast bridge deck systems, thus broadening its long-term impact.

County bridge analyzed in research project needing replacement prototype barrier.

Integrated Traffic Flow Control in a Connected Network

Grantee: University of Southern California

Center Name: Pacific Southwest Region University Transportation Center

Research Priority: Improving Mobility of People and Goods

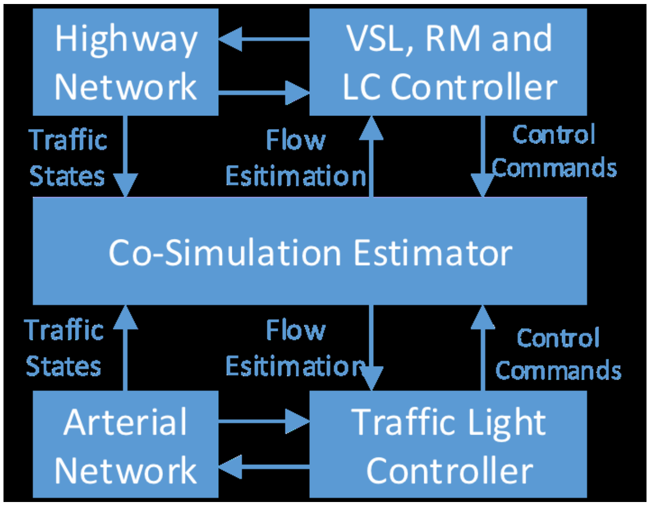
Research Project Funding: $100,000

Project End Date: December 31, 2018

Project Description: The purpose of this recently completed project was to use dynamic traffic control to reduce congestion associated with incidents and bottlenecks. While the techniques researchers developed can be applied in today's system, V2I and/or vehicle to vehicle communication (V2V) will allow the realization of their full benefits. Building upon promising preliminary results researchers developed lane change and variable speed controllers that integrate with ramp metering control and traffic light controllers to better control traffic flow. Preliminary results are based on treating all lanes in a highway as having the same density and traffic flow. The next step is to model the flow in each lane separately and allow different flow characteristics in each lane. A lane based model enables researchers to consider the traffic characteristics in lane; for example, the outside lane typically has more trucks and slower travel speeds than inside lanes. Researchers used the same cell transmission model and triangular fundamental diagram that was proven adequate in previous work, which models the flow in each lane. Researchers then used the model to develop variable speed limit controllers which will integrate with ramp metering and lane change controllers. A spatial model was used develop lane change controllers using an optimization procedure rather than the preliminary ad hoc method used in previous studies. The lane change controller generates commands for drivers to change lanes before reaching the incident or bottleneck to maximize throughput and reduce congestion.

Outputs: The output is a method to reduce congestion from incidents or bottlenecks by giving commands to drivers regarding lane changes. In the case of incidents, drivers can be warned upstream to reduce travel speeds, shift to an alternate route, or move to unobstructed lanes. At the same time, ramp metering can be adjusted to reduce (or temporarily eliminate) additional traffic entering the highway. In the case of bottlenecks, lane controls can add to the effectiveness of ramp meters by smoothing out traffic across lanes or directing lane changes for exits to avoid bunching. Using these control systems will result in reduced congestion. This research is an example of how V2V and V2I communications can be used to improve traffic flow.

Outcomes/Impacts: State and local transportation agencies will have access to improved incident management and monitoring systems to manage the transportation network. These methodologies and management tools will result in reduced travel time delays during incidents. Also, these systems will assist in maintaining normal operating conditions, safety and reliability of the transportation network.



Coordinated Control for Connected Network

Developing a Cost-Effective Bus-to-Pedestrian Near-Miss Detection Method Using Onboard Video Camera Data

Grantee: University of Washington

Center Name: Pacific Northwest Transportation Consortium

Research Priority: Improving Mobility of People and Goods

Research Project Funding: $92,000

Project End Date: June 30, 2018

Project Description: Public transit and pedestrian safety have gained increasing attention, as they influence the mobility of both pedestrians and transit users. Bus-to-pedestrian collisions often result in injuries, fatalities and insurance losses. For example, according to Washington State Transit Insurance Pool, a large portion of the collision-related transit losses are with pedestrians in the Washington region. To address the problems in bus-to-pedestrian near-miss detection, researchers developed a method that can detect bus-to-pedestrian near-miss events to support bus-to-pedestrian collision avoidance applications and provide an additional data source for safety statistical analysis. Specifically, researchers defined indicators for near-miss events in videos taken by onboard front-facing cameras, then developed a video processing framework to automatically detect and record near-misses.

Outputs: A cost-effective system to automatically extract vehicle-pedestrian near-misses from onboard monocular cameras is being developed. Experimental results show that the system is comparable to a commercial system with multiple camera sensors regarding accuracy. Further, the current system is developed for running on a desktop computer. In addition, researchers have begun transferring the current system to a real-time onboard near-miss detection system, taking real-time video inputs and generate warnings to drivers when any conflict is detected. This technology transfer required some modification of the algorithms since onboard computers are generally less powerful in terms of computational power. A promotional video has also been created.

Outcomes/Impacts: The results of this project reduces the number of bus-pedestrian related incidents and corresponding costs occurring. With the real-time onboard near-miss detection tool serving as a collision warning system, it is expected the safety of vulnerable road users will be improved. Second, the outputs enhances data sources for decision makers to use in planning and operations. The near-miss detection events collected by the system will be a new data source for traffic safety studies, which is likely to provide valuable suggestions for related agencies. In the long term, this system will impact driver' behaviors, thus better informing drivers of situation awareness of certain risky scenarios.

Potential conflicts with crossing pedestrians

Tier 1 Centers

Understanding Attitudes Towards and Behavioral Impacts of Transformative Technologies in Transportation

Grantee: Arizona State University

Center Name: Center for Teaching Old Models New Tricks

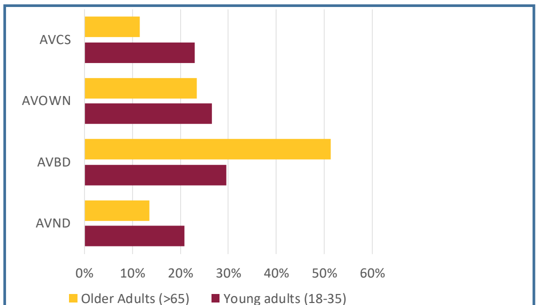
Research Priority: Improving Mobility of People and Goods

Research Project Funding: $650,000

Project End Date: September 30, 2019

Project Description: Emerging transportation technologies including electric and autonomous vehicles and emerging mobility services such as ride-hailing and vehicle sharing are bringing about transformative changes in the transportation landscape. With the emergence of new transportation technologies and services, it is critical that transportation forecasting models be enhanced to account for behavioral dynamics that will result from the increasing penetration of disruptive technologies in the transportation marketplace. To enhance transportation forecasting models, people's attitudes towards and perceptions of emerging technologies and services need to be measured and understood. Armed with such an understanding, it will be possible to specify and develop behavioral models that account for attitudes and perceptions, adoption cycles, and adaptation patterns. This project involves the collection of survey data from a sample of 1,000 residents in the Phoenix metro area to understand how the market perceives, adopts, and adapts to transformative transportation technologies. The focus of this Phase-I effort is to collect a rich dataset of users' attributes and current mobility choices, together with attitudes, perceptions and stated preferences towards new mobility options and technologies. This project is providing a data collection protocol and methodology that can be widely adopted in any jurisdiction interested in replicating the study.

Outputs: A key output of the project is the data collected through the survey effort. The data collected includes respondent characteristics (e.g., age, gender, income), current patterns of mode usage (e.g., weekly frequency of using bus, bicycle, and shared mobility services), and projected usage of emerging modes of transportation (e.g., ownership of AVs; frequency of use of mobility-on-demand services). The data include rich information on people's attitudes towards and perceptions of new mobility options. The project also includes many T2 activities to train practitioners on how to use the data collected to forecast travel demand under alternative future scenarios. Documentation and training materials are being produced and distributed so that agencies around the country can easily replicate the study approach and data collection protocols in their own jurisdictions.



AVND	Taking a taxi ride in an autonomous car with no driver present
AVBD	Taking a taxi ride in an autonomous car with a back-up driver present
AVOWN	Owning an autonomous car
AVCS	Participating in an autonomous car-share system for daily travel

Choice of AV Adoption by Age Group

Outcomes/Impacts: The data gathered through this project is helping to produce plausible scenarios of the future, and develop accurate forecasts of transportation system performance under alternative futures. This research will directly contribute to improved forecasting of travel demand, improved planning and design of transportation infrastructure (to accommodate changes in demand brought about by emergence of new transportation technologies), and improved formulation of policies and educational awareness campaigns that would ensure a safe, sustainable, and smart transportation system in the future. This project will result in more informed transportation plans and designs that could save thousands of lives, save thousands of person-hours of congestion, and greatly improve well-being and economic opportunity for all segments of population.

Uncertainty Quantification of Cyber Attacks at Intelligent Traffic Signals

Grantee: Clemson University (Lead); Benedict College

Center Name: Center for Connected Multimodal Mobility

Research Priority: Improving Mobility of People and Goods

Funding: $94,350

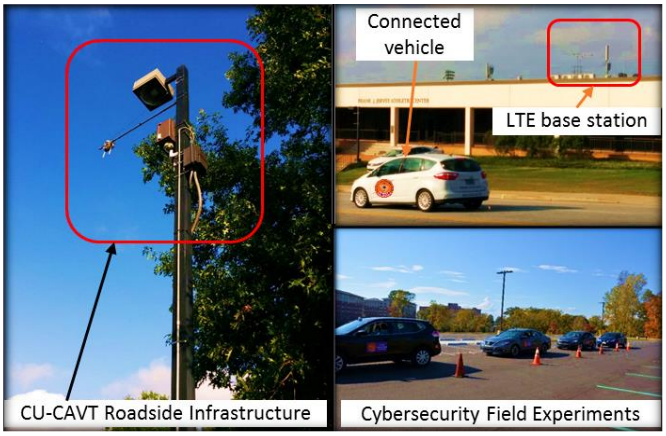
Project End Date: May 31, 2019

Project Description: This research supports the development of transportation cyber-physical systems (CPS) for CAVs by enhancing the functionality of the Clemson University Connected and Autonomous Vehicles Testbed (CU-CAVT). CU-CAVT provides a unique testing ground for future transportation technologies that will make travel more safe, secure, congestion-free and sustainable. Realization of the potential benefits of CAVs in terms of safety, security, mobility, and environmental sustainability is hindered by a lack of access to real-world and real-time data from CAVs to support the CAV applications development process. The first research focus is to develop a scalable and secure CAV application development platform (CAVDeP) that enables CAV application developers to build, debug, and test CAV applications in real time in order to provide the right level of protection for V2I/infrastructure-to-vehicle (I2V) wireless communication interfaces. The second research focus is on the cybersecurity of V2I and I2V communication interfaces through the development of a new software-based security architecture, called CVGuard. The third research focus is to develop CAV applications that coordinate the exchange of data between traffic signals, vehicles, and pedestrians in real time so that vehicles can maneuver in a safe, efficient and environment-friendly manner at signalized intersections. The fourth research effort is focused on improving the safety of AVs in a CPS environment through the development of a hazard detection and maneuvering approach, which can help AVs navigate safely during unexpected roadway events, whether caused by a deliberate action, (e.g., a roadblock), or unintentionally, (e.g., debris).

Outputs: The following are key outputs from the research effort:

1. Software packages for a scalable and secure CAV application development platform, CAVDeP.
2. Software packages for a cyber-attack detection and mitigation platform, CVGuard.
3. Software that processes information from traffic signals, pedestrians and vehicles to coordinate vehicle flow at intersections, ultimately improving safety, mobility and the environment.
4. Computer vision-based software that detects unexpected events and helps CAVs to maneuver safely.

CPS Infrastructure and Field Experiments



Outcomes/Impacts: CAV technologies will significantly reduce crashes, save fuel, reduce congestion delays, and increase roadway efficiency and cost-effectiveness. The CAVDeP platform is directly contributing to realizing these benefits by helping to move CAV technology from the lab to the road. CVGuard is providing robust security to help protect connected transportation systems from external cyber-attacks. The computer vision-based software will provide CAVs with maneuvering capability through unexpected events, which will ensure the public's trust in driverless vehicles while improving passengers' safety and comfort.

Functional Reliability of Tunnels and its Impact on Transportation Network Resilience

Grantee: Colorado School of Mines

Center Name: University Transportation Center for Underground Transportation Infrastructure

Research Priority: Improving the Durability and Extending the Life of Transportation Infrastructure

Research Project Funding: $330,000

Project End Date: June 30, 2020

Project Description: Tunnels are typically one of the most critical links in a transportation network and they can greatly undermine network resilience when they lose functionality, either entirely or partially, because of hazardous traffic conditions, increase traffic demand, and routine maintenance, repair or retrofit. Closure of or limited access to traffic tunnels is very costly and has negative impacts on the commuting public. Each tunnel owner or manager typically analyzes events that affect tunnel functionality on a case-by-case basis. This project aims at developing two fundamental products to enable this analysis, namely: 1) a tunnel operation data collection framework that can be adopted for critical tunnels across the country, and 2) a probabilistic framework for quantifying tunnel resilience (functionality loss) as a conditional distribution of event type and intensity.

Outputs: The research team has developed a framework for data collection and analysis for critical roadway tunnels in the United States to gather functionality-loss data from tunnel daily operation. A probabilistic framework for event-based tunnel functionality loss analysis has been developed to enable fast response to and recovery from events to reduce their impact and improve tunnel robustness and resilience. The project team has held multiple meetings and visits with the Colorado Department of Transportation to use the Eisenhower-Johnson Mountain Tunnel on I-70 as a test bed, and acquire extensive historical operation record data from the tunnel to test the newly developed framework. The research team collaborates with an industry partner to enable collection of critical tunnel operation data through a computer-based platform. The research team is also conducting a survey study with the department of transportation tunnel owners to identify the status of operation data collection for tunnels. The project has a very strong education and workforce development components. In Summer 2018, the Center organized two summer camps for about 30 grade school students to mentor and motivate them to pursue careers in science, technology, engineering, and mathematics, particularly in underground transportation infrastructure.

Grade school students and their teacher, and Colorado School of Mines researchers visiting the Eisenhower-Johnson Mountain Tunnel to learn about tunnel construction, maintenance and operations.

Outcomes/Impacts: The expected outcome of the research is to strengthen the decision-making process needed to address events that can affect tunnel traffic functional resiliency such as hazardous traffic conditions, increase traffic demand, and routine maintenance, repair or retrofit. The impacts of the improved operational capability and resiliency are increased traffic efficiency and safety, and lower tunnel operational cost.

The Air Quality and Health Impacts of Projected Long-Haul Truck and Rail Freight Transportation in the United States in 2050

Grantee: Cornell University

Center Name: Center for Transportation, Environment, and Community Health

Research Priority: Preserving the Environment

Research Project Funding: $40,543

Project End Date: December 31, 2018

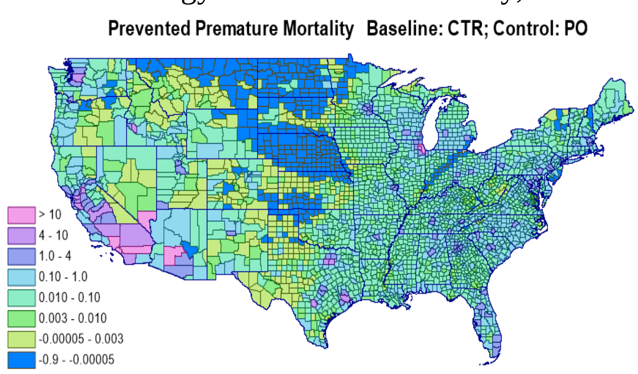
Project Description: Diesel engines are often used to power commercial freight transport. However, diesel emissions have a substantial negative impact on the environment and public health. Diesel exhaust emissions comprise significantly high amounts of particulate matter and its precursors, which can cause respiratory and cardiovascular problems and premature death. In this study, researchers focused on freight transportation sectors and link the evolution of freight emissions to air quality modeling and health impact assessment. By examining multiple emission scenarios based on varying policy assumptions, we systematically modelled the impacts of future freight emissions on $PM_{2.5}$ concentrations, and the associated change in health outcomes (e.g., premature mortality, morbidities) and economic benefits.

Outputs: An integrated modeling system (WRF-SMOKE-CMAQ-BenMAP) was established to incorporate the Weather Research and Forecasting (WRF) model, the Sparse Matrix Operator Kernel Emissions (SMOKE) system, the U.S. Environmental Protection Agency Community Multi-scale Air Quality (CMAQ) model and Environmental Benefits Mapping and Analysis Program (BenMAP) model. By considering fleet turnover, climate policy, and technology evolution, this study examined the air quality and public health impacts of projected freight emissions in 2050 over the continental United States. The study quantified changes in diesel fine particulate matter ($PM_{2.5}$) emissions on air quality, health, and economic benefits.

Outcomes/Impacts: With projected business and socioeconomic growth and fleet turnover in freight, simulated $PM_{2.5}$ concentrations have resulted in widespread reductions, between 1-1.5 μg m^{-3}. This translates into health benefits of 10.3 (95% CI: 6.9 – 13.6) thousand prevented premature deaths, corresponding to $107 (95% CI: $10 – $291) billion in health cost savings annually. The carbon pricing climate policy can obtain approximately 6% more health benefits nationally, it also affects the health outcomes regionally due to a demand transition from truck to rail. Further technology improvements to eliminate high-emitting conditions in the truck fleet provide substantial additional benefits. These results support that a combination of continuous adoption of stringent emission standards and improvements in vehicle technology and fuels are necessary, as well as rewarding, to meet the sustainable freight and community health goals.

Control (CTR) scenario - Stringent emission control policies are continuously applied under a high gross domestic product (GDP) growth rate (the U.S. GDP is projected to increase by 80% from 2005 to 2050, and the U.S. GDP per capita is expected to double in that period).

Climate policy (PO) scenario – This has the same GDP growth rate as the CTR scenario, but employs a climate policy in the form of a carbon tax to emulate a 450-ppm stabilization scenario. In this



Prevented premature mortality due to the changes in $PM_{2.5}$ concentrations between the PO scenario and CTR scenario (PO minus CTR) at the county-level

Modeling Adoption of Autonomous Vehicle Technologies by Freight Organizations

Grantee: Florida Atlantic University (Lead); University of Memphis

Center Name: Freight Mobility Research Institute

Research Priority: Improving Mobility of People and Goods

Research Project Funding: $179,523

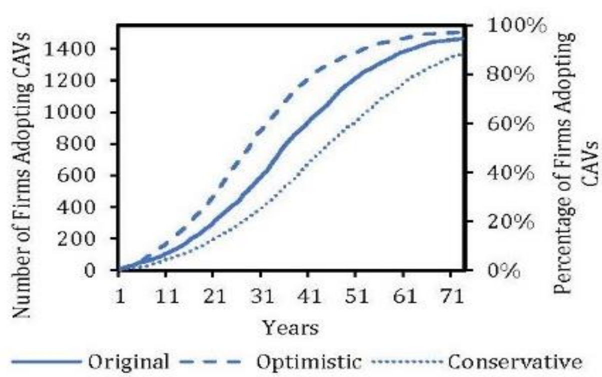
Project End Date: August 31, 2018

Project Description: Over the last several years, many new technologies have created opportunities to address the challenges facing freight transportation organizations. Innovations such as CAVs, truck platooning, smart parking systems, collaborative/shared logistics systems e-commerce, and Unmanned Aerial Vehicle or drone delivery systems may very well reshape the field of freight transportation. These innovations are influencing the behavior of consumers and organizations alike, altering the network of freight supply chains at all levels.

Despite the many potential benefits of incoming transportation technologies, there are several barriers that need to be resolved before widespread adoption of these innovations is possible. For example, CAVs face unresolved issues such as liability in case of a collision, balancing between communication and security/privacy, safety concerns, reliability of the automation system, necessary infrastructure changes, and regulatory legislation for CAV manufacturers. However, it is difficult to address these issues without first having information about the rate at which these innovations will be adopted. Transportation planners need to understand where and when these innovations will appear to prepare suitable legislation and infrastructure to accommodate the new vehicles. There is ample literature for individually adopted innovations, but there are few studies which deal with the adoption of innovations by an organization. Therefore, it is essential to develop a method for predicting the adoption of organizational innovations. This project endeavored to quantify organizational adoption using the theory of diffusion of innovations and applies the approach in a case study to understand implications using several assumed policies.

Outputs: The outputs of this project were 1) identification of emerging technologies which are influencing freight planning and operations; 2) a review of the existing theoretical and methodological approaches to organizational innovation adoption; 3) a survey of stakeholders to identify their inclinations towards the emerging technologies; 4) the development of a predictive model of the adoption of CAVs by organizations, and 5) an outline of future research steps necessary to meet the evaluation needs of local agencies, metropolitan planning organizations, and state departments of transportation.

Outcomes/Impacts: The research outcome provides: 1) capability within freight organizations to estimate future adoption rate of CAVs for purposes of assisting legislators and transportation planners to prepare and plan for short- and long-term smart infrastructure; and 2) the availability of a predictive model tool for state and local agencies for use in the planning process for the transportation system with CAVs and other organizationally adopted transportation innovations.



Potential freight CAV adoption with varying external (CoN) and internal influences (CoM)

Extending Maximum Length of the Folded Steel Plate Girder Bridge System, exceeding 100 ft. with Capability to Incorporate Camber

Grantee: Florida International University

Center Name: Accelerated Bridge Construction University Transportation Center

Research Priority: Improving the Durability and Extending the Life of Transportation Infrastructure

Research Project Funding: $110,000

Project End Date: March 29, 2019

Project Description: The nation's bridge inventory is aging, and most of substandard bridge spans needing replacement are under 100 feet in length. Concrete is currently the only economical material for these shorter girders. With available funding far less than bridge upgrade needs, a competitive alternative material is needed for accelerated replacement of a large number of substandard spans that are 100 feet and shorter in length.

The existing Folded Steel Plate Girder Bridge System (FSPGBS), developed by researchers at the Accelerated Bridge Construction (AWSC) University Transportation Center, provides an economical short-span steel bridge alternative for spans less than 60 feet in length. This trapezoidal-shaped beam is lightweight and well suited for ABC applications. Its cross-section is stable without internal or external cross frames for streamlined fabrication and is open along the bottom for ease of safety inspection. Construction contractors and design consultants have recommended the development of a modified version of the FSPGBS for span lengths approaching 100 feet to provide a steel girder alternative to concrete girder bridges in this span range. Under this project, the maximum length of the FSPGBS will be extended to about 100 feet. Construction of several test specimens by a steel fabricator and laboratory testing of the test specimens will be completed by early 2019.

Outputs: Project outputs include design and fabrication details for a next-generation FSPGBS with a strengthened cross-section to accommodate spans up to 100 feet in length. Additional output will include detail specification language for ABC installation with light cranes.

Outcomes/Impacts: Bridge construction costs are expected to be more competitive with the addition of the FSPGBS, with a maximum length of about 100 feet, as an ABC alternative, to concrete girders for short-span bridge replacements. Long-term durability of FSPGBS spans is anticipated to be very competitive due to the simplified details, allowing construction using local workforces in rural areas that need light construction equipment and ease of safety inspection.

SPGS test specimen prior to deck prefabrication

FSPGS with shorter length (less than 60 feet) was used in several bridges in 2016 and 2017 for replacing substandard bridges in Pennsylvania, as part of the State's major bridge replacement program.

Climbing Robots with Automated Deployment of Sensors and Nondestructive Evaluation Devices for Steel Bridge Inspection

Grantee: Missouri University of Science and Technology (Lead); University of Nevada, Reno

Center Name: Inspecting and Preserving Infrastructure through Robotic Exploration

Research Priority: Preserving the Existing Transportation System

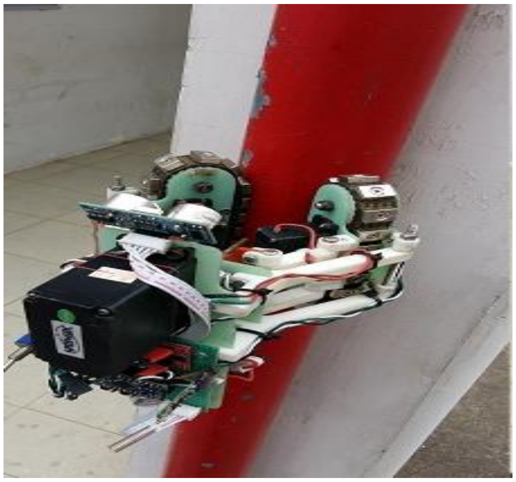
Research Project Funding: $321,238

Project End Date: December 31, 2019

Project Description: Currently, inspectors are required to manually access/climb to various areas of bridges and visually inspect their structural condition every two years. This project will develop and evaluate an alternative, automated platform that can support a nondestructive evaluation of bridges for faster, cheaper, safer and more consistent inspection. The platform is a battery-powered robot with magnetic wheels. It is small enough to climb on the surface of steel members without attracting travelers' attention, thus causing no interruption to traffic flow and no safety issue. It can potentially detect fatigue cracks, loose bolts, and steel corrosion when equipped with various devices such as an eddy current sensor, high-resolution camera, light detection and ranging sensor, and ultrasonic flaw detector.

Outputs: Two types of robots are being designed and built to climb on flat and curved surfaces, respectively. The flat-surface crawler includes one rigid body supported on four magnetic wheels in parallel. The curved-surface crawler has two rigid parts connected/hinged with a feed-crew mechanism and supported on two chains that can be automatically oriented to adhere to and climb on a curved surface. Their prototypes with control and localization systems have been evaluated for system performance in autonomous operation under various application settings. They can continue to operate autonomously for at least one hour on vertical faces and the underside of flat steel members and adhere strongly to curved steel surfaces while carrying a payload of up to eight pounds.

Outcomes/Impacts: This project will result in the filing of one patent on the design and fabrication of climbing robots on steel surfaces. Once tested to satisfaction, climbing robots will provide a new platform that can transform manual inspection into automated inspection of our nation's aging infrastructure, thus improving the efficiency, safety, consistency and cost-effectiveness of the inspection process. When equipped with various sensors, they will enable the acquisition of repeatable and quantifiable high-quality data towards a data-driven, cost-effective asset management of bridges. Once commercialized, climbing robots may provide new jobs in the manufacturing industry. A video demonstration of climbing robots can be viewed via this link: https://ara.cse.unr.edu/?page_id=11.



A roller-chain, tank-like robot on a curved surface

Bicycling and Pedestrian Infrastructure Improvements Realized in Communities of Less than 10,000 People

Grantee: Montana State University

Center Name: Small Urban, Rural and Tribal Center on Mobility

Research Priority: Improving Mobility of People and Goods

Research Project Funding: $53,933

Project End Date: January 2, 2019

Project Description: The presence of infrastructure for bicycles and pedestrians is a strong indicator of whether people in a community walk and bicycle. To date, much of the research related to infrastructure improvements for bicycle and pedestrian modes has focused on large cities. However, the funding mechanisms and support staff to implement this infrastructure in large cities are often not available in small communities (those with less than 10,000 people), thereby making improvements in these areas especially challenging. Yet, a community that can implement such improvements can provide its citizens with additional transportation options. This research project, which focused on small communities in Maine, Minnesota, and New Hampshire, serves as a building block in understanding the current state of bicycle and pedestrian infrastructure implementation by first identifying and studying locations that have successfully made infrastructure improvements (and comparing them with communities that have not or only minimally invested), synthesizing these findings, and identifying common trends across the communities. Of the 82 interviews conducted across 30 communities in Maine, Minnesota, and New Hampshire, characteristics found to be associated with small communities reporting success include 1) reported adherence to speed limits; 2) communities having many project champions; and 3) various programs that support walking and bicycling, a bicycling and pedestrian group, and a community approval process.

Outputs: People need safe, easy and convenient ways to get where they need to go, and roads are often barriers for people walking and biking. Because of this research, the Minnesota Department of Transportation has created a new process to identify troublesome junctions/intersection in rural communities where populations are often low, traffic speeds are high, distances are far, and car ownership is spotty. The new methodology involved collecting video of people crossing and walking along the roads, reviewing and tabulating the information (traffic volumes, speeds, etc.), brainstorming safety countermeasures with all the jurisdictions involved, and working to evaluate and finally implement countermeasures.

Outcomes/Impacts: The results of this research highlighted potential policy changes that would allow smaller communities greater access to funding sources that do not require a match, modeled after the previous Safe Routes for School program, to implement bicycle and pedestrian infrastructure. The Minnesota Department of Transportation recognizes the barrier that finding match puts on smaller communities and is exploring any necessary legislative changes to improve funding opportunities. Funding is key to implementing infrastructure improvements that will improve pedestrian and cyclist safety, by reducing vehicle conflicts with pedestrians and cyclists. Further, by having safe infrastructure, more people may be likely to walk and bike.


Demonstration project in Troy, New Hampshire

Understanding Access to Grocery Stores in Food Deserts in Baltimore City

Grantee: Morgan State University

Center Name: Urban Mobility and Equity Center

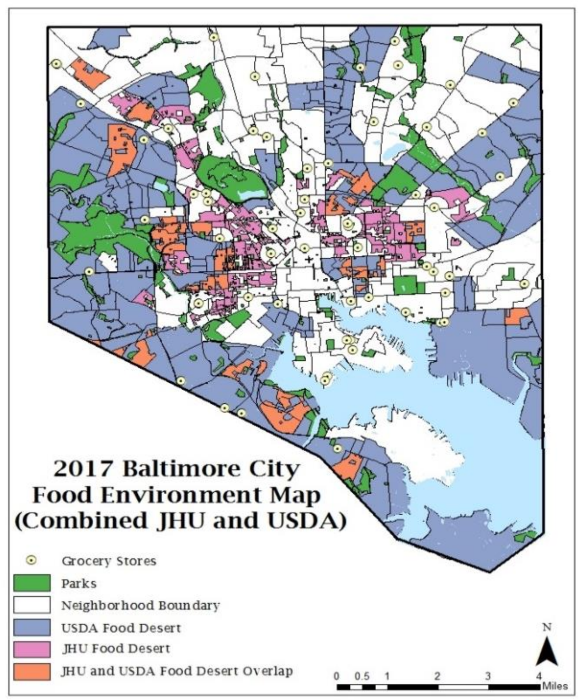
Research Priority: Improving Mobility of People and Goods

Research Project Funding: $90,165

Project End Date: June 30, 2018

Project Description: As Americans have moved from the city to the suburbs, relying on cars to get to the grocery store, urban areas have been left without access to quality food options. Known as "food deserts," these areas often limit transit-dependent residents to corner stores or fast food franchises that lack fresh, healthy food. This has far-reaching, cost-inducing health consequences, and nearly one in four Baltimore residents lives in a food desert. But determining what constitutes a food desert is more complicated than just calculating as-the-crow-flies distance to the nearest grocery store, a measure that doesn't reflect how people travel and shop. This project establishes a food desert metric score that considers public transportation access, vehicle ownership, and roadway network and it also gives a greater understanding of how people in food deserts try to access grocery stores. The new metric will be useful for community advocates and stores that might consider locating in a food desert. By surveying the travel patterns of residents of Baltimore, a clearer understanding of the factors that lead to reduced grocery access will be determined.

Outputs: The results of this study are being used to develop a partnership between Baltimore City's Department of Planning and an on-demand ride-sharing company to provide grocery store access to residents of West Baltimore. This study aids in the pricing and structuring of this partnership. This research will study the travel patterns of residents of Baltimore City to determine which socio-demographic and geographic factors affect grocery buying location and frequency. Using a survey of 500 residents, a food desert metric measures accessibility to stores using the following indicators: frequency of trips to grocery stores and the number of stores visited in a month. The factors include network distance, vehicle accessibility, income, and location of stores. In addition, this metric provides researchers and community advocates alike with an accurate way to measure people's access to healthy food options. The outcomes of this work may be used by governments to develop incentives to entice grocers.



Food deserts located in Baltimore City

Outcomes/Impacts: It is expected that the food desert metric score will be applicable to impoverished areas across the nation. This research is also expected to generate further policy discussion about the role of transportation in accessing grocery stores and consideration of current transit routes. It will help private industry determine where to locate stores – and find an untapped customer base – and provide community advocates with a way to document the needs of the community.

Monitoring and Control of Overweight Trucks for Smart Mobility and Safety of Freight Operations

Grantee: New York University (Lead); Rutgers, The State University of New Jersey

Center Name: Connected Cities for Smart Mobility towards Accessible and Resilient Transportation

Research Priority: Improving Mobility of People and Goods

Research Project Funding: $250,000

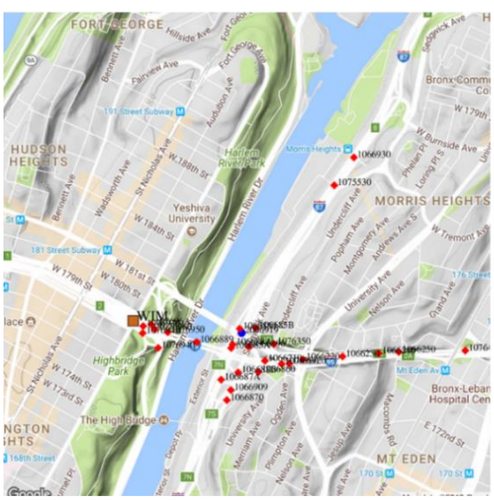
Project End Date: February 28, 2019

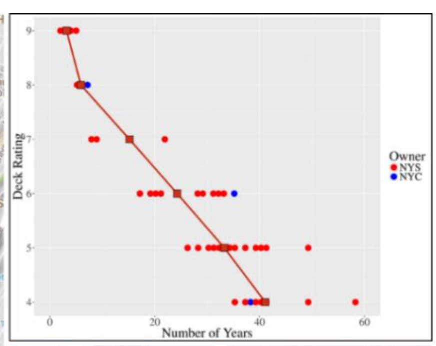
Project Description: This ongoing multi-year project is investigating technologies to screen overweight trucks, including a high-speed weigh-in-motion (WIM) system with high-accuracy sensors integrated with a license plate reader and/or camera. The project team is evaluating the feasibility of these technologies compared to current screening practices at weighing stations. During the first year of the project, infrastructure damage cost associated with overweight trucks and permits was evaluated to provide guidelines for developing policies and fee structures. Additionally, the team has reviewed and identified various types of WIM technologies available in the literature. The research team is working with the New Jersey and New York City Departments of Transportation on field implementation of the technologies that will be developed in this project.

Outputs: The outputs of this project will include several components:

- An application for damage cost evaluation of overweight trucks (accomplished during the first year)
- Calibrated WIM systems to be installed at locations in New Jersey and New York City (planned for second and third years)
- An application for autonomous ticketing of overweight trucks (ongoing)

Outcomes/Impacts: This ongoing project will produce provisional guidelines for autonomous ticketing using WIM technology and an integrated WIM system for screening trucks for overweight violations. These outputs will assist enforcement officers on highways with screening for overweight trucks without interrupting traffic flow, and would also have the potential to reduce infrastructure maintenance costs, thus improving durability and extending the lifespan of roads and bridges. Additionally, with the use of bridge deterioration models and life cycle cost analysis, this project isolated the damage cost incurred by overweight trucks, which can help transportation agencies accurately assess and recover these costs.





Bridge Deck Deterioration Model for New York City Bridges

Multi-Scale Models for Transportation Systems Under Emergency

Grantee: North Carolina Agricultural & Technical University

Center Name: Center for Advanced Transportation Mobility

Research Priority: Improving Mobility of People and Goods

Research Project Funding: $912,384

Project End Date: June 30, 2019

Project Description: The range of emergencies that can affect transportation networks varies from foreseeable weather-related events (e.g., severe storms), to man-made disasters (e.g., terrorist attacks) to epidemics (e.g., 2014 Ebola disaster). Over the past decade, the frequency and intensity of these disasters have increased, causing significant disruptions in local and regional transportation systems. How to prepare for and respond to a disruption in transportation systems is a complex decision incorporating a variety of factors, from system use to system preparation. Moreover, unexpected human behaviors (e.g., disordered movements) often occur during emergency situations. The human behaviors under panic affect the process of evacuation and further complicate decision-making related to the preparation of and response to disruptions. To address these challenges, project researchers have developed simulation models of human behavior in an airport during an emergency and are currently developing decision-making models for emergency response in a regional highway transportation system and a regional air transportation system. Researchers will integrate the multi-scale models to create a comprehensive decision-making framework for emergencies.

Outputs: The project team has been developing optimization and simulation models for emergency response in local and regional transportation systems. Optimization models developed in this project assist in determining which actions are taken to prepare for and respond to disruptions in transportation systems. Computational models based on particle dynamics and agent-based models are developed to investigate the effects of human factors (i.e., age, gender, handicap, group travel) and environmental factors (i.e., exits, barriers, layout) on the responses to the emergency situations in terms of effectiveness and efficiency, such as time taken to evacuate an area. Analyses and models in this project are conducted at two interdependent scales – at the local scale of individual transportation modes and transportation hubs (e.g. airports), and at a macro-scale across geographic regions or at a network level.

Outcomes/Impacts: The project will improve the effectiveness and efficiency of response activities in local and regional transportation systems during an emergency event, such as a hurricane. Deploying effective response activities to a hurricane can improve the mobility of people and disaster relief during and after a hurricane. Furthermore, the project will lead to insights into the environmental and human factors impacting emergencies, thereby assisting policymakers in designing and implementing a more efficient response to the emergent situations.

Highway conditions during the emergency evacuation associated with Hurricane Katrina

Exploring Strategies to Improve Mobility and Safety on Roadway Segments in Urban Areas

Grantee: San Jose State University (Lead); Howard University

Center Name: Mineta Consortium for Transportation Mobility

Research Priority: Improving Mobility of People and Goods

Research Project Funding: $281,250

Project End Date: December 31, 2018

Project Description: Congestion is a critical problem in dense urban areas. Several strategies have been developed to improve throughput, including signal re-timing and signal coordination. In urban areas, there are often combinations of signalized and un-signalized intersections and the Manual on Uniform Traffic Control Devices (MUTCD) has prescribed warrants for signalizing intersections. However, where unsignalized intersections do not meet the MUTCD warrants, their adverse effect on mobility is compounded. This research investigated driver compliance with stop-signs at all-way stop control (AWSC) intersections that are near upstream or downstream signalized intersections. Thirty isolated segments in the District of Columbia were examined and results indicate that to achieve a minimum compliance rate of 95% at AWSC intersection, a minimum distance of 1,298 ft. between the signalized and unsignalized intersections is required. The research showed that coordinating unsignalized and existing signalized intersections improves mobility and throughput.

Outputs: A model that can accurately predict driver compliance rates at all-way stop control (unsignalized) intersections based on the distance between the AWSC and adjacent signalized intersections was developed. This model can be used by urban jurisdictions to predict compliance rates at existing and planned AWSC intersections and to predict congestion and throughput improvements, i.e., reduced control delays and increased average travel speeds, through the installation of coordinated signals.

Outcomes/Impacts: This research may inform the MUTCD to better understand the impacts of signalized and unsignalized intersections in urban areas and to identify when a coordinated signal may lead to improved travel outcomes. Urban jurisdictions may implement the research recommendations at appropriate unsignalized intersections which could lead to reduced congestion and improved travel times.

Signalized controls could improve urban mobility at all-way stop intersections.

Developing a Transportation Emissions and Health Data Hub

Grantee: Texas A&M University

Center Name: Center for Advancing Research in Transportation Emissions, Energy and Health (CARTEEH)

Research Priority: Preserving the Environment

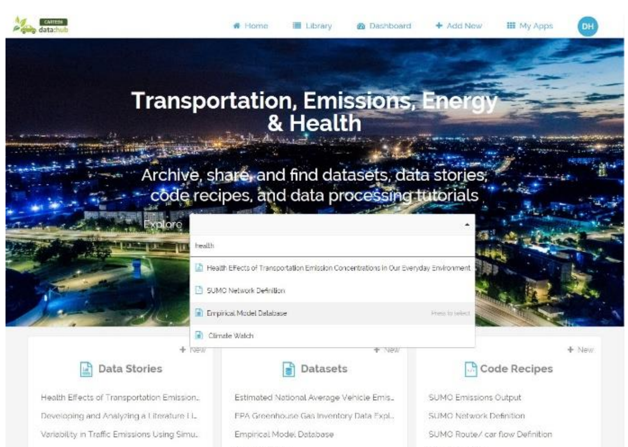
Research Project Funding: $250,000

Project End Date: November 30, 2018

Project Description: CARTEEH's research focuses on understanding the links between transportation and health, with an emphasis on transportation emissions and energy. The center's work involves collaborations amongst researchers with a wide variety of expertise in the areas of transportation, civil and environmental engineering, transportation and urban planning, public health, epidemiology, toxicology, and environmental science. The CARTEEH data hub supports and enhances these collaborations by allowing its researchers and students to share data, models, and ideas. Using the data hub, researchers will be able to acknowledge and understand the types of data generated by other research fields, as well as the models used to analyze them. The data hub not only supports the immediate data storage and organizational needs of CARTEEH, but also helps generate new research ideas, and increase the cost-effectiveness of data management by promoting reuse and leveraging of resources.

Outputs: This project resulted in a unique web-based platform that will underpin research activities undertaken within CARTEEH. It allows CARTEEH and non-CARTEEH researchers to explore the types of data available for transportation-health research, and thus help promote effective exploration in these areas. The code and methods used to develop the data hub and its broad vision as a repository for not only data, but also for models and ideas will be useful for other organizations seeking to develop effective, research-oriented data management practices that improve efficiency.

Outcomes/Impacts: The long-term goal for the data hub is for it to be used to organize and share data, models, and ideas amongst transportation and health researchers and practitioners, and to promote interdisciplinary collaboration. The data hub enables leveraging of existing data and ongoing and recently-completed research, to promote efficiency and eliminate unnecessary duplication of research and analysis efforts. This ongoing, 'self-organization' of materials will promote data reuse, and encourage the exchange and harmonization of research techniques and models used by different research organizations and other institutions.



Homepage for CARTEEH Data Hub

Center for Safety Equity in Transportation Baseline Data Establishment

Grantee: University of Alaska (Lead), University of Hawaii, Manoa, University of Idaho, University of Washington

Center Name: Center for Safety Equity in Transportation (CSET)

Research Priority: Promoting Safety

Research Project Funding: $1,100,000

Project End Date: August 31, 2019

Project Description: The efforts funded under CSET Baseline Data in year one (2019) are to identify and acquire data related to rural, isolated, tribal, and indigenous (RITI) transportation safety, recognizing that road users from RITI communities have a higher transportation risk. Pinpointing causal factors and identifying effective solutions to collisions involving RITI community road users requires solid safety datasets and analytical tools. These efforts are intended to establish a baseline using existing and relevant data to inform and evaluate CSET safety efforts.

Examples include:

- Identify and document existing crash data sources in RTI communities;
- Gather and integrate region-wide multiple-year (2010-2015) RITI community safety-related baseline data, including traffic flow characteristics, crash attributes and contribution factors, crash-related trauma data and medical records, weather conditions, etc.;
- Design and implement online data platform and its supporting relational database, such as the Structures Query Language database, to unify data storage and management;
- Develop methods for RITI community safety data quality control and cleaning;
- Document the characteristics of emergency response at RITI communities and identify gaps and opportunities for life-saving and injury mitigation;
- Conduct a time series analysis to explore the changes in crash risk and severity over time to identify the factors in rural and tribal areas considering all travel modes, including traditional motor vehicles and non-traditional modes such as all-terrain vehicles and snow machines.

Outputs: Two notable outputs include an interactive baseline data platform for visualizing and analyzing rural crashes (led by University of Hawaii at Manoa), and a regional multi-source database system for safety data management (led by University of Washington).

Outcomes/Impacts: These data and products will serve to measure CSET performance and overall contribution to RITI transportation safety over time and help the center better evaluate what work has been done and what the research needs of RITI communities are. These efforts will allow state departments of transportation and other transportation agencies to identify and track key safety issues for RITI areas in their jurisdictions.

Unique traffic composition in Fort Yukon, AK

Fatigue Crack Control in Waterway Lock Gate Pintle Locations Subjected to Multi-Modal Fracture

Grantee: University of Arkansas

Center Name: Maritime Transportation Research and Education Center

Research Priority: Preserving the Existing Transportation System

Research Project Funding: $176,347

Project End Date: August 14, 2020

Project Description: Lock gates are an important part of the transportation infrastructure within the United States, having many economic, safety, and environmental benefits over rail and highway transportation systems. Unfortunately, many existing lock gates throughout the United States have reached or exceeded their initial design life and require frequent repairs to remain in service. Unscheduled repairs often increase as gates age, having a local economic impact on freight transport which can create economic ripples throughout the nation. Fatigue and corrosion are key causes of unscheduled service interruptions, degrading lock gate components over time. One particularly complicated region where fatigue cracks occur is near the pintle, a ball-and-socket joint which allows gates to open and close. The objective of the proposed research project is to identify the root cause of multi-mode fractures within lock gate pintle locations and develop crack mitigation strategies (fatigue repairs for existing cracks).

Outputs: Results and conclusions from the proposed project will be disseminated in at least one peer-reviewed journal publication and conference proceeding. Additionally, the detailed finite element simulation data and material multiaxial tests will provide valuable information to other researchers investigating fatigue repair strategies (allowing calibration of other models against our experiments and simulations).

Outcomes/Impacts: Outcomes of the project include an implementable pintle fatigue retrofit strategy for the U.S. Army Corps of Engineers stakeholders, ultimately improving waterway infrastructure reliability. Additionally, novel multi-mode fatigue data for composite materials will be generated and disseminated in peer-reviewed publications. These data will also be accessible through the CERN Zenodo site. Design, implementation, and the effectiveness of the fatigue retrofit strategies will be documented in a detailed final report. Students involved in the project will gain unique research-based experiences and have opportunities to contribute to the Nation's waterway transportation infrastructure through interaction with the U.S. Army Corps of Engineering stakeholders during the project's duration.

Newt Graham Lock and Dam No. 18, Fort Gibson, Oklahoma

Multi-Modal Distributed Simulation Combining Cars, Bicyclists, and Pedestrians

Grantee: University of Iowa (Lead); University of Wisconsin-Madison

Center Name: Safety Research Using Simulation

Research Priority: Promoting Safety

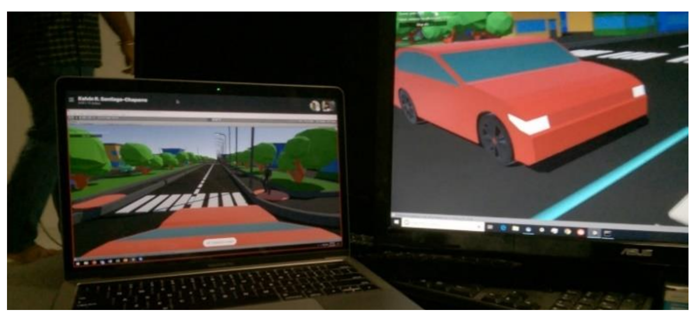
Research Project Funding: $285,812

Project End Date: August 31, 2018

Project Description: This project developed a connected multi-modal simulator platform that could be used to link vehicle, bicycling, and pedestrian simulators so that all participants in an experiment can share the same virtual environment in real-time regardless of their physical location. Task 1 of the project included the creation of Pedestrian and Driving Simulators – creation of a streamlined version of a Unity-based environment that can be networked with another Unity-based system that can be operated with off-the-shelf steering controls. Task 2 included of the addition of Networking Capabilities to Simulators – adding networking capabilities to enable two geographically-distant sites running the tool created on Task 1 to conduct experiments in which one site hosts a subject participating in the experiment as a pedestrian while the other site hosts another subject participating in the experiment as a driver. Task 3 included a of Creation of Test Scenario - a test scenario to understand the performance of the tool created in Tasks 1 and 2 over the network and how the performance can impact experimental results. Task 4 included a Test Experiment and Network Performance Data Collection - a pilot study to test to data logging procedures of connected simulator system developed in Tasks 1 and 2. Task 5 included development of a Case Study on Alternative Approach Using RTI Platform - a test experiment in which an approach similar to the one described in Tasks 1 through 4 will be employed using connected RTI simulators. Task 6 included Data Analysis and Report Preparation—analyzing data collected during the experiments to understand the benefits and limitations of a connected simulator environment for human-in-the-loop simulations.

Outputs: Software code was developed to facilitate the linking of two types of simulation platforms which resulted in improved agent-based simulation tools used by traffic engineers as a research tool. This project demonstrated that technology can be used to study the nature of complex vehicle and pedestrian interactions. Through multi-agent simulations, the behavior of multiple drivers who interact can be studied thus making it possible to develop better risk-taking models used in the traffic safety field.

Outcomes/Impacts: The future impact of this work will be an increase in public safety by reducing crashes involving pedestrians. This project lays the groundwork for improving transportation safety through the understanding of interactions between different types of road users, which is of particular interest to ride-share companies and automated vehicle developers currently, as well as legislative bodies and vehicle manufacturers and city planners in general.



A typical test in which the view of the simulation environment from the driver and pedestrian perspective (wearing an HTC VIVE) were compared to make changes to the simulation platform developed.

Modeling Tamping Recovery of Track Geometry Using the Copula-Based Approach

Title: Grantee: University of Nevada, Las Vegas (Lead); University of Delaware

Center Name: University Transportation Center on Improving Rail Transportation Infrastructure Sustainability and Durability

Research Priority: Improving the Durability and Extending the Life of Transportation Infrastructure

Research Project Funding: $50,000

Project End Date: September 30, 2018

Project Description: Assessing and maintaining track geometry within acceptable limits are key components of railroad infrastructure maintenance operations. Track geometry conditions have a significant influence on rider comfort and safety. To maintain the ride quality and safety of the track, maintenance activities pertaining to track geometry, such as tamping, are performed. Tamping enhances the track geometry quality but fails to return the track geometry to an as-good-as-new condition. Most studies have evaluated tamping recovery using deterministic techniques, which assume that tamping recovery is dependent on the track geometry quality prior to tamping. However, they fail to capture the uncertainty of the recovery values. Probabilistic approaches are increasingly being used to account for the uncertainty but fail to model the underlying dependence between the variables, which may exhibit nonlinear dependencies such as tail or asymmetric dependence. To accurately model the tamping recovery phenomenon, this research conducted by the University of Delaware employed the copula models in combining arbitrary marginal distributions to form a joint multivariate distribution with the underlying dependence. Copula models are used to estimate the tamping recovery of track geometry parameters such as surface (longitudinal level), alignment, cross-level, gage, and warp.

Outputs: The study developed a new model to estimate the recovery of track after damping. It is found that the track recovery after the tamping show high variations that can be captured only by copula-based models that can incorporate the "non-normal" behavior. The copula-based approach was found to be the most effective to model the tamping recovery process with the recovery behavior exhibiting a distinct three-parameter log-normal distribution in the case of surface, alignment, and warp and a three-parameter log-logistic distribution in the case of cross-level and gage. It is imperative to examine all the track geometric parameters and not focus on one or two parameters. Similarly, non-normal behavior was observed for the track quality condition before and after tamping.

Outcomes/Impacts: The results of this activity can be used to improve the quality of track maintenance by providing better guidance on how to improve the effectiveness of the track tamping operation. This, in turn, leads to a better track condition, improved ride quality, and reduced overall maintenance cost. In addition, the results can help develop improved track maintenance scheduling models by providing a better understanding of the quality of the track, its overall condition, after tamping maintenance. This will result in improved maintenance efficiency and reduced maintenance costs. Finally, by better understanding the tamping recovery phenomena more effective maintenance management models can be developed that will result in better and more durable track conditions, with corresponding improvements in ride quality and safety.

Production Tamper

Optimal Variable Speed Limit Control for Mixed Traffic Flows in a Connected and Autonomous Vehicle Environment

Grantee: University of North Carolina, Charlotte

Center Name: Center for Advanced Multimodal Mobility Solutions and Education

Research Priority: Improving Mobility of People and Goods

Research Project Funding: $90,007

Project End Date: April 30, 2019

Project Description: Traffic congestion occurs frequently with continually increasing traffic demand (including both passenger cars and heavy vehicles), which is detrimental to transportation mobility, efficiency, the environment, and safety. Due to a limited budget, government agencies at the local, state, and federal levels must work together to seek new ways to meet increasing traffic demand rather than simply relying on the physical expansion of roadways. As such, active traffic management strategies have been proposed and used by transportation researchers and practitioners to optimize existing roadway networks. Variable speed limit (VSL), has received increasing attention and been recognized as a promising way to relieve traffic congestions. Even though a lot of promising results have been obtained from the studies on VSL controls, several critical issues related to the VSL operation remain to be addressed. For example, although connected and autonomous vehicles are to gain greater market penetration, the optimal variable speed limit control for mixed traffic flows in a connected and autonomous vehicle environment has not been studied adequately. Consequently, this project will to systematically study the optimal VSL control for mixed traffic flows at bottlenecks in a connected and autonomous vehicle environment. Several multi-objective nonlinear integer models have been formulated for the VSL control for mixed traffic flows both under normal conditions and in a connected and autonomous vehicle environment. Discrete optimization-based solution algorithms have been developed to solve these VSL models. Finally, the developed VSL algorithms have been implemented and evaluated by using a real-world freeway corridor as a case study.

Outputs: Several multi-objective nonlinear integer optimization models have been formulated in which the objective is to minimize the total system travel time and total speed variation on the selected freeway segments with bottlenecks. Different advanced meta-heuristic solution algorithms (e.g., genetic algorithm and tabu search) have been developed and compared to optimize the VSL control for mixed traffic flows in a connected and autonomous vehicle environment under different market penetration rates.

Outcomes/Impacts: The systematic optimization models and efficient solution algorithms developed as results of this project for solving the VSL control system can be directly applied and deployed to relieve freeway congestion, improve safety, and reduce greenhouse gas emissions and fuel consumption under a variety of different situations.

Design of an optimal variable speed limit control system for relieving congestion at bottlenecks

Local Barriers to Regional Transportation: Understanding Transit System Fragmentation from an Institutionalist Framework

Grantee: University of Texas, Arlington

Center Name: Center for Transportation Equity, Decisions and Dollar

Research Priority: Preserving the Existing Transportation System

Funding: $96,382

Project End Date: August 31, 2018

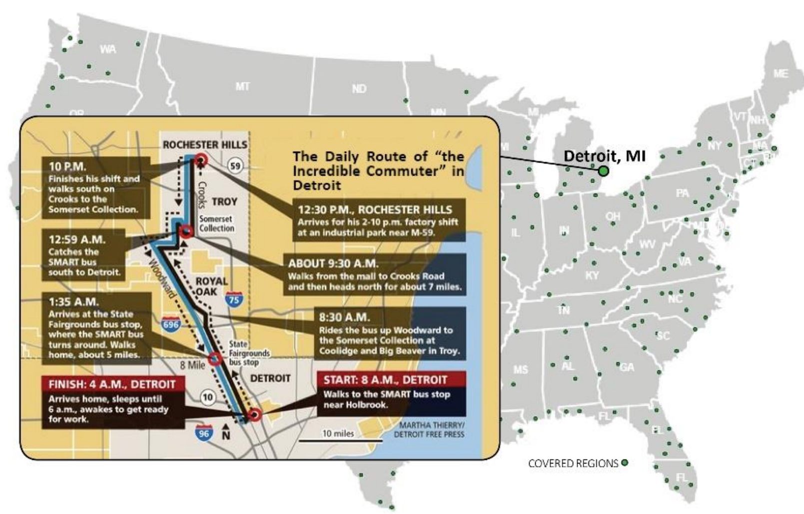
Project Description: While the federal government spends billions on transit projects each year, many regions have poor coordination of services, with some regions having over 25 transit agencies failing to offer integrated schedules, fares, and services, while other regions have large swaths that are completely unserved. Many of these inefficiencies are not due to a lack of technology or funding, but to failure of the local funding and governmental structure. For example, many states allow local jurisdictions to opt out of the transit system entirely, creating a patchwork of cities without access to jobs, health care, education, and other services needed to climb the economic ladder.

This study quantified the effects of local and state governance and finance policy on the public transportation system. Researchers examined 12,571 separate jurisdictions in the top 200 metro regions in the United States. Researchers assembled comprehensive data on fragmentation in the transit system, as well as the governance and finance mechanisms being employed at the local, regional and state levels to provide transit that crosses local jurisdictional boundaries.

Outputs: This project produced the first comprehensive database of transit agency governance, covering 47 states, allowing comparisons across 12,571 local governments, and 618 transit agencies. The study also created a national index of transit fragmentation, as well as "regionalization," that quantifies region's success at bridging its jurisdictional fissures. In addition, the final outputs include a step-by-step manual for the index computation, an interactive tool visualizing the index and master database, and a series of training sessions for local and regional elected and staff officials.

Outcomes/Impacts: The outputs of this research will assist policymakers seeking to build incentives into the use of public funds that encourage cross-jurisdictional transit service. The final index will make cross-regional comparisons possible, allowing local and state policymakers to adopt successful solutions from other regions.

Additionally, this dataset is open source, available to policymakers and researchers across the United States. This research can also serve as a demonstration of the possibilities for making transportation more efficient and effective through the collection of cross-jurisdictional governance and finance policy data, which can be applied to other transportation policy areas like capital projects, toll roads, and growing areas like app-based, on-demand services.



Challenges of commuting with poorly connected transit agencies with a patchwork of cities opting out of the transit system

Issues in Setting a Metropolitan Planning Organization Process for Megaregion and Inter-Regional Planning in the Texas Triangle

Grantee: University of Texas, Austin

Center Name: Cooperative Mobility for Competitive Megaregions

Research Priority: Improving Mobility of People and Goods

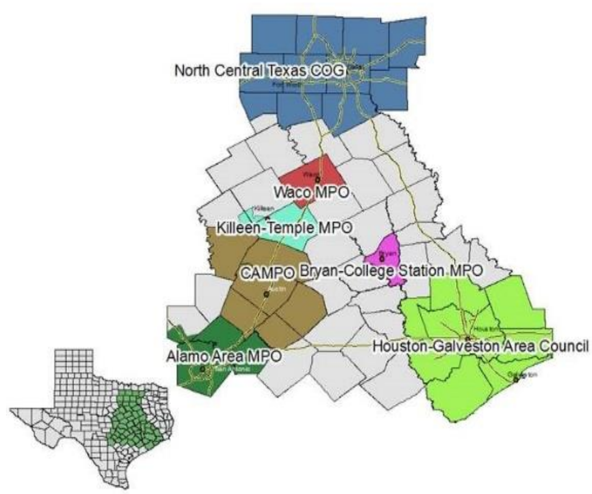
Funding: $261,886

Project End Date: January 31, 2019

Project Description: America's population is predicted to double by 2050 and many elements of our infrastructure network will see increased stresses. This will require a new planning paradigm to plan for inter-regional system capacity, maintenance, mobility, and emerging trends. Previous research indicated that Metropolitan Planning Organizations (MPOs) are an ideal conduit to conduct such megaregion/inter-region planning. However, the specific activities that MPOs should undertake have yet to be delineated in practice. The current system of localized incremental planning may not be able to structure effective tools, partnerships, and systems needed for internalizing the impacts of planning decisions taken by one city or region on surrounding regions. Nor can megaregion mobility challenges of tomorrow be resolved by amalgamating transportation plans, as opposed to a structured approach to planning that considers megaregion impacts and equitably allocates resources. This project analyzed how implementing a framework for megaregional planning could be structured. It focused upon two major components that were viewed as an impediment to such planning: (1) analyzing Texas Triangle anchor city MPO structures and agreements to determine capacity for such planning; and (2) assessing how MPOs had responded to MAP-21 performance metric goal requirement, as a proxy for capacity to develop a megaregion plan.

Outputs: This research provides recommendations for anchor-city MPOs in the Texas Triangle to conduct interregional planning based on existing federal and state regulations. The research team focused on low-cost changes that would result in the highest impact when integrated into the transportation planning process. For example: formalizing a megaregion planning focus between the MPOs and Texas Department of Transportation or expanding non-voting memberships on Transportation Policy Boards to enhance informal coordination. The research also identified potential barriers to implementation, which calls for additional research to evaluate the merits of altering the policy framework that currently governs MPOs.

Outcomes/Impacts: The recommendations in this report can be implemented within the existing regulatory framework and can be applied to MPOs outside of the Texas Triangle megaregion. The identification of barriers and opportunities to interregional planning within the existing regulatory environment provides insight into the amount of flexibility that MPOs do or do not have in terms of implementing new federally designated goals. The nuances of the national transportation process evaluated in this report are integral to understanding the possibility of integrating future changes at the MPO level and contribute to the national policy discussion of innovating national transportation planning processes.



Anchor City MPO boundaries in Texas Triangle Megaregion

2013–2017 PROGRAM-WIDE PERFORMANCE INDICATORS

UTC Program-wide performance indicators are used to measure productivity at individual UTCs and for the UTC Program as a whole. They are not intended to be used to compare UTCs, as each center has a unique combination of attributes that make exact comparisons impossible. This section provides a high-level summary of six program-wide indicators for four years of MAP-21 and the first year of the FAST Act grants covering a total of four years with our MAP-21 grants overlapping with the first-year FAST Act grants. Performance indicators 1 through 5 present data on education and workforce development measures while performance indicator 6 measures research and technology.
The information below provides the number of each type of UTC and corresponding award amounts:

MAP-21
- Five National UTCs, the total award for each was $8,419,200
- Ten Regional UTCs, the total award for each was $7,717,600
- Twenty Tier 1 UTCs, the total award for each was $4,209,600

FAST Act
- Five National UTCs, award for first year (2017) was $2,804,300
- Seven Regional UTCs, award for first year (2017) was $2,570,600
- Twenty Tier 1 UTCs, award for first year (2017) was $1,402,200

Courses

Transportation-related courses offered

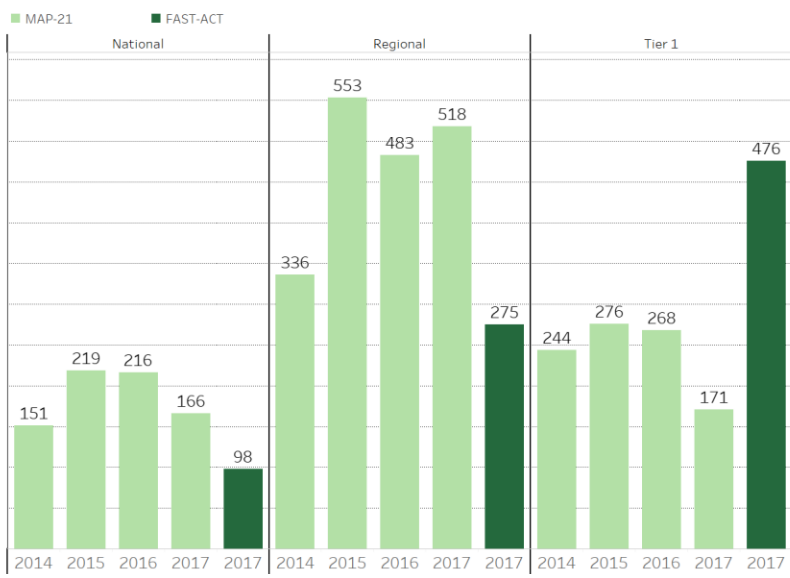
The first indicator measures transportation-related courses offered during the 2013-2017 reporting period and taught by faculty and/or teaching assistants who were associated with the UTC. There are two sub-categories: undergraduate and graduate. As shown on the charts below, the UTCs are offering a significant number of undergraduate and graduate-level courses relevant to transportation to students seeking advanced degrees. Undergraduate and graduate transportation-related courses cover topics including, but not limited to, traffic impact assessment, transit design, freight transportation systems, advanced materials testing, highway bridge design, and transportation engineering. The general consensus among interview participants from the UTC Annual Report to Congress in 2015, was that students who graduated from UTC Programs are engaged with transportation-related work and have the required skills to enter the field.[6]

Undergraduate Courses

Number of transportation-related **undergraduate** courses offered during the reporting period that were taught by faculty and/or teaching assistants who are associated with the UTC

Graduate Courses

Number of transportation-related **graduate** courses offered during the reporting period that were taught by faculty and/or teaching assistants who are associated with the UTC



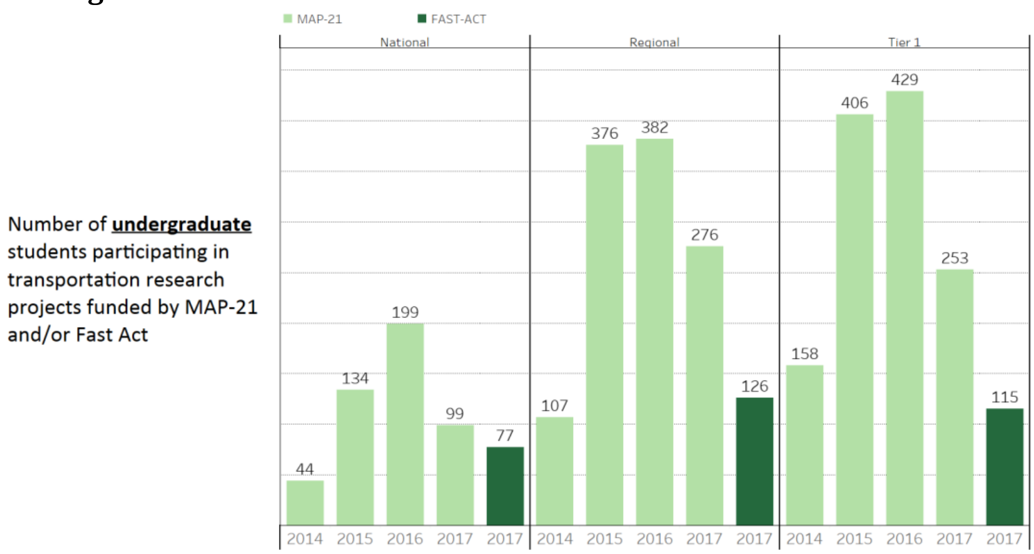
[6] USDOT, OST-R, UTC Annual Report to Congress 2015, pgs. 15-16.

Students

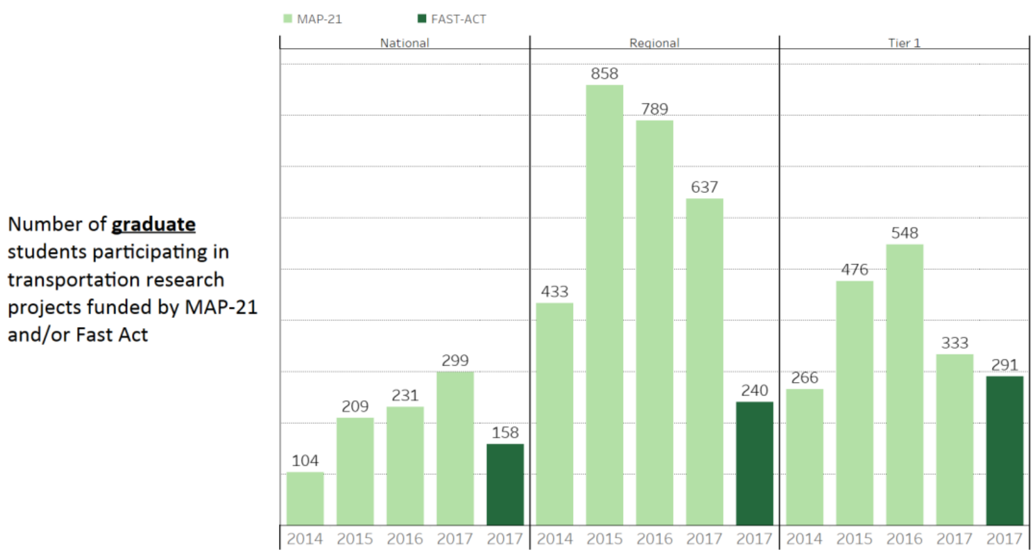
Students doing transportation research projects

The second indicator measures the involvement or participation of undergraduate and graduate students in transportation research projects funded by the grant during the 2013 -2017 reporting period. All levels of UTCs supported both undergraduate and graduate students. During years two and three, MAP-21 regional and Tier 1 UTCs have more universities participating in the program and they supported more than 375 undergraduate and graduate students. MAP-21 regional UTCs supported a significant number, more than 750 graduate students involved or participating in transportation research projects during years two and three.

Undergraduate



Graduate



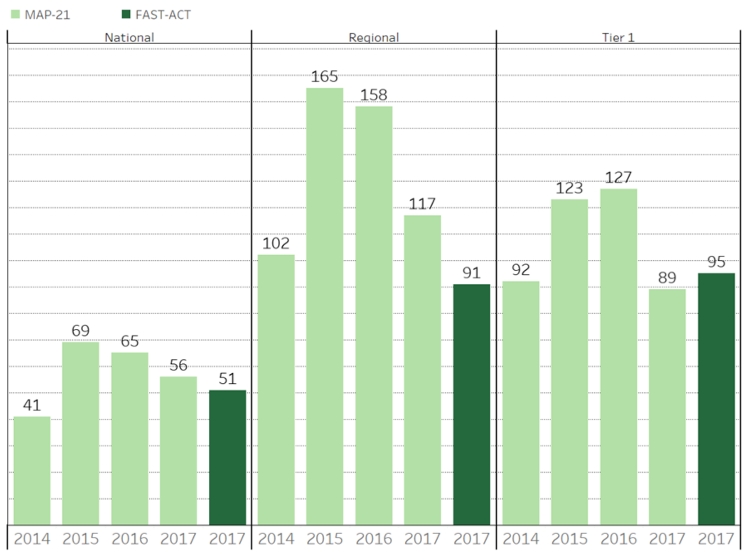
Degree Programs

Transportation-related advanced degree programs

The third indicator measures the number of transportation-related advanced degree programs that used grant funds (UTC federal funds and/or match) during the 2013–2017 reporting period to support graduate students. All UTCs supported graduate students pursuing transportation advanced degrees. The number of master's degree students supported by grant funding is slightly higher than doctoral students.

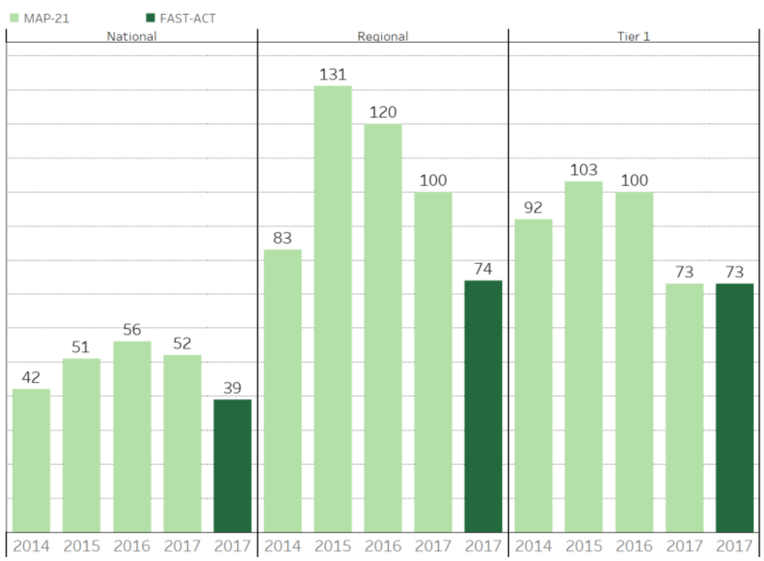
Master's

Number of transportation-related **Master's Level** degree programs that utilize grant funds to support students



Doctoral

Number of transportation-related **Doctoral Level** degree programs that utilize grant funds to support students

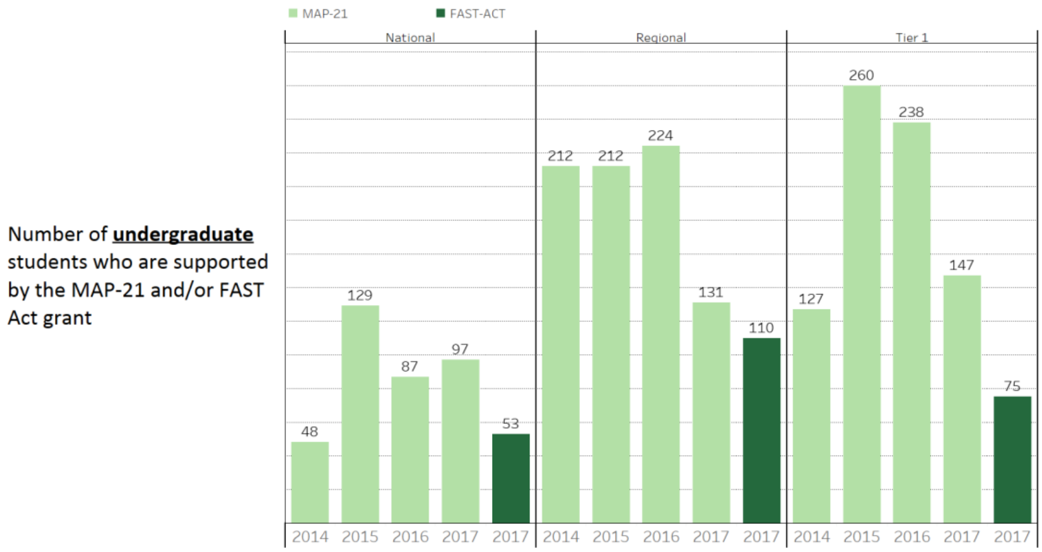


Students Supported

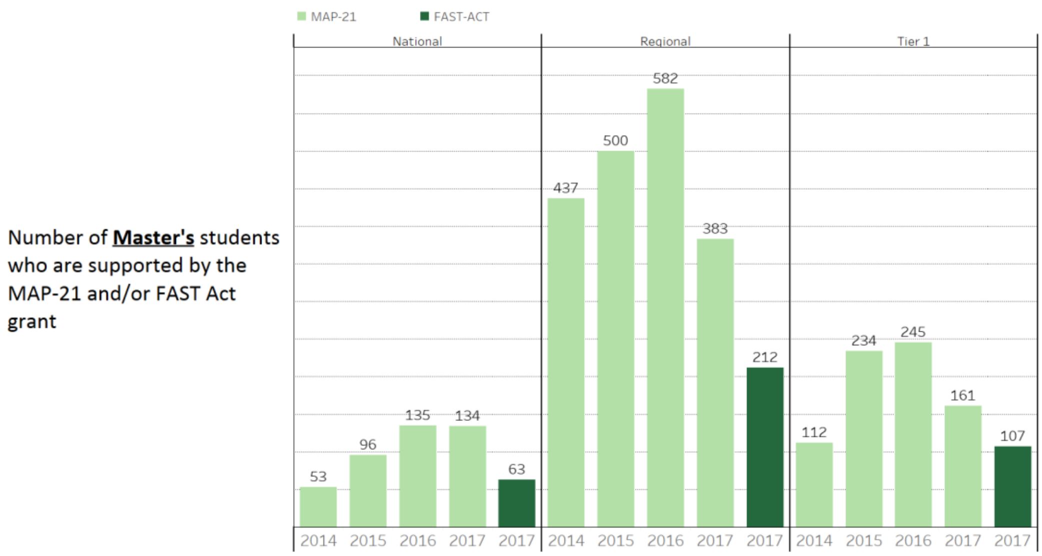
Total students supported

The fourth indicator measures the total number of students supported by grant funding including undergraduate, master's and doctoral students during the 2013 – 2017 reporting period. Here, the UTCs are reporting the number of students who received financial support from federal funds and/or match in the form of tuition relief, wages or stipend. Overall, undergraduate and graduate students were supported by both MAP-21 and FAST Act grants. UTCs grant funds supported more students pursuing master's degrees followed by doctorate students. MAP-21 national and Tier 1 UTCs numbers for master's and doctoral students supported were almost comparable.

Undergraduate

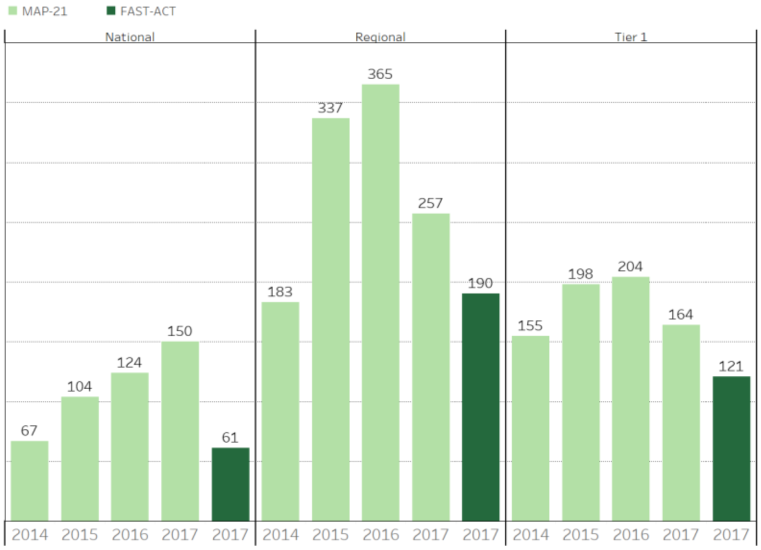


Master's



Doctoral

Number of **Doctoral** students who are supported by the MAP-21 and/or FAST Act grant



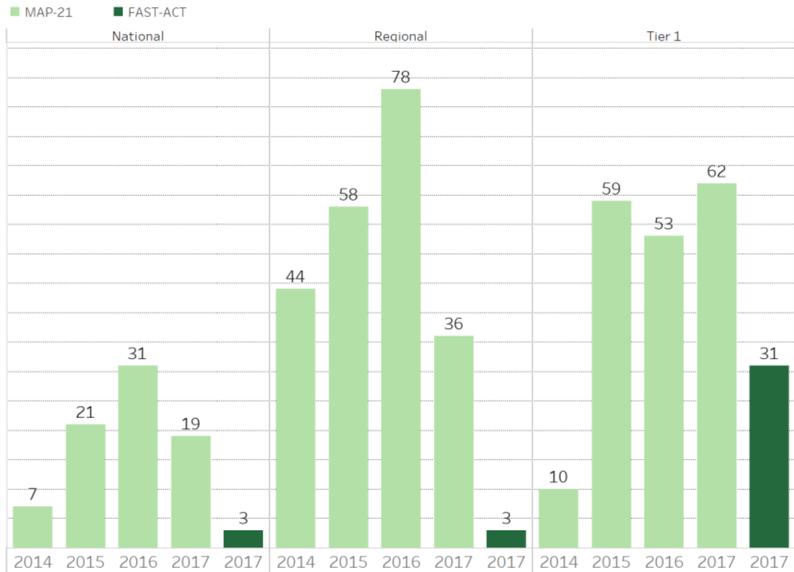
Degrees Awarded

Student receiving degrees

The fifth indicator measures the number of undergraduate, master's, and doctoral students who received financial support from UTC federal funds and/or match during all or any part of their studies AND received their degrees during the 2013 - 2017 reporting period. Due to the late release of the FAST Act grants, the number of undergraduate, graduate and doctoral students supported by the grant is slightly lower than normal. UTCs supported a significant number of master's degree students in years 2015 totaling 370 and 439 in 2016. Similar to master's students, doctoral students who received a degree showed a modest increase during the past four years.

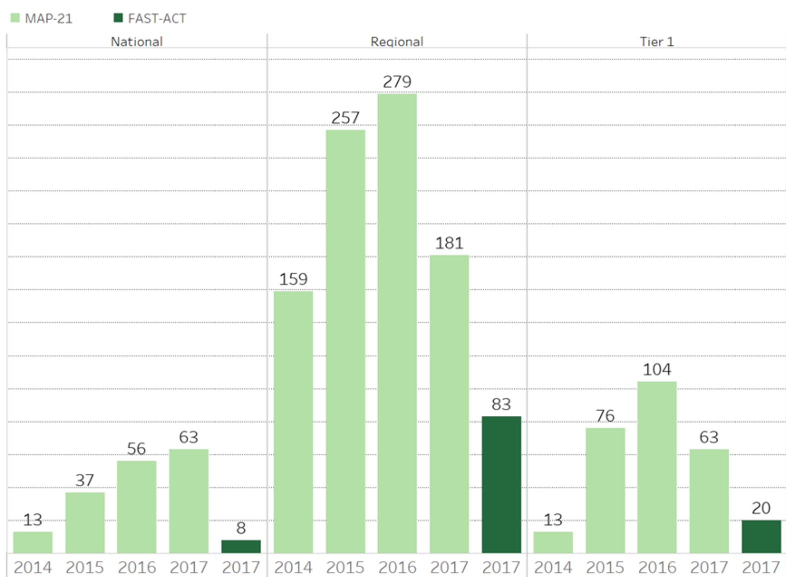
Undergraduate

Number of **undergraduate** students supported by this grant who received degrees



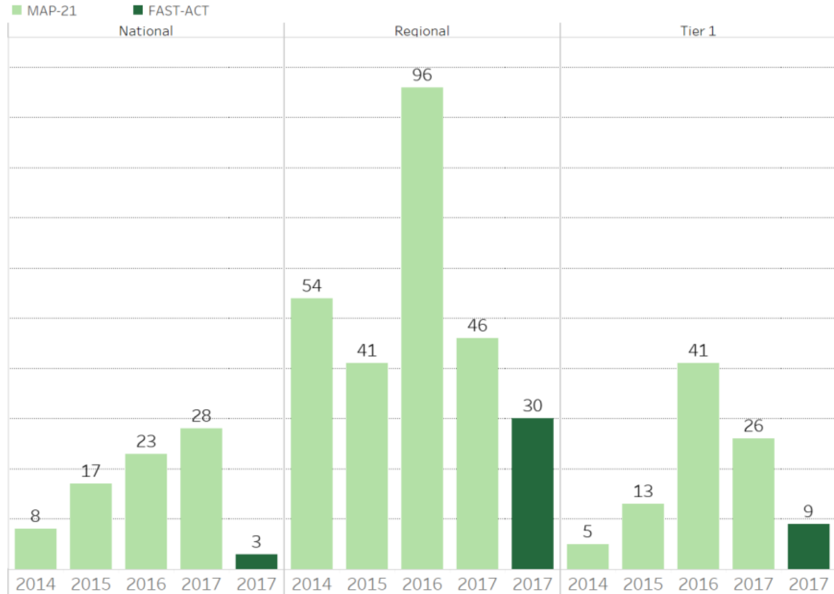
Master's

Number of **Master's** students supported by this grant who received degrees



Doctoral

Number of **Doctoral** students supported by this grant who received degrees

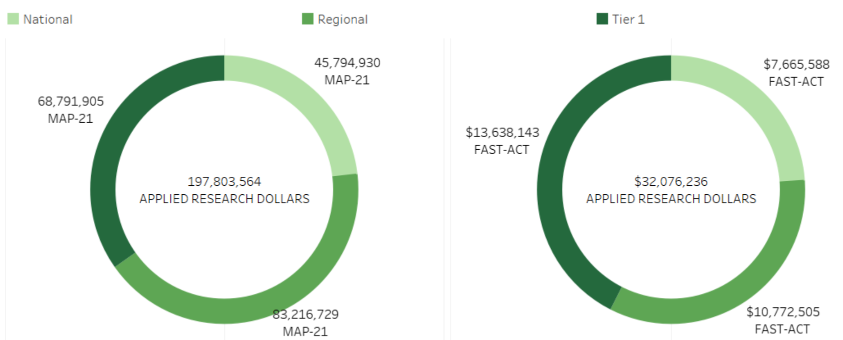


Research

Applied and advances research projects

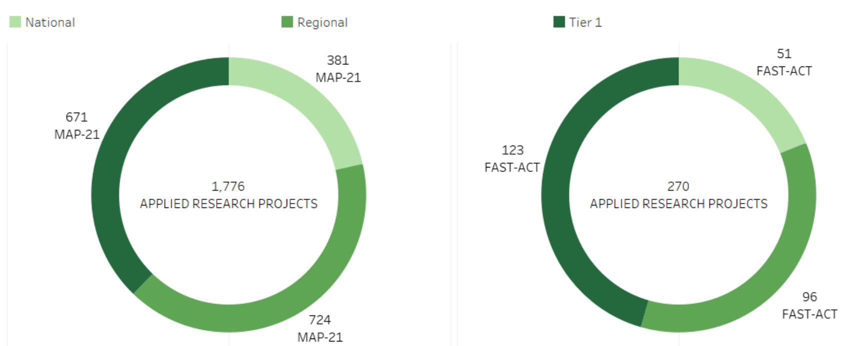
The sixth, and final performance indicator measures the number of applied and advanced research projects selected for funding using grant funds during the 2013-2017 reporting period. This indicator has two parts: 1.) applied research projects and budget, and 2.) advanced research projects and budget. MAP-21 and FAST Act UTCs funded a total of 2,039 applied research projects over the course of four years (October 2013 to October 2017). As one state DOT representative noted… "UTC research is applied in the sense that it may lead to policies…a lot of our UTC research does end up either providing information, education, or leads to a policy or informs the conversation. It is information we need in order to make better policy decisions. That's really important."[7] Most state DOTs and regional transportation planning organizations have stated that they primarily benefit from applied research.[8] State DOT staff are more interested in research they can use; however, a UTC director from a different state said that its Center conducts a lot of applied research that is produced for MPOs and cities rather than for the state.[9]

Applied (#)



Total dollar value of **Applied research** projects selected for funding using UTC grant funds (Federal and/or Recipient share) that you consider to be applied research

Applied ($)

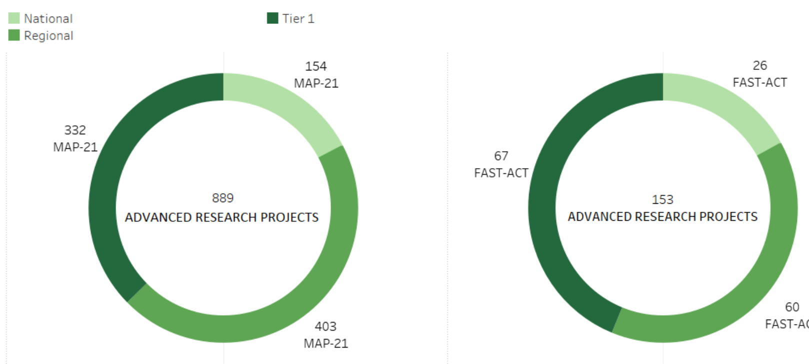


Number of **Applied research** projects selected for funding using UTC grant funds (Federal and/or Recipient share) that you consider to be applied research

[7] USDOT, OST-R, UTC Annual Report to Congress 2015, p. 14.
[8] Ibid, p. 19.
[9] Ibid, p. 20.

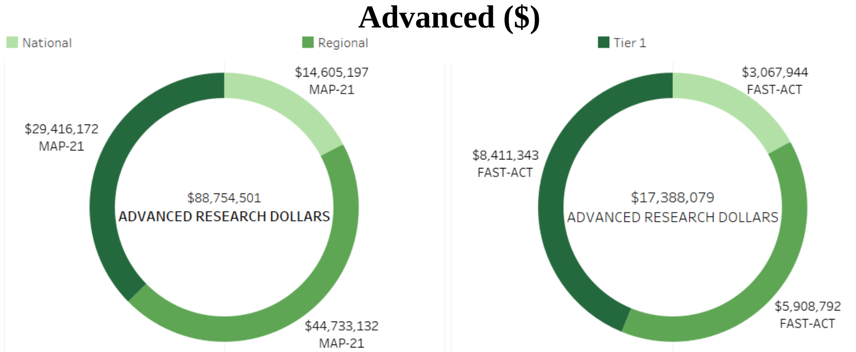
UTCs funded a total of 1,040 advanced research projects over the course of four years. The dollar value for 1,040 advanced research projects selected for funding over the past four years totaled approximately $106 million (actual total $105,641,238).

Advanced (#)



Number **Advanced research** projects selected for funding using UTC grant funds (Federal and/or Recipient share) that you consider to be advanced research

Advanced ($)



Total dollar value of **Advanced research** projects selected for funding using UTC grant funds (Federal and/or Recipient share) that you consider to be advanced research

NOTE: This report is a first in a series of annual reports as required by Section 5505(d)(2) of 49 United States Code as amended by the FAST Act.

LIST OF ACRONYMS

ABC	Accelerated Bridge Construction
AWSC	All-Way-Stop Control
AV	Autonomous Vehicle
BenMAP	Environmental Benefits Mapping and Analysis Program
CARTEEH	Center for Advancing Research in Transportation Emissions, Energy and Health
CAV	Connected and Autonomous Vehicles
CAVDeP	Connected and Autonomous Vehicle Application Development Platform
CCAT	Center for Connected and Automated Transportation
CCPIC	City and County Pavement Improvement Center
CMAQ	Community Multi-scale Air Quality
CPS	Cyber-Physical Systems
CSET	Center for Safety Equity in Transportation
CU-CAVT	Clemson University Connected and Automated Vehicle Testbed
CV	Connected Vehicle
DT	Double Tee
FAST Act	Fixing Americas Surface Transportation Act
FSPGBS	Folded Steel Plate Girder Bridge System
GFRP	Glass Fiber Reinforced Polymers
I2V	Infrastructure-to-Vehicle
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
MAP-21	Moving Ahead for Progress in the 21st Century
MASH	Manual for Assessing Safety Hardware
MPO	Metropolitan Planning Organization
MUTCD	Manual on Uniform Traffic Control Devices
NITC	National Institute for Transportation and Communities
OST-R	Office of the Assistant Secretary for Research and Technology
R&D	Research and Development
RITI	Rural, isolated, tribal, and indigenous
SAFE-D	Safety Through Disruption
SAFETEA-LU	Safe, Accountable, Flexible, Efficient, Transportation Equity Act: A Legacy for Users
SMOKE	Sparse Matrix Operator Kernel Emissions
Surtrac	Scalable Urban Traffic Control

T2	Technology Transfer
TEA-21	Transportation Equity Act for the 21st Century
USDOT	United States Department of Transportation
UTCs	University Transportation Centers
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VSL	Variable Speed Limit
WIM	Weigh-In-Motion
WRF	Weather Research and Forecasting