Long-haul Truck Freight Transport and the Role of Automation: *Collaborative Human - Automated Platooned Trucks Alliance (CHAPTA)*

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Executive Summary

Truck platooning has received attention from U.S DOT FHWA [1.], public/private partnerships [2.], and private companies like Uber (who bought start-up OTTO) and Peloton Technology. Much of the motivation for their platooning efforts has been driven by fuel savings of ~5% for the lead vehicle, and ~10% - 15% for the vehicles behind the lead vehicle. Although these fuel savings are significant, when the total cost of owning and operating an over-the-road truck is considered, overall cost savings attributable to conventional platooning are on the order of 2-5%. The revenue associated with long-haul trucking (trips greater than 100 miles in duration) is approximately $117 Billion annually. In an industry of this size, 2-5% represents $2.34B to $5.85B.

Although automation plays a role in existing platooning concepts and research, advances in driverless vehicle technology promise significantly higher savings and address the existing shortage of long-haul truck drivers. The collaborative platoon, consisting of a combination of human driven/supervised trucks and fully driverless trucks, offers significantly lower operating costs than conventional platooning, and directly addresses driver shortages.

By introducing collaborative human – automated platooned trucks, where *M* drivers supervise a platoon of *N* vehicles, fuel savings, reduced greenhouse gas emissions, and the driver shortage are addressed. In this model of platooning, fuel savings increase slightly, but the total operating costs of the platoon can be effectively reduced by up to 24.6% in a situation where two drivers operate a platoon of five vehicles.

The stakes are quite high. Reducing long-haul trucking costs by 14.7%[1] has a significant impact on the U.S Economy – saving 14.7% on an $117B industry represents a savings of ~$17.3B.

Although the financial benefits of collaborative platoons are substantial, many human factors, operational, workforce, and institutional issues must be addressed before those benefits can be fully realized, and before cooperative platoons of trucks will operate on U.S. roadways.

Goal. The goal of CHAPTA as proposed herein is to bring together stakeholders (see Table 1 for a partial list of stakeholders) to ***cooperatively*** and ***quickly*** bring collaborative human – autonomous platooned trucks to U.S. highways. CHAPTA focuses on four elements of the collaborative platoon system:

- Human Factors.
  - How does the human interact with and within the platoon?
- Operations.
  - How does the platoon interact with other traffic on public roads?
- Workforce Development.
  - Drivers – retention and (re)training; managers – dispatch and control.
- Institutional issues.
  - Insurance/liability, job-loss perception, job displacement.

Table 1. Stakeholders with a vested interest in hybrid truck platoons.

Fleet operators	Economists and financiers
Truck OEMs, Tiered suppliers	Standards organizations
Technology providers (OTTO, Peloton)	FMCSA – US DOT, State DOTs
Insurance companies	Warehouses
Educators	Retailers

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[1] This model assumes that the long-haul truck operates in a platoon 60% of its on-road time. The more time in a platoon, the higher the savings.

It is important to note that vehicle guidance and control R&D is not the focus of CHAPTA. Vehicle guidance and control, in this context, is adequately addressed by other academics and private companies (OTTO, Peloton Technology). CHAPTA develops pre-competitive human design insight, operational guidelines, and support for standards development, which will enable the collaborative platoon to operate on the nation's highways alongside other human-driven and autonomous vehicles.

The competitiveness of the U.S. freight transport system also relies heavily on the introduction of platoons; research and deployments in the U.S. now lag far behind those in Europe and in Asia. Europe has had a long succession of truck platoon programs dating back to the 1990s: Chauffeur (1995-2000), KONVOI (2005 – 2009), SARTRE (2009-2012), and most recently, the European Truck Platooning Challenge (2016), which involves truck platoons crossing national borders. In Asia, the Singapore Ministry of Transport and the Port of Singapore Authority have recently signed agreements with Scania and Toyota Tsusho, respectively, to deploy a collaborative human-automated platooned trucks to be used on public roads [3.]

Just as long-haul freight transport affects almost every sector of society and the economy, the work to be undertaken by CHAPTA will be of interest to those same sectors of society and the economy. Examples of questions to be answered by CHAPTA of relevance to stakeholders include:

- <u>Insurance</u> – how will the performance of the platoon affect the frequency and severity of crashes involving both the platoon and adjacent vehicles?
- <u>Economists and financiers</u> – will the driver shortage of today turn into a surplus in the next decade? What is the effect of that surplus?
- <u>Fleet operators</u> – how will platooning affect recruiting (which personalities are well suited for platooning) and operations (scheduling platoons, who leads, who follows, for how long, etc.)?
- <u>Technology providers</u> - how should an autonomous truck "act" to be accepted by its human colleague?
- <u>Truck OEMs</u> – can today's tractors become tomorrow's traction units without the need for human accommodations in the cab?
- <u>Tiered suppliers</u> – what information is needed inside the cab by the humans, how frequently is that data needed, and what modes are appropriate?
- <u>Retailers and warehousing</u> – what effect do lower transport costs have on my products, and how best to take advantage of it?
- <u>State and Federal DOT regulators, standards organizations</u> – minimum performance standards for vehicles operating in a platoon, communication protocols beyond SAE J2735 and SAE J2945.

CHAPTA will be housed at the Montana State University (MSU) Western Transportation Institute (WTI). Two WTI facilities will play a key role in CHAPTA:

- WTI Driving simulator. The simulator can be used to determine
  - personality types well-suited to driving in and monitoring hybrid platoons,
  - workload limits on human supervision of platoons,
  - autonomous truck behaviors that convey trustworthiness,
  - the proximity between vehicles for which humans can remain comfortable,
  - the type, frequency, and modalities of information to be presented to the driver.
- TRANSCEND test facility. TRANSCEND can be used to test and verify
  - performance limits in poor weather, road, and atmospheric visibility conditions,
  - human tolerance of close vehicle-to-vehicle spacing,
  - robustness of vehicle-to-vehicle communications and cyber security,
  - the size limit N_{max} of a hybrid platoon, and the optimal ratio M/N, where M represents the number of humans in the platoon, and N the total size of the platoon.

Introduction

Autonomous vehicles have captured the nation's attention – and fancy. Google, Uber, Lyft, and even Ford promise full, SAE level-5 autonomy within the next five years. If an automotive manufacturer is to remain viable into the next decade, it must offer autonomous technology in its products. Autonomous capability promises significant improvements over human-driven vehicles in terms of safety, mobility, congestion reduction, and driver distraction. The advent of autonomous vehicles will likely change society more in the next 10 years than the automobile has in the past 75.

In the urban environment where Google, Uber, Lyft, Ford, and other ventures are likely to initially deployed, autonomous vehicles will *co-exist* with human driven vehicles for quite some time. What the model of platooning described herein offers is a *collaboration* between human-driven or human-supervised trucks and automated trucks. The impetus for this collaboration between human-driven and automated trucks is a shortage of long-haul truck drivers; this shortage is projected to reach 175,000 drivers by 2025, up from an estimated 48,000 in 2015 [4.].

To place this in context, a description of the costs of long-haul trucking is in order. The American Transportation Research Institute (ATRI) cites that 80,868 miles are driven annually by each truck-trailer combination [5.]. The numbers associated with the total cost of long-haul trucking are shown in Table 2.

Table 2. Annual cost of long-haul trucking in the United States using calendar year 2015 data from ATRI [5.]

Motor Carrier Costs	Per vehicle, per mile, 2015	ATRI Annual Cost Estimate	Percentage
Fuel Costs	$0.45	$29,190,113,280.00	24.9%
Truck/Trailer Lease or Purchase Payments	$0.27	$17,506,304,640.00	14.9%
Repair & Maintenance	$0.18	$11,321,520,000.00	9.9%
Truck Insurance Premiums	$0.09	$5,770,740,480.00	5.0%
Permits and Licenses	$0.02	$1,591,482,240.00	1.1%
Tires	$0.05	$3,182,964,480.00	2.8%
Tolls	$0.03	$1,772,626,560.00	1.7%
Driver Wages	$0.58	$37,548,629,760.00	32.0%
Driver Benefits	$0.14	$9,005,460,480.00	7.7%
Totals	**$1.81**	**$116,889,841,920.00**	**100.0%**

The annual cost of operating a long-haul tractor-trailer rig, with per-mile cost of $1.81 and an average annual mileage of 80,860 miles is $146,112.30; fuel accounts for $36,487.64. The CHAPTA operational model assumes that a tractor-trailer will spend 60% of its operational time in a platoon. The cost savings for a five-vehicle platoon operating at the 60% duty cycle with a human in every cab is shown in Table 3. Values for the fuel savings associated with platoons of more than 2 vehicles are not well-established, so values for the trailing vehicles have been given upper and lower bounds.

It is important to note that driver salary (32.0%) and fuel costs (24.9%) are the two highest costs associated with long-haul trucking; salary, benefits, and fuel comprise 64.6% of the cost of long-haul trucking. Clearly, saving fuel and driver costs are the mechanism by which long-haul truck operational costs will be reduced with the advent of automated vehicle technology.

Table 3. Operational cost savings (attributable to gains in aerodynamic efficiency) using a human-in-the-cab platooning model with the vehicle operating in a platoon 60% of the time.

Category	Lower Bound on Aero. savings	Upper Bound on Aero. savings
% fuel savings for first vehicle	5%	5%
% fuel savings following vehicles	10%	20%
Total annual fuel savings, 5 vehicles, $$$	$9,027.67	$17,052.26
Savings for lead vehicle	$1,003.07	$1,003.07
Savings for each following vehicle	$2,006.15	$4,012.30
Percent of total (5 vehicle) operating cost saved	2.2%	4.20%

Table 3 illustrates that although the fuel savings percentages are quite substantial, the overall cost of operating the tractor-trailer is reduced by substantially less than five percent.

The trucks capable of operating in a platoon have the necessary actuation hardware to operate autonomously: automated steering, automated braking, automated throttle, and now automatic-manual transmissions. The cost to implement a driverless tractor-trailer is incremental, facilitating the collaborative human - automated platooned trucks. The cost savings when operating with fewer drivers is substantial, as shown in Table 4.

Table 4. Cost savings for a five-vehicle platoon attributable to gains in aerodynamic efficiency and a reduction in labor costs facilitated by human-robotic collaboration. "4 Humans" means one driverless, automated truck in the five-vehicle platoon.

Total annual labor savings, $, for 80,860 annual miles		4 Humans	3 Humans	2 Humans
		$46,554.09	$93,108.18	$139,662.27
Percentage of total operating cost saved - fuel economy and robotic drivers	5%/10%	9.0%	15.8%	22.6%
	5%/20%	11.0%	17.8%	24.6%
Total annual savings accumulated by the 5 vehicles in the platoon.	5%/10%	$36,636.00	$64,244.34	$91,852.67
	5%/20%	$44,660.60	$72,268.93	$99,877.27

As Table 4 illustrates, operating a platoon of five vehicles with only two human operators reduces the cost of operating that platoon by 24.6%. Assuming a 60% platoon duty cycle and that the annual, aggregate cost of long-haul trucking is ~$117B, such a platoon model would save ~$17.2B annually. This is a substantial incentive for the trucking industry, and represents a significant impact on the U.S. economy.

The international competitiveness of the U.S. Freight Transport system also relies heavily on the introduction of platoons; research and deployments in the U.S. now lag far behind those in Europe and in Asia. Europe has had a long succession of truck platoon programs dating back to the 1990s: Chauffeur (~1995-2000), KONVOI (2005 – 2009), SARTRE (2009-2012), and most recently, the European Truck Platooning Challenge (2016), which involves truck platoons crossing national borders. In Asia, the Singapore Ministry of Transport and the Port of Singapore Authority have recently signed agreements with Scania and Toyota Tsusho, respectively, to deploy a human-autonomous hybrid platoon to be used on public roads [3.].

Reduced transport cost frees capital for other investment, fueling economic growth.

Although variations exist between the projects described above, drivers remain in the cab of each of the vehicles in the platoon. This operational model does save fuel, but neglects cost savings associated with driverless vehicles within the platoon, which is the focus of the research program proposed herein.

As enticing as the $17.2B sounds, a substantial effort is required to make this concept a reality, including the formulation of standard operating procedures, emergency operating procedures, communication standards (likely complementing SAE J2735 and SAE J2945 DSRC standards), vehicle performance guidelines, and more. These must be formulated prior to receiving state and federal approval to operate collaborative human - automated platooned trucks on U.S. interstates and highways. CHAPTA addresses many of these issues.

The objective of this research is to build the foundation, from the *human* perspective, for a collaborative human - automated platooned trucks. Vehicle guidance technology is not to be developed under this work; that development is left to private industry and other well-funded academic programs. However, the *evaluation* of that vehicle guidance technology in the context of a collaborative human – automated platooned trucks is within the scope of CHAPTA.

CHAPTA will focus on addressing four themes:

1. Human Factors.
2. Operations.
3. Workforce Development.
4. Institutional Issues.

Research questions.

The research questions can be mapped to the three themes described above. Answers to these questions will lay the foundation upon which the stakeholders will build the collaborative human – automated platooned truck system.

Human Factors

1. **Personality suited for platoons.** Not every driver is suited to the rigors and demands of long-haul truck transport; long, isolated hours on the road, being away from home for days or weeks at a time generally points to an independent, “my-way” personality. This personality type may be in conflict with an occupation for which collaboration is at the top of the job description. One research question is to determine the personality type well suited for the collaborative human – automated platooned trucks.

   Most research in human personality to determine those who are well-suited for human-robot interaction addresses anthropomorphic robots (i.e.,[6.]) or conversely, what personality traits the anthropomorphic robot should exhibit to attract human interaction [7.]. However, in the context of humans operating in a platoon, only relatively simple guidelines exist for the design of the robotic behavior [8.]. Those guidelines are insufficient for establishing which personality type is amenable to participating in a human-robotic platoon interaction.

   CHAPTA research will be undertaken to determine which personalities are well-suited for these systems, how to recruit drivers with these personality traits, and how to screen potential drivers to ensure that their personality is well-suited for platoon operations.

2. **Cueing promoting trust.** Driver behavior, especially in a lead-follow situation, affects the comfort, trust, and willingness of a driver to follow the vehicle ahead. Drivers with aggressive personalities are unlikely to follow a driver traveling at or slightly below the speed limit, or tolerate speed variations. For a human to collaborate with a robot, comfort, trust, and willingness must exist in the relationship. In the context of human-robotic highway collaboration, behaviors and cues (acceleration & deceleration rates, time of initial brake apply, type of brake application (steady application vs. two taps of the brake pedal to warn drivers behind of imminent braking), lane position variability should jibe with the human personality, or trust and comfort will fail to be present, causing stress and other issues to arise, risking the viability of the platoon.

As shown in [9.], humans will view non-anthropomorphic robots in a favorable light, if the robots are exhibiting behaviors aligned with human expectations. Therefore, it follows that for a human to show trust and comfort with the other vehicles in the platoon, those vehicles must exhibit behavior aligned with the expectations of the humans in the platoon.

CHAPTA research will be undertaken to determine which driving cues are most relevant to trust and comfort, and the human sensitivity to these cues to establish bounds on those robotic behaviors which are most likely to be accepted by human drivers.

3. **Information.** Attention allocation is particularly pertinent to real-life dynamic operations (e.g., driving a car or flying a plane) that involve multi-tasking. With a multitude of incoming information to be attended to and a limited amount of attention available, the ability to process important information may be compromised, resulting in an impaired response and possibility, harmful consequences. The consequence of multi-tasking on traffic safety, for example, is often discussed in the context of driver distraction, particularly with the increasing use of in-vehicle technological devices ([10.];[11.]) and use of cell phones ([12.][13.]). The combined task load should be significantly below the maximum resource threshold to accommodate unexpected demands imposed by the driving task (Figure 1).

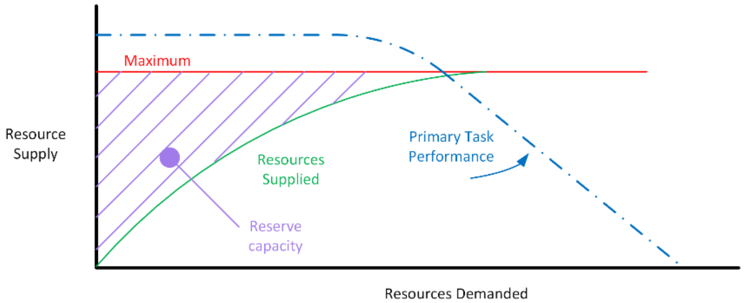

Figure 1. Illustration of performance deterioration as combined task demands exceed resource allocation limits (adapted from [14.])

In the context of the collaborative human – automated platooned trucks, these (and more) research questions will be addressed by CHAPTA:

a. If *M* represents the number of humans in a platoon, and *N* represents the number of vehicles in the platoon, what is the minimum ratio $(M/N)_{min}$ for an operational human-robotic platoon? Does, and if so, how does this ratio change with increasing *N*?

   This ratio is affected by the expected workload on each human in the platoon, the level of autonomy offered by the driverless units in the platoon, operating conditions (including weather, atmospheric visibility, road geometry, individual vehicle performance, etc.), and the total size of the platoon.

b. For the *M* humans collaborating with and monitoring the (*N*-*M*) driverless vehicles, what information should be provided to each of the *M* humans in the platoon?
   i. How should that information be distributed amongst the human drivers?
   ii. How much information can be handled by a human driver?
      1. Under normal operating conditions?
      2. Under sub-nominal operating conditions?

c. How frequently should information be provided?

d. What modalities should be used?
   i. Haptic
   ii. Tactile
   iii. Audible

   iv. Graphical
      1. In-vehicle displays
      2. Displays mounted on the rear of the vehicle/trailer directly ahead.

Operations

A simplified version of the concept of operations is shown in Figure 2. The primary focus of the CHAPTA pre-competitive research is highlighted in the dashed rectangle – entering the limited access highway, operating on the limited-access highway, and exiting the limited access highway. The entering and exiting processes include the "launch" and "landing" pads where trucks with human drivers can connect with the robotic trucks to form the platoon before entering the limited access roadway. These launch and landing pads could be truck stops, rest areas, parking lots, or lots designed solely to support cooperative hybrid human – autonomous platooned trucks.

Although operations outside the dashed rectangle are important to the success of the cooperative hybrid human – autonomous platooned trucks, those operations are affected by competitive decisions and inter-company alliances, and are therefore outside the scope of CHAPTA.

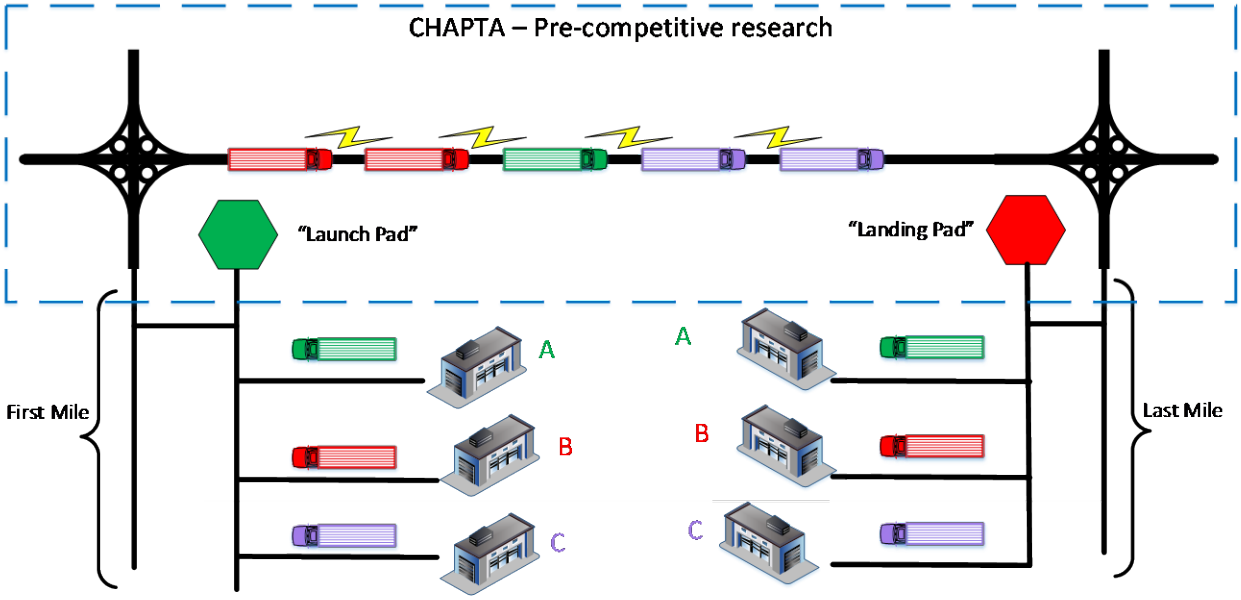

Figure 2. The cooperative human – autonomous platooned trucks system. The system has two phases: the platoon operations phase where autonomy plays a key role, and First & Last Mile phase which requires a human in each vehicle. The phase transition occurs at the "Launch" and "Landing" pads.

The collaborative human – automated platooned trucks must operate on interstate and other limited access highways in mixed traffic conditions, co-existing with other human-driven cars, trucks, motorcycles, and other platoons. The operational model of the platoon must be designed to safely interact with these other highway users. To this end, research questions include

1. What is N_{max}, the maximum size of a workable platoon in terms of control, latency, economics, and safety?
2. In what position within the platoon should the human drivers be located?
   a. For the best performance of the platoon.
   b. For the highest degree of safety for the humans in case of catastrophic failure.

3. Communication protocols
    a. How can SAE J2735 and SAE J2945 be leveraged for collaborative human – automated platooned trucks?
    b. What additions to SAE J2735 and J2945 are required for collaborative human – automated platooned trucks?
    c. What additional data is needed to facilitate the dispatch of truck platoons – trip origin, trip destination, and timing? Although the dispatch process is competitive, the data protocols and communication methodologies to facilitate dispatch is pre-competitive.

4. How are vehicles "certified" for platoon use?
    a. Minimum performance requirements – acceleration, braking, working communications.
    b. How to organize vehicles within the platoon with respect to performance – for example, highest performers at the tail of the platoon.
    c. What components of the autonomous system are addressed in the daily "pre-trip" inspection?
        i. How are they tested or verified by the driver?
        ii. What tools does the driver need to execute the pre-trip test?
5. Platoon protocol
    a. For entrance and exit ramps.
    b. For "Launch" and "Landing" pads (see Figure 2).

Workforce Development

1. Driver training and retention
    a. How to (re)train existing drivers to operate/supervise a cooperative human – autonomous truck platoon.
    b. How to attract and retain drivers who are well suited to operate a cooperative human – autonomous truck platoon.
2. Dispatch and Control
    a. Formation of platoons: scheduling based on human and traction unit availability, origin, destination, and goods delivery timing.
    b. First mile / last mile transition between limited access highway and origin/destination.

Institutional issues

1. Perception that jobs are being "eliminated"
    a. How to message driver shortage?
    b. Future driver demand based on deployment models.

2. Job displacement, worker reassignment.
    a. Short-haul vs. long-haul trucking: first- and last-mile operations vs. interstate driving.
    b. New positions created: robotics technician, master scheduler, first- and last-mile driving.

3. Insurance and Liability
    a. Liability limits – greater than human-driven vehicles?
    b. Special considerations? Lead truck, following truck(s), last truck?

Membership and Governance.

CHAPTA is a self-governed organization focused on pre-competitive research. Broad research directions are highlighted above, but members decide annually specific research projects.

CHAPTA members and academic researchers annually create problem statements. WTI research staff draft pre-proposals from these problem statement, providing a simplified statement of work and estimated budget for all of the research problem statements submitted. CHAPTA members review the research pre-proposals, down-select, and rank-order those of most interest to the CHAPTA. Given the available budget, the top pre-proposals which fall within the 1.5x the available budget are then selected for a full proposal. WTI research staff develop the full proposals from the down-selected pre-proposals, addressing comments derived from the down-selection process. Once the full proposals are complete, the members decide, through voting, on which projects are pursued (within the available budget, of course).

Membership fees affect governance through voting rights. The membership schedule and voting benefits are highlighted in Table 5 below.

Table 5. Membership levels and associated project decision votes.

Participant Level	Annual Fees	Number of Votes
Platinum	$50,000	4
Gold	$40,000	3
Silver	$30,000	2
Bronze	$20,000	1

Votes can be used on a per-project basis. For instance, ACME Trucking, a platinum member, finds favor with Human Factors Problem Statement 2, and Operations Problem Statement 5, but between the two, favors Human Factors Problem Statement 2. ACME Trucking can put three of its four votes for Human Factors Problem Statement 2, and its remaining vote for Operations Problem Statement 5. Increasing levels of participation come with an increasing number of votes, providing additional influence and flexibility in the choice and execution of research projects.

Personnel

Craig Shankwitz: Senior Research Engineer, Western Transportation Institute; Research Professor, Mechanical Engineering, Montana State University, Alliance Director. Dr. Craig Shankwitz serves as a Senior Research Engineer for the Connected Vehicle Initiative at the Western Transportation Institute at Montana State University. He leads the development of a WTI research team that will explore and develop applications of autonomous and connected vehicle technologies to roads and transportation systems in rural areas and small cities. Prior to coming to MSU, Dr. Shankwitz was a principal R&D engineer at MTS Systems in Eden Prairie, MN, where one of his tasks was to design and develop a patented, robotic motorcycle rider which can be used for testing in a wide variety of applications. Prior to MTS, Dr. Shankwitz served as a Research Associate Professor and the Director of the Intelligent Vehicles Lab at the University of Minnesota. The focus of the IV Lab was the deployment of technology which simultaneously improves mobility and safety for the ground transportation network. Deployments include DGPS- and radar-based Driver Assist Systems for seven Alaska DOT snow-removal machines (to clear runways, roads, and mountain passes in Alaska), and ten buses equipped with Driver Assist Systems for narrow bus-only-shoulder operations in the Twin Cities Metropolitan area. Shankwitz received his Ph.D. in Electrical Engineering from the University of Minnesota in 1992 in the area of control theory. He holds seven patents, with two pending.

Nic Ward: Professor of Mechanical and Industrial Engineering, Montana State University, Human-factors technical lead. Dr. Nicholas Ward (F. Erg. S) obtained his Ph.D. in Human Factors psychology from Queen's University (Canada) in 1993. He conducted traffic research in Europe for 11 years at the University of Loughborough and the University of Leeds. Dr. Ward is currently a Professor of Mechanical and Industrial Engineering at Montana State University and the Director for the Center for Health and Safety Culture at the Western Transportation Institute. Dr. Ward has led interdisciplinary and international research consortia to study traffic safety research including intelligent transportation systems, driver behavior (impairment), and traffic safety culture. He is an international leader in the definition and advancement of traffic safety culture as a new traffic safety paradigm. His leadership and research in this area has contributed to the development of the National Toward Zero Deaths (TZD) Strategy to transform traffic safety culture. It has also resulted in his invitation to participate as the North American representative in the European Union funded project to develop a cultural approach to traffic safety (http://www.trasacu.eu/). Dr. Ward was also recently appointed as the Subject Matter Expert for the NCHRP Domestic Scan (14-03) on Successful Approaches for the Development of an Organization-Wide Safety Culture in Transportation Agencies.

Steve Albert: Executive Director, Western Transportation Institute. Steve Albert has 35 years of experience, successfully leading multi-million dollar centers, managing projects, providing QA/QC, and most importantly, ensuring sponsor needs and intent are satisfied. Steve's facilitation talents were recognized throughout his career starting in Houston where he was appointed by Houston Mayor, METRO General Manager to oversee all mobility related projects. The same abilities were applied to the I-95 Corridor Coalition where Steve led all states from WDC to Maine to agree on incident management strategies and implementation. He has served as the Executive Director of WTI for more than 20 years, where he has developed 5 FHWA Centers of Excellence and has received lifetime achievement awards from ITE and the Council of University Transportation/ ARTBA. He has also received an award for public–private partnerships from President Ronald Reagan.

Facilities

WTI Driving Simulators. WTI has developed a suite of advanced laboratories/facilities to support Human Factors research. The WTI Driving Simulator Laboratory houses one of the most advanced high fidelity driving simulators of any research university in North America - eight-channel virtual reality motion-based (6 degrees of freedom) driving simulator with dual-cab installation which is used for human factors experimentation and system evaluations.

The state-of-the-art facility allows research teams to conduct complex and realistic traffic research in a controlled environment before extending the research to a naturalistic setting of test track and open road studies. The simulator serves as a proving ground for various interventions, all designed to save lives by avoiding crashes. Housed in a dedicated 1,700 square foot laboratory, the suite of simulators has a range of capability to appropriately match simulation fidelity to research question complexity to provide cost effective research programs, ethical exposure to risk factors, visualization of system concepts prior to real world implementation, realistic interaction with near-crash events, and the reliable control of relevant scenario conditions. Controlled test-track studies and naturalistic on-road studies are then used to validate and extend research conclusions.

TRANSCEND. Established in 2007 through sponsorship of the Research and Innovative Technologies Administration of the U.S. Department of Transportation (USDOT) and in partnership with the Montana Department of Transportation (MDT), TRANSCEND is a large-scale field facility providing space for researchers to study multi-disciplinary transportation challenges in a full-scale environment without interfering with or affecting the traveling public.

TRANSCEND serves as a test ground to support the research and development of Autonomous and Connected Vehicles (AV/CV) and provides the USDOT with a unique opportunity to conduct research in a cold and rural environment. TRANSCEND offers what developers of collaborative human – automated platooned trucks need to develop, test and evaluate their systems: variable visibility, variable road conditions and pavement types, and exposure to weather and atmospheric conditions which challenge the most robust of systems.

The 230-acre facility offers four miles of real-world paved test surface; a highly innovative, multidisciplinary research staff; and a comprehensive communications, power, and data networking infrastructure. TRANSCEND has a state-of-the-art snowmaking system to simulate winter snow and ice conditions on-demand in a controlled manner.

A 2000 square foot heated shop building is available for instrumenting vehicles, conducting experiments, and maintaining equipment. Multiple research offices are connected to the shop to allow researchers access to computers and the internet. An intranet connection allows researchers to access databases housed at the main WTI research office in Bozeman. A weather station and a robust communication system are also available for use.

Of particular relevance to collaborative human – automated platooned truck testing is the winter testbed.

The snowmaking testbed is a key component of the research facility, and as such was the first testbed to be expressly designed and developed for installation at TRANSCEND. Design and development of the testbed began in 2007. The system is composed of water distribution pipelines, a 1.3 million-gallon reservoir, a low-pressure pump system, a high-pressure pump assembly, and several snowmaking fan guns (Figure 3, left side).

The snowmaking equipment makes about 8,000 cubic feet of snow per hour using 24,000 gallons of water, drawing from the reservoir. The low-pressure pump system pulls water from the bottom of the reservoir to the high-pressure pump. The high-pressure pump system further pressurizes water to the hydrants and the snowmaking guns. A snowmaking event is shown in Figure 3 (right).

The four fan guns are mobile and multi-positional, which increases the capacity to control variables and create a range of environmental condition scenarios, including snow, rain and ice:

- Snow making capacity is maximized when the temperature is below 25 degrees and the relative humidity is low.
- When the temperature is warmer, the snow guns can create a downpour of rain.
- At certain cold temperatures, the guns can be used to simulate an ice storm.

Figure 3: Fan gun snowmaker (left), man-made snow event across the test track (right).

Complementing the ability to change the tire-road coefficient of friction at TRANSCEND is the ability to quantify road-tire friction coefficient. On-site, TRANSCEND has this capability with a Halliday RT3 wheel friction device. The Halliday RT3 wheel friction device uses a meter that records continuous road surface grip in wet or dry road conditions, as well as during anti-icing, snow removal and deicing operations. It provides grip readings to the operator of a winter maintenance vehicle via an in-cab control panel. This device allows the quantification of road-tire friction prior to, during, and after testing. An aerial view of TRANSCEND is provided in Figure 4.

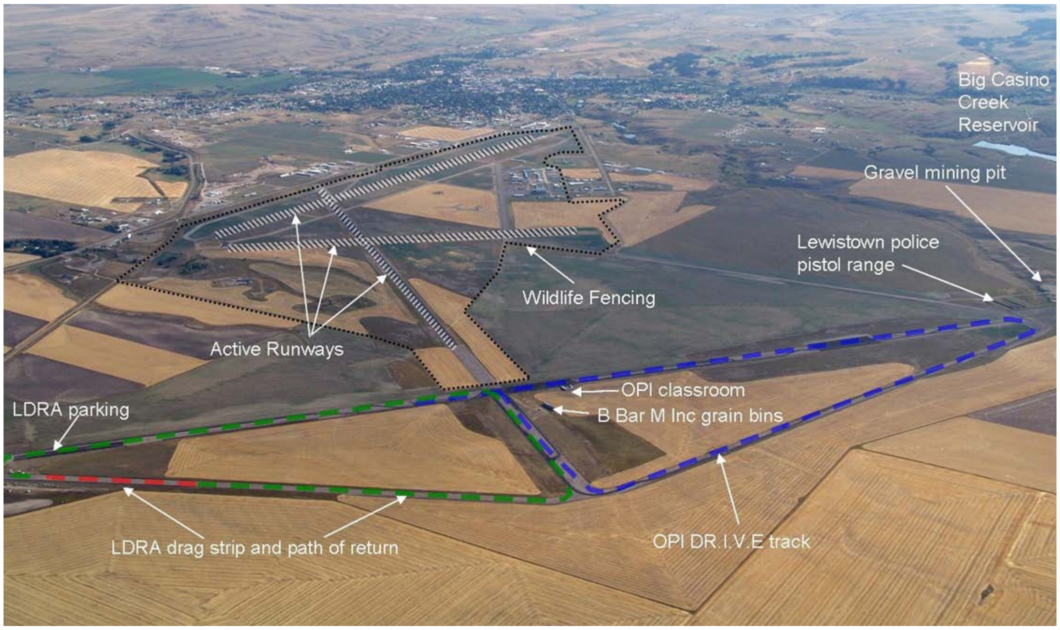

Figure 4. Existing tracks and facilities at the Lewistown airport, where TRANSCEND is located.

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