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Planning a Trucking Research Consortium using Industry Customer Discovery and Innovation Ecosystem Mapping

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Abstract

Trucking is a critical segment of the economy, supporting the supply chains of many other sectors, moving goods that account for about half of U.S. gross domestic product. However, it remains the least automated, least safe, most labor-intensive, most polluting of all transport modes. Automation, electrification, and interconnected operation of trucks could help resolve driver shortage, supply-chain disruption, delivery service delays, emissions, and road safety issues.

This paper reports on the development of a plan to bring together the knowledge and business ecosystems related to trucking technologies into an industry-university consortium, while providing students at three universities with learning through interdisciplinary research. The consortium's vision is to converge and apply knowledge in emerging technologies in connected, electrified, and automated freight trucking and public transport networks to advance agile logistics and mobility for all. With an impending award from the National Science Foundation for administrative costs, the consortium will bring together diverse private and public sector stakeholders to conduct research on commercial vehicles, freight supply chain networks, and pertinent information systems to accelerate the adoption of automated and electrified systems to transport people and goods efficiently and flexibly. It is particularly focused on attracting diverse students to be trained in trucking technologies, and on focusing research on societal and economic challenges related to trucking.

Introduction and Background

Trucking is a critical sector, supporting the supply chains of many other sectors and moving nearly every product consumed in the U.S. This linchpin of the economy employed over 8 million, including 3.5 million drivers [1], as of 2022, when road trucks transported 72.6% of U.S. freight tonnage, worth about half of the nation's GDP. The American Trucking Association predicts that freight costs will increase 50% from 2021 levels by 2032 [2]. Yet, the sector remains the least automated and most labor-intensive transportation mode, causing high fatalities and pollution. Medium-duty and heavy-duty vehicles consume over 20% of energy and create 23% of greenhouse gas (GHG) emissions from transportation [3, 4]. Trucking caused 20% of workplace deaths in 2019 more any other industry [5]. Besides having the 7th highest fatality rate, long-haul drivers also suffer other work-related illnesses [6]. Pressure on human drivers and managers due to modern e-commerce and fast deliveries can lead to poor decisions and supply chain delays [7]. Transport delays quickly cascade through the complex non-linear transportation system, leading to the bullwhip effect [8], distorting demand and supply. Inadequate freight transportation during the recent pandemic led to manufacturing shutdowns and empty store shelves [9]. There is increasing industry interest in automation to mitigate delays [10]and overcome episodic disruptions [11].

Vehicle electrification and automation technologies focused on expensive private cars may not benefit all citizens. Commercial vehicles, including trucks, buses, and delivery robots, can benefit from these technologies to enhance mobility and improve life for underserved populations. Connected, electrified, and automated trucking (CEAT) can help reduce driver shortages, supply-chain disruptions, service delays, emissions, fuel demand, and road crashes. CEAT can also improve agility, safety, and predictability, and can enable innovations throughout supply chains and transit networks. Electrification can significantly reduce fossil fuel usage, GHG emissions, environmental criteria pollutants, and noise pollution. Research is needed on how transport and logistics providers and road authorities can best use automation and electrification to address supply-chain resilience, mobility for disabled and underserved people, lower emissions, infrastructure utilization, traffic congestion, flexible manufacturing, workforce shortages, work-life balance, and the safety of truckers, road workers, and vulnerable road users.

The paper reports on a work-in-progress to formally utilize industry customer discovery and innovation eco-system mapping methods to construct a network model of knowledge contributors in university, government, and business sectors, while also identifying communities of collaborators and players with strategic roles in trucking modernization. Contributors to the modern trucking value stream include original vehicle manufacturers, component suppliers, software developers, fleet owners, transportation companies, infrastructure providers, university innovators, and transportation planners. First, an extensive and rigorous customer discovery process, primarily by networking and telecommunication within the US, provided many insights into industry needs and opinions. Second, a series of industry-targeting workshops and meetings were held to determine industry interest and to discuss potential university research plans. Finally, a formal ecosystem mapping process was launched by a student group to discover communities and trends in both business and innovation spheres. Ecosystem maps are tools to understand the relationships and dependencies between the various actors and parts that contribute to creating customer experiences. The work helps plan a future industry-university consortium by creating comprehensive eco-system maps of electrification and automation technologies for commercial freight trucks and buses.

Separately, the work benefited from other related research and pilot projects by faculty and students at the universities involved. As an example, the lead graduate student author is conducting an ongoing pilot project focused on addressing the transportation and logistics needs of food pantries in a major Midwestern city, working with a large group of undergraduate students at one participating campus located in its downtown. Originally, this project started in the context of the Covid 19 pandemic to develop and refine contactless delivery vehicles, which was of interest to industry collaborators and was proposed by an industry foundation. However, as engineering and informatics students actively engaged with the food pantry community it became clear that their needs were much broader and systemic, rather than simply technical, and would require diverse perspectives and skills to solve. The effort was then redirected to improve operations of several food pantries in the city, leveraging the proximity of community organizations and capitalizing on a wealth of local expertise. The project uses the concepts of value-stream mapping and lean six-sigma that is typically used in manufacturing operations, as well as ethnographic research with contextual inquiry to expose hidden pain points and to explore user preferences and challenges. Within the framework of supply chain management, the 'RAID' management technique was used to methodically address and manage risks, conduct assessments, handle issues and recognize dependencies. Cross-functional and multidisciplinary student teams from four schools at the lead institution are participating over an academic year, receiving academic credit, and working concurrently and collaboratively from different perspectives. An engineering and technology student team is analyzing the material flow within and to/from five food pantries, including the internal pantry floor processes, using industrial engineering principles. An informatics and computing student team is seeking to comprehend and enhance the information flow integral to pantry operations. A business student team helped manage the project and enhance pantry operations, and an art and design student team worked to actively bridge the gap between concept and reality through a human-centric design approach.

This project and other pilot projects will serve as a learning model of community engaged research for future faculty-student research projects of the consortium. It is intended that the planned consortium will similarly engage highly multidisciplinary student-faculty teams at participating universities as they address the future of trucking.

Consortium Goals

The adoption of electrification, automation, and digital connectivity technologies in freight logistics, public transport, and supply chain sectors brings in significant pre-competitive research needs, including assessing technology adoption trends, operational strategies, powertrain and energy delivery modes and requisite infrastructure, and economic and societal impacts of the transformed industry. Universities can work with industry and community organizations to ensure societal benefits in this transformation. The planned consortium envisions a spectrum of research in logistics and vehicle technologies to meet societal needs. Some research objectives include: (*i*) organizational strategies for democratized CEAT adoption; (*ii*) optimizing rural and urban rapid produce and food collection and distribution, (*iii*) electric powertrain management systems that optimize charging and fuel usage based on existing and evolving infrastructure, *(iv)* fleet synchronization in platoons through vehicle data communication and decision support tools for participating businesses, (*v*) market penetration prediction and business case analyses for CEAT, and (i*v*) preparing future workers and researchers for the transformed trucking industry. Some important unmet research needs are discussed below:

<u>Green Transportation with Net-Zero Emission:</u> CEAT can help significantly reduce GHG and criteria emissions through features such as electrified drivetrains, automated off-peak and geo-fenced operation, and connected travel with drag reduction and energy sharing. New research is needed to understand the synergistic interaction of these features, promote widespread adoption, and achieve the net-zero reality. Industry seeks knowledge of how customers and dealers value or do not value the economic, social, and environmental benefits of CEAT. The environmental and societal gains of CEAT can outweigh any social cost, but with benefits dependent on the number of operational CEAT fleets. While batteries can be used to electrify light vehicles and regional short-distance freight delivery trucks, long-haul heavy trucks may benefit more from fuel-cell and hydrogen fuel infrastructure technologies [12], as battery weight limits range. Challenges include the actual and perceived durability and safety of fuel cells, hydrogen fuel systems, and batteries, and the scarcity of rare-earth metals until resolved by market mechanisms [13]. Currently, market demand for these metals is dominated by one country [14] where, ironically, the most rapid transport electrification in the world is being accompanied by the largest continued building of coal-fired electricity power plants. Even in the US, where natural gas now dominates electricity generation, the actual GHG benefits of electrification must be continuously verified by rigorous research by unbiased parties, especially academia with the involvement of students who must learn to sort facts from ‘greenwashing’.

Road Safety and Driver Health & Satisfaction: Safety must always be a top priority in transportation. Truck drivers are much more likely to suffer fatalities than other sector workers and endure many work-related illnesses [6] [15]. Large trucks are involved in 11% of road crash deaths [5], and fatigue contributes to a fifth of truck crashes [16]. Measures such as electronic logging devices (ELD) and treating conditions like sleep apnea help ensure driver safety and reduce fatigue [17]. With increasing vehicle automation (Fig. 1, [18]), vehicle crew may serve as safety backup operators, rather than driving. This technology requires demographically unbiased human-factors research on maintaining their alertness and ability to take control when necessary. Understanding driver drowsiness and fatigue under L3-L4 autonomy is crucial for predicting human-machine performance and addressing mental state and training needs.

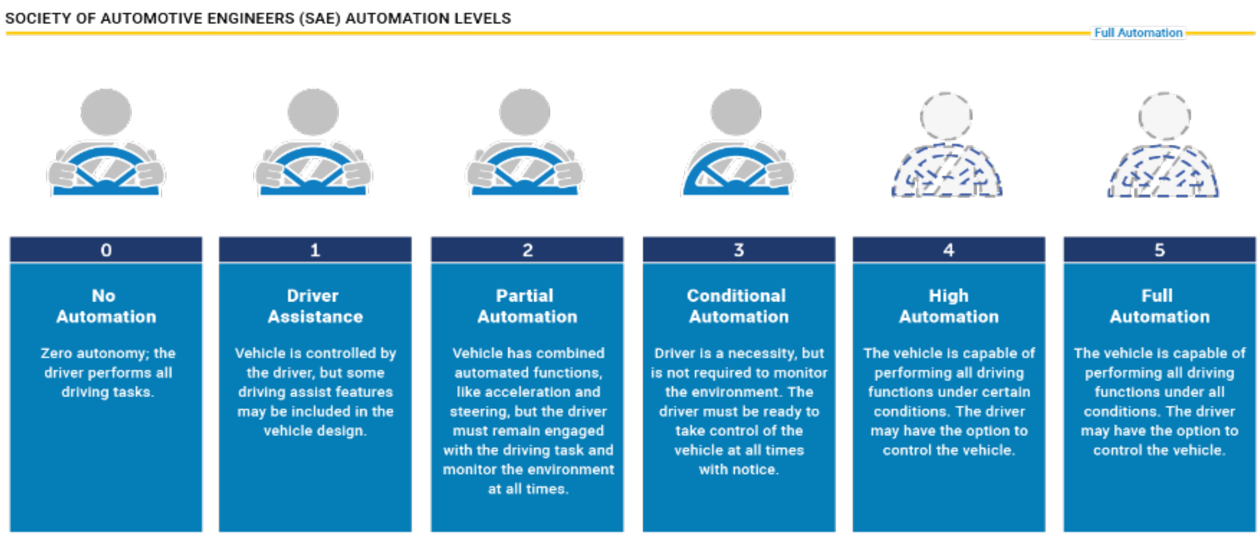

Fig. 1 Society of Automotive Engineers (SAE) Levels of Vehicle Automation [18]

Automated & Connected Trucks: Platooning and caravanning are emerging operational strategies for connected trucks, where a set of (semi)automated trucks travel together, sharing information for coordinated steering, braking, and speed control. Platooning benefits include fuel savings due to aerodynamic drag reduction [19], attracting industry interest [20-22]. Research is needed on managing mixed traffic environments, fleet synchronization, centralized/spontaneous platoon formation, and decision support tools. Caravanning is a more futuristic concept now being researched by both the sites [23] [24], that merges automated vehicle technologies and intelligent transportation infrastructure. Caravanning can optimize transport network utilization and reduce congestion by utilizing highly skilled pilots for valuable payloads on a 24/7 schedule, but research is needed to ensure this is done with better and not worse human lifestyle options. Cargo transfer between seaports and inland 'dry' ports is an area for pilot studies on caravanning that is of interest for improving safety in the port industry (especially from drayage companies, terminal operators, and port authorities). Growing industry interest in the field deployment of connected trucks requires collaborative and synergistic research on market penetration, adopter preferences, and system models of supply chains.

Autonomous Delivery Robots (ADRs) for Last-mile Delivery Services: Optimal integration of last-mile delivery robots and long-haul trucks will help complete the supply chain. The COVID-19 pandemic accelerated e-commerce and put a global spotlight on essential services such as door-to-door and contactless delivery. Logistics service providers partnered with autonomous technology developers to deploy ADRs in some U.S. cities and university campuses. Rapid but uneven technology development must be matched by research into the gaps and barriers toward marketplace adoption, such as accessibility for people with disabilities. The safe interaction of ADRs with humans is also of concern to policymakers, logistics operators, and the public.

Trucking Workforce Mismatch, Unemployment, and Creating Futuristic Workers: Automation will transform the role of human drivers in the trucking industry [6]. The trucking industry believes it is already experiencing severe labor shortages, with an estimated shortage of 80,000 truck drivers before the COVID-19 pandemic, projected to further double by 2028 [25], although some dispute whether this . The International Transport Forum [26] predicts that up to 70% of truck driver jobs could be automated by 2030. On the other hand, the Teamsters union and others have pushed state legislatures to ban autonomous trucks, fearing job losses. In the near future of Level 3-4 trucks, human drivers may still need to take control in certain situations, whereas Level 5 fully driverless trucks may appear as regulations and legislation allow. This situation will require new human-machine interaction environments and planned workforce development to accommodate different human roles in the industry.

Data Management: The digital data revolution [27] (artificial intelligence, virtual and augmented reality, data science, blockchain, e-commerce) is revolutionizing logistics. It enables new strategies (e.g., optimal route networks and modes, end-to-end supply chain visibility, customer tracking), tactics (optimal truckloads, vehicle choices), and operations (real-time tracking, handling weather, traffic, emergencies, failures). CEAT-enabled freight logistics are synergistic with these digital trends and can drive these new strategies, tactics, and operations. These include merged warehouse and fleet logistics, real-time control, compatible data formats, and self-adaptive supply chains. However, there are risks and ethical issues to consider, similar to other AI and big data technologies, such as the intrusive monitoring of drivers and their states of mind. Industry needs accurate market predictions based on understanding adopter behavior and models that predict supply-chain system behavior across diverse subsystems.

Anticipated Impact

The consortium aims to help improve U.S. supply chains and public transportation through industry and community-engaged research that examines challenges to the wider adoption and democratized benefits of electrified and automated commercial road vehicles. The initiative will conduct pre-competitive research, assess adoption trends, and promote cross-disciplinary education and workforce development. The consortium will especially promote technology development that brings benefits to all segments of society, through reducing environmental pollution, improved working conditions, wider accessibility, and affordable mobility.

The consortium will actively work to broaden the participation of underrepresented groups in multiple disciplines, with diversity, equity, and inclusion (DEI) being central to the consortium's mission. Graduate and undergraduate students conducting research will collaborate with industry stakeholders, not only gaining real-world experience, but being encouraged to think critically from multiple disciplinary perspectives and to raise important societal concerns.

Partnering with existing university outreach programs will be used to attract students to research projects, expand internship programs, and organize activities for secondary-school students to foster early interest in STEM careers, with attention to underrepresented minorities and women. Student competitions related to electrified and automated vehicles will be promoted to attract and develop workforce in this area.

Strategy and Efforts to Build Consortium

The consortium will engage students and faculty with the priority on these key themes (Fig. 2)

- Societal Benefits: Contribute to lower fatalities, emissions, congestion, and logistics costs. Advance vehicle technologies that improve safety, reduce delays, and transform the future of work and lifestyle in the trucking industry. Creating safety awareness for all road users; protection of vulnerable users. Create education pathways for under-represented students.
- Industry Engagement: Collaborate with the trucking and logistics industries to guide the transition to autonomous and electrified vehicles, addressing concerns such as operating costs and fleet management. Work with manufacturers to reassess design requirements and redevelop workforce, seeking human-centered innovations beyond autonomous driving software and electric drivetrains.
- Government Collaboration: Share research with state and federal stakeholders, contributing to decisions on regulations and research directions for connected and autonomous vehicles.

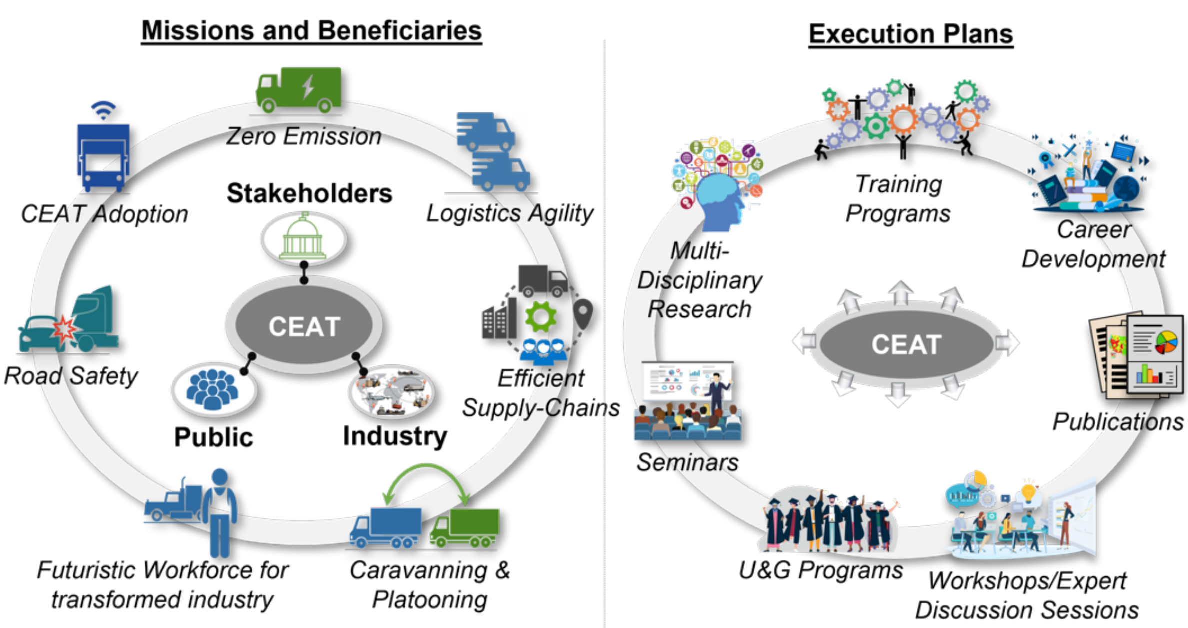

Fig. 2 Missions, Beneficiaries, and Execution Plans of the Consortium

Completed Activities and Current Status

Bootcamp. Project leaders received training and gained valuable insights on effective center launch strategies. With this training, a comprehensive customer discovery process was conducted to understand industry needs and identify potential members. The team engaged with freight logistics, vehicle/powertrain OEMs, automotive suppliers, technology providers, trucking companies, port operators, utilities, transit agencies, and many others, typically with video link meetings, as well as several visits and tours to local companies. Our teams interacted with over seventy-five companies broadly related to commercial transportation to determine what industry viewed as the most pressing challenges facing their companies within the center's research areas of trucking electrification and automation. Leaders also attended several relevant industry trade shows and conferences such as SAE ComVec to connect with industry experts. These meetings informed the preliminary selection of research projects to present during a planning workshop. A website was developed to provide information about the consortium, its vision, mission, research thrusts, membership benefits, research team, and the various events organized by the center.

Industry workshop. A two-day in-person planning workshop was held in 2023 with lengthy promotion to industry, including a social gathering for students and faculty to connect with industry experts in a relaxed setting. The formal workshop was attended by 22 industry members from 19 companies to discuss the proposed consortium model, value propositions, and needed financial commitments. Industry members were presented with 11 proposed projects, followed by industry feedback on each project. Breakout sessions on 3 subtopics allowed attendees to share their feedback on the projects and discuss industry priorities, including those missing from the projects. These perspectives were documented and used to guide the faculty project investigators in refining their projects based on this feedback. A poster session was held with undergraduate, graduate, and postdoctoral researchers, as well as the faculty, presenting their proposed and ongoing research. This allowed for more in-depth discussion about specific research projects and highlighted the student talent in existing programs at the sites. On the second day of the workshop, faculty members presented their responses to the industry feedback, addressing the concerns and comments industry provided and sharing how they would modify their projects based on that feedback. Industry attendees expressed their preferences for the projects they found most promising and relevant.

The team submitted a proposal to the National Science Foundation (NSF) to support administrative expenses of the consortium. A total of 21 companies and other organizations each provided a letter of commitment to join the center when inaugurated, with 13 of these organizations committing to some financial support in the form of membership fees. Their identities will be revealed when a membership agreement is formally executed and membership is made public. The team was recently informed that the grant is recommended for funding from the NSF's Industry-University Collaborative Research Center (IUCRC) program. This will allow the consortium to be formally launched in 2024, with research projects to be funded by industry members of the consortium. Formal membership agreements and operating procedures of the consortium are currently being drafted.

The potential research projects that have been proposed by faculty members at participating universities are listed in Table 1, organized under major research thrusts. Under the IUCRC model, an industry advisory board will formally evaluate faculty research proposals and will periodically allocate funding from pooled membership fee contributions. Pre-competitive research would be intended for wide dissemination, filling the gap between basic research and industry-proprietary technology development. Depending on the industry sectors represented in the consortium, a smaller subset of the listed research thrusts will be considered for initial focus.

Table 1 Research projects proposed for initial consideration

Research Thrust	**Research Projects**
Mixed Traffic Sensing, Coordination, and Optimization (including Platooning/ Caravanning)	Yard Operations – Planning with Disparate Models
	3D-360 Traffic Tracking with AI Imaging
	Real-Time Caravanning and Platooning Coordination Cooperative Control of Tightly-Spaced Autonomous Platoon/Convoy/Caravan
	Machine Learning-Based V2X Communication System for CEAT
	Traffic Jam Back-of-Queue Collision Warning and Mitigation
Vehicle & Infrastructure Electrification Technologies	Battery Materials Recycling & Recovery
	Durable Fuel Cells for Long-Haul Trucking
	Strategies for Long-Haul Electric Freight Logistic System and Electric Public Transit Systems with a Vision of Net Zero Emission
Business & Economics of Freight Transportation	Market Penetration of Connected, Electrified, and Automated Commercial Fleets (Trucks, Autonomous Delivery Robots, and Buses) in Mixed Traffic
	Business Case and Success of CEATs
Human Machine Interaction in the Trucking Industry	Human Elements in the World of Electrification and Automation
	Driver Fatigue and Drowsiness Detection in Semi-Automated Driving
Commercial Vehicle and Component Design, Mechanics & Materials	Lightweight Composite Materials for Trucks and Bus Battery Packs
	Tractor and Truck Design for Driverless Economics

A student team is currently working to develop ecosystem and value stream maps for freight trucks equipped with electrified powertrains and SAE Level 2-5 advanced driver assistance systems (ADAS) or automated driving systems (ADS), anticipating road use by 2030 or sooner. The ecosystem map will identify key industry sectors and players using software tools for organizing and visualizing their roles. The objective is to understand relationships, dependencies, and value-contributing elements before proceeding to the value-stream mapping, where the focus shifts to describing these entities and their relationships and the value contributed by their processes. This student team's work will be used by project leaders to develop technology roadmaps and to further promote the consortium to identified industry sectors.

Challenges and Lessons Learned

The typical challenge in creating a major consortium is funding from government agencies and industry. Even though the value of industry- and community-engaged research seems clear, the internal reward and motivation structures of both academia and businesses do not tend to create incentives for such work. The work of creating a consortium thus requires patient and prolonged effort until sufficient resources and a critical mass of participants are assembled.

It is also important to engage many stakeholders, especially underserved communities, and bring their needs to the forefront in the deployment of new technologies. Student and faculty groups have been effective in brainstorming ideas for research projects to be proposed to the consortium. As exemplified by the food pantry project, such community engaged efforts can bring many issues to light for industry consideration for future research.

Acknowledgement

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