Transportation Research Interdisciplinary Perspectives 38 (2026) 102094

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: www.elsevier.com/locate/trip

Enhancing transportation education to reflect technological advancements in connected and automated vehicles

Jisoon Lim [a], Amirmahdi Tafreshian [a], Neda Masoud [a,*], Henry X. Liu [a,b,c], Andre Carrel [d], Shan Bao [e,f], Daniel Work [g], Gábor Orosz [a,b]

[a] Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, United States of America
[b] Department of Mechanical Engineering, University of Michigan, Ann Arbor, United States of America
[c] University of Michigan Transportation Research Institute, University of Michigan, Ann Arbor, United States of America
[d] Department of Civil, Environmental, and Geodetic Engineering, The Ohio State University, United States of America
[e] Department of Industrial and Manufacturing Systems Engineering, University of Michigan, Dearborn, United States of America
[f] Department of Civil, Environmental, and Geodetic Engineering, University of Michigan, Dearborn, United States of America
[g] Department of Civil and Environmental Engineering, Vanderbilt University, United States of America

ARTICLE INFO

Keywords:
Autonomy
Connected and automated vehicles
Transportation education
Backward design
Learning objectives

ABSTRACT

Connected and automated vehicles (CAVs) represent a transformative technology that can revolutionize how people and goods move. The private sector is at the forefront of developing this technology, and many municipalities are attempting to prepare for a more connected and automated future. At the same time, as the CAV technology is not mature yet, academics are directing most of their attention to research on CAVs and their impact on the transportation system, overlooking the need for workforce development. The objective of this paper is to assess the needs for workforce development in CAVs, to identify potential obstacles that educators face in fulfilling those needs, and to propose ways to overcome the obstacles. Toward this end, a workshop was designed to bring together experts to identify the best ways to meet the demand for a workforce skilled in CAVs. As the field of CAVs can be diverse, a survey was distributed ahead of the workshop to identify the main themes around which the workshop was designed: (1) next generation infrastructure for CAVs, (2) human factors with CAVs, (3) modeling, simulation, and testing of CAVs, and (4) travel behavior in the context of CAVs.

1. Introduction

Traditionally, transportation engineering programs have primarily focused on the design, operations, and planning of transportation systems while considering the interactions between road infrastructures, vehicles, and users (Sinha et al., 2002). Although these focuses remain of utmost importance, our perspectives and approaches to them have been greatly impacted by the introduction of new technologies such as connectivity, automation, shared transportation, and electrification.

The connected and automated vehicle (CAV) technology comes with the promise of revolutionizing transportation systems by enhancing driving safety, transforming how people and goods move, and curbing the environmental footprint of the transportation sector. Despite its potentials, CAV technology is, for the most part, at the research stage, with academics and the private sector focusing on CAV infrastructure (Saeed et al., 2021; Ersal et al., 2020; Liu et al., 2019; Sanusi et al., 2022; Mahdavian et al., 2019; Jiang et al., 2021), CAV-related human factors (Wang et al., 2022; Sarker et al., 2019; Zhang et al., 2022; Fisher et al., 2020; Zhang et al., 2021; Sharma et al., 2017; van Wyk et al., 2020; Hung et al., 2022), modeling, simulation, and testing of CAVs (Liu et al., 2022; Sun et al., 2021; Zhang and Masoud, 2020; Molnár et al., 2022; Gunter et al., 2019; Stern et al., 2018; Ge et al., 2018; Feng et al., 2018; Pariota et al., 2020; Do et al., 2019), and implications of CAVs on travel behavior (Zmud et al., 2018; Masoud and Jayakrishnan, 2017; Kröger et al., 2019; Lavieri et al., 2017; Rubin, 2016; Karimi et al., 2026), among other topics. While academic research often jointly considers vehicle connectivity and autonomy, the industry remains primarily focused on the autonomy of vehicles due to the slower commercialization of connectivity technologies.

In the past, transportation engineers have been responsible for the design, operations, and planning of transportation systems (Hendrickson, 2017). Today, however, the automated vehicles (AV) industry is seeking trained experts to contribute to the sustainable development of AV systems (Ivanov et al., 2018). Consequently, automation

* Correspondence to: 2350 Hayward St, Ann Arbor, MI 48109, United States of America.
E-mail address: nmasoud@umich.edu (N. Masoud).

https://doi.org/10.1016/j.trip.2026.102094
Received 8 October 2025; Received in revised form 29 May 2026; Accepted 1 June 2026

technology has increased the demand for expertise in cloud computing, artificial intelligence (AI), and big data. Additionally, in recent decades, a wide spectrum of companies – from high-tech firms to original equipment manufacturers (OEMs) and mobility service providers – have entered the transportation market, altering the landscape of decision-makers (Miranda, 2023).

Thus, there is a growing concern in the transportation job market about whether computer scientists will eventually dominate the field (Hendrickson, 2017; Miranda, 2023). However, transportation engineering's focus on the naturalistic driving environment distinguishes it from other disciplines involved with CAVs in advancing toward a driverless future. Therefore, we argue that the transportation engineering profession will continue to play a significant role in this field, provided that transportation educators integrate these emerging technologies into their curricula.

Unlike studies that focus primarily on technical aspects of CAV technologies, this paper examines the educational, organizational, and interdisciplinary dimensions required to support the long-term deployment of connected and automated transportation systems. The study contributes to transportation research by synthesizing perspectives from academia, industry, and government stakeholders to identify workforce gaps, curriculum needs, and implementation barriers associated with emerging mobility technologies. As such, this paper bridges transportation education, policy, and practice while offering a structured framework for future curriculum development in rapidly evolving transportation domains.

1.1. Previous efforts in enhancing transportation education

To equip the new workforce with such emerging technologies, it is crucial for transportation engineering programs to adapt to them. Several recent studies have highlighted the need to modernize transportation education in response to evolving technological and societal demands. For instance, Bisht (2025) examines efforts to revamp curricula for road safety professionals in India in response to changes in transportation infrastructure and roadway capacity. Similarly, Morariu et al. (2025) investigate the use of challenge-based learning to enhance transportation education programs in Finland within the context of autonomous shipping. Extending this discussion to logistics education, Baker et al. (2023) highlight the growing mismatch between rapidly evolving industry practices and existing educational materials, while noting the limited attention devoted to systematically updating workforce training programs. These studies underscore the broader need for transportation education programs to continuously evolve alongside emerging technologies and workforce requirements.

Another factor that contributes to the urgency of incorporating CAV technology in transportation education is the change in the career prospects of transportation engineering graduates. In the past, graduates from transportation engineering programs were primarily employed by government agencies, such as departments of transportation (DOTs) and metropolitan planning organizations (MPOs), consulting firms, or research organizations. However, today's graduates have expanded opportunities to work for high-tech companies, major original equipment manufacturers (OEMs), and mobility service providers in addition to the more conventional companies and organizations (e.g., Shock, 2023; U.W. Civil & Environmental Engineering, 2023). These new career prospects undoubtedly require different skill sets and tools, which must be reflected in the curriculum.

There have been several attempts to create interdisciplinary courses focusing on AV design in response to the need for integrating new technologies into transportation engineering curricula. For instance, Lau et al. (2020) introduces a cross-disciplinary course on AV system design, covering design, implementation, and evaluation under the First Principles of Instruction (FPI) framework (Merrill, 2002). The course can be taught both in-person and remotely, emphasizing learning-by-doing through multidisciplinary design projects (Lopez et al., 2015; Liu et al., 2021). Other proposed methods for training students include using toy cars (Scheffe et al., 2020) and simulation platforms (Wang et al., 2020; Samak et al., 2021).

Despite these efforts, they remain insufficient to bridge the gap between academia and industry and fully address job market demands. First, while the industry prioritizes the autonomy aspect of the technology, academia must also place equal emphasis on the connectivity aspect. Since both autonomy and connectivity will play critical roles in the future of transportation, it is essential that educational programs prepare the workforce to be proficient in both areas.

Second, as we incorporate technological advancements into curricula, it is important to move beyond a strictly research-centric approach and ensure that academic programs align with the current and future needs of the job market. Transportation engineering, governed by a system-level perspective, stands at the nexus of a number of fields in engineering, planning, and economics that bring together vehicles, infrastructures, and travelers. This interdisciplinary focus of transportation engineering distinguishes it from other fields, thereby necessitating a careful examination of how technological advancements can be integrated into educational material. In fact, because many transportation education programs receive financial support from industry, government agencies, and other partners, periodically evaluating and updating curricula to reflect evolving workforce needs can help ensure that these investments translate into relevant educational outcomes and workforce preparedness (Kothari et al., 2022).

1.2. Study objective

The goal of this study is to pinpoint educational gaps in CAV systems within the context of the four themes identified in this paper and to highlight the teaching material that needs to be developed to fill these gaps. Beyond curriculum redesign alone, this study positions transportation education as an interdisciplinary and policy-relevant component of the broader transition toward connected and automated transportation systems. As transportation systems become increasingly shaped by various technologies such as automation, connectivity, AI, data-driven operations, and emerging mobility services, workforce preparedness becomes a critical challenge affecting not only academia, but also transportation practice, public policy, infrastructure deployment, and industry innovation. In this regard, pedagogical design and workforce development are not merely educational concerns, but strategic considerations that influence how future transportation systems are planned, operated, regulated, and implemented.

The interdisciplinary nature of CAV systems further demands coordination across transportation engineering, computer science, human factors, operations research, urban planning, public policy, and data science. At the same time, transportation professionals are increasingly expected to bridge theoretical, technological, and societal considerations while communicating across traditionally separated disciplines. Consequently, identifying educational gaps and developing adaptive curricula represent an important step toward preparing a workforce capable of supporting the deployment and governance of future transportation technologies.

In order to discuss gaps in transportation education related to CAVs and ways to fill in those gaps, the Center for Connected and Automated Transportation (CCAT), the Region 5 University Transportation Center (UTC), together with Mcity, the first dedicated, real-world test bed for CAVs located at the University of Michigan (UM) campus, held the *Autonomy in Transportation Education* workshop in April 2022. Centering on the necessity of incorporating autonomy-related learning materials into transportation education, this workshop was designed to serve the following goals:

1. Identify the knowledge gaps of the existing transportation education programs and suggest new learning objectives with regard to CAV technology;

2. Identify the barriers in creating CAV educational content and propose solutions to resolve them;
3. Identify the recommended modes of teaching to overcome such barriers and fill the noted knowledge gaps (by means of new or revised course modules, hands-on exercises, experiments on test tracks or on public roads, new courses and degrees, etc.).

The workshop involved a carefully selected group of experts from academia and industry with insights on job market demand for CAV experts as well as on current curricula in transportation engineering programs and how they can be improved. The pre-workshop survey was distributed to identify a few key domains in the broad field of CAVs on which the workshop could focus. Through this structure, the study aims to bridge transportation research, educational practice, and workforce development by synthesizing perspectives from multiple stakeholder groups involved in the evolving CAV ecosystem.

The rest of this paper will elaborate on the outcomes of the survey, discuss how the agenda for the workshop was informed by the survey outcomes, and summarize the takeaways from the discussions during the workshop. Specifically, we first provide a background of the workshop on how it aims to restructure the existing transportation education curricula in Section 2. Section 3 presents the *Autonomy in Transportation Education* workshop that is designed to discuss gaps in transportation education related to CAVs, along with the survey results conducted prior to the workshop. Section 4 outlines the discussions in the four themes of the workshop. Finally, Section 5 evaluates the workshop results, summarizes the findings of the paper, and discusses post-workshop outcomes.

2. Background

In this section, we outline key considerations within the curricula redesign process. To redesign the transportation engineering curricula, we propose effective ways to fill in the current gaps by designing new training modules and/or revising the existing curriculum. In the literature of pedagogy, this design process is referred to as *backward design*. We provide a brief introduction to this concept by first describing the basic principles of the science of learning and then explaining the design of learning and teaching materials "with the end in mind." Then, we compare different teaching methods/modalities that are considered while revising the curriculum.

2.1. Backward design

According to one of the oldest and most popular theories of learning, namely social constructivism, knowledge is constructed by the learner in a social context (Dewey, 1923; Vygotsky and Cole, 1978; Bruner, 1996). Such literature indicate that (*i*) knowledge is constructed, not transmitted, (*ii*) one learner may construct knowledge in one way, while somebody else might construct it in a different way, and (*iii*) learners need to feel they belong in the classroom or any community in which they are trying to learn, and also the cultures that learners bring into the classroom affect the way that knowledge is constructed. As such, the literature summarize how learning occurs translates into the classroom in certain ways. First, we learn best when we are active, enabling us to do something with the attained knowledge. Second, we need to make connections because we learn better when we know the global picture, as opposed to little pieces that are disconnected. Also, we learn best when what we are learning connects to what we value. Third, the sense of belonging is really tied to learning. We learn best when we feel that not only do we belong to a community of learners, but also we can be a part of the field. This brings us to the following quote from Herb Simon:

"Learning results from what the student does and thinks and only from what the student does and thinks. The teacher can advance learning only by influencing what the student does to learn" (Ambrose et al., 2010).

As a key takeaway, we should move from content-centered teaching toward student-centered teaching when designing learning, where the first step is to know who are going to be our students.

After learning who the students are, we may apply a backward design (Wiggins et al., 2005) model to design lessons or curriculum. In backward design, once we know who the students are, we think about what we want the students to know at the end of a lesson or at the end of the learning experience. That is why it is also referred to as "beginning with the end in mind" (Covey, 2006). For backward design, we take three steps: (1) identifying the desired results, which are going to form our goals and objectives, (2) identifying evidence that can inform us whether the students are in fact making acceptable progress toward those learning objectives, and (3) planning the learning activities so that the learning experiences become the process by which we take the students to the desired result. We followed these three steps during the workshop discussions to adhere to the principles of backward design.

2.2. Teaching modality

Another consideration in curricula redesign is teaching modality. Modes of teaching may include online and in-classroom teaching. While online teaching offers benefits such as centralized course organization and management and flexibility in learning pace, its downsides include the difficulty of getting to know other participants, building rapport, and meaningful interactions that need intentionality (Bach et al., 2007). Yet, the COVID-19 pandemic significantly accelerated the adoption and development of online learning across engineering disciplines, including transportation, civil, and supply chain engineering (Garcia-Alberti et al., 2021; Abbasnejad et al., 2023). Studies have highlighted both the feasibility and the effectiveness of online modality in delivering technical content, fostering engagement, and maintaining learning outcomes (Farley and Burbules, 2022; Galvis and Carvajal, 2022). In engineering education specifically, asynchronous video lectures, remote labs, virtual simulations, and discussion forums have become integral components of program delivery, offering increased accessibility for non-traditional and working students (Gregg and Dabbagh, 2023). In light of these developments, future curriculum redesigns in transportation education should not only acknowledge the expanded role of online modalities but also explore how best practices can be integrated to strengthen student outcomes across various delivery formats.

On the other hand, the benefits of in-person teaching include familiarity of students with the learning environment, hands-on learning, and non-verbal communication. Its downside is that all students are expected to learn at the same pace (Peine and Coleman, 2010). Table 1 summarizes the benefits and disadvantages of each mode. Given the benefits and disadvantages of each mode, a question arises: *can we combine the best of both worlds?* This hybrid mode (Doering and Veletsianos, 2008) is typically referred to as blended learning. It comprises any teaching method that uses technology in the classroom to support students, such as using clickers in the classroom or using online discussion boards, such as Piazza,[1] for students to ask questions. If we think about the science of learning and best practices in pedagogy, we can teach well in any environment — online, in-person, or blended.

It is worth mentioning that Garrison et al. (1999) suggest that effective educational experience for teaching and learning online lies at the intersection of cognitive, teaching, and social presences. Cognitive presence governs how the student or the practitioner interacts with the material/content. The teaching presence controls how the teacher interacts with the students. Finally, social presence, the element that often gets left behind, defines how students interact with each other. A strong social presence combined with a strong teaching presence typically leads to a strong cognitive presence.

[1] An online learning management system that allows discussions and class engagements; https://piazza.com/.

Table 1
Online teaching vs. In-classroom teaching.

Online	In-Classroom
Pros: – Centralized course organization and management – Flexibility (students can learn at their own pace, and in remote locations) – Automatic feedback/monitoring	**Pros:** – It is familiar – Hands-on learning – Non-verbal communication – Unplanned interactions are easy
Con: – Getting to know each other, building rapport, and meaningful interactions needs intentionality	**Con:** – All students learn at the same pace and in the same way

3. *Autonomy in transportation education* workshop

In this section, we introduce the *Autonomy in Transportation Education* workshop, which applies the backward design model to tackle the shortcomings of the current education system.

3.1. Workshop outline

The workshop, co-hosted by CCAT and Mcity, aimed to address gaps in transportation education related to CAVs and explore ways to bridge them. Specifically, this workshop was designed to tackle the three goals introduced in Section 1.2.

Prior to the workshop, a survey was distributed to experts in industry and academia, which we detail in the upcoming section. The objective of this survey was to identify a few key domains in the broad field of CAVs on which the workshop could focus.

The workshop was held virtually on April 11, 2022 from 12:00 to 17:00 EDT. We recruited 36 attendees[2] from academia, industry, and government sectors.

The workshop kicked off by providing the participants with some background on the vision for the workshop. The outcome of the survey that helped us to identify the four themes of the workshop was briefly presented to the audience. Next, a representative from the University of Michigan Center for Research on Learning and Teaching (CRLT) delivered a lecture on "Understanding by Design". This presentation laid a solid foundation for attendees by delving into the fundamental principles of backward design. These principles became the cornerstone upon which all subsequent discussions in the workshop were built. By establishing this groundwork, we ensured that the outcomes of our discussions remained firmly rooted in the context of backward design. This strategic approach will serve as the backbone for our new transportation engineering curriculum, providing a robust framework that will guide the entire design process.

After such introductions, the audience was split into four groups, one for each theme, to dive into deeper conversations based on a list of questions shared with all the participants prior to the workshop. The workshop's organizing committee, comprised of experts from various fields directly and indirectly associated with CAV research, education, and field implementation, carefully identified these participants as authorities in their respective domains. Authors of this paper participated in each of the themes and led the discussions for the corresponding group.[3] Each group of participants joined a virtual break-out session, where the theme lead led the discussion to cover a list of topics within their groups.[4]

Discussions took place in two stages. During the first stage, the participants freely shared their thoughts on the list of questions while notetakers transcribed the discussions for each break-out room. The participants expressed their agreement/disagreement with the survey results and provided appropriate solutions to the shortcomings of the existing curricula. This stage was followed by a break during which the theme lead and the notetakers combined their transcripts and drafted a discussion report. During the second stage, the participants finalized the report and summarized the takeaways of their discussions. Finally, the workshop concluded with the theme leads providing the entire audience with a summary of the takeaways from the discussions in their break-out rooms.

Following the workshop, our long-term overarching goal is to develop an innovative transportation education curriculum that comprehensively addresses the identified knowledge gaps related to CAVs. This curriculum will strive to integrate the proposed solutions derived from the workshop discussions, utilizing the principles of backward design. By doing so, we aim to create a robust educational framework that bridges these gaps and ensures a well-rounded understanding of CAV technology by the future workforce.

3.2. Workshop survey

As mentioned, we conducted a short survey to help set the direction for the workshop. The purpose of this survey was to acquire a general idea about the existing gaps between what is needed in the workforce and what transportation engineering programs offer to students. As such, we distributed the survey[5] among CAV experts in academia and industry, both in the private sector and the public sector. The survey was prepared with the organizer's prior knowledge of the existing curriculum's shortcomings and feedback from their peers. In what follows, we present a summary of 75 valid responses that we received from December 21, 2021 to January 30, 2022.

First, we asked participants whether they noticed a knowledge gap in the skill set of recent graduates in their corresponding sector. Among the survey participants, 59 participants (about 79%) answered "yes" and continued with the survey for follow-up questions, while 16 participants answered "no." Because the remaining survey questions focused on identifying and characterizing perceived educational gaps, the analysis presented in Figs. 1–3 and Tables 2–4 pertains only to the 59 participants who answered "yes".

Figs. 1–3 depict such 59 participants' backgrounds. First, as depicted in Fig. 1, the majority of participants were from academia (40%) and government agencies (20%), respectively. Also, a total of 20% of survey takers were involved in consulting jobs, and about 20% of them belonged to research institutions in the public and private sectors. Also, as shown in Fig. 2, 49% of the participants held Ph.D. degrees, 27% held Master's degrees, 24% received a Bachelor's degree.

Finally, as noted in Fig. 3, the majority of participants were reported to be professors in academic institutions (27%), and the rest were involved in a variety of positions including directors, engineers, researchers, consultants, managers, CEOs, vice presidents, etc.

Then, the next set of questions provides inspections of the knowledge gap recognized by the survey participants. We first asked them

[2] The full list of attendees can be shared upon request.

[3] More specifically, A. Carrel, S. Bao, D. Work, and G. Orosz led a discussion for themes 1, 2, 3, and 4, respectively.

[4] The workshop discussion questionnaire can be found here: https://drive.google.com/file/d/1_S6jE3PZdQdh9JRtdwz67E_GonBsvtNa/view?usp=drive_link.

[5] The workshop pre-survey can be found here: https://drive.google.com/file/d/1pdlRJ1gfeBWeWbAdR79p823WhRf6n-WN/view?usp=drive_link.

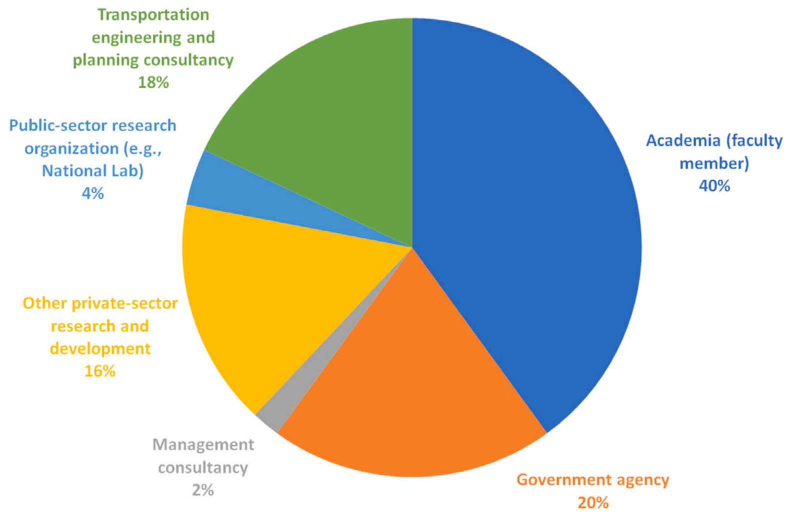


Fig. 1. The distribution of the participants' corresponding sector.

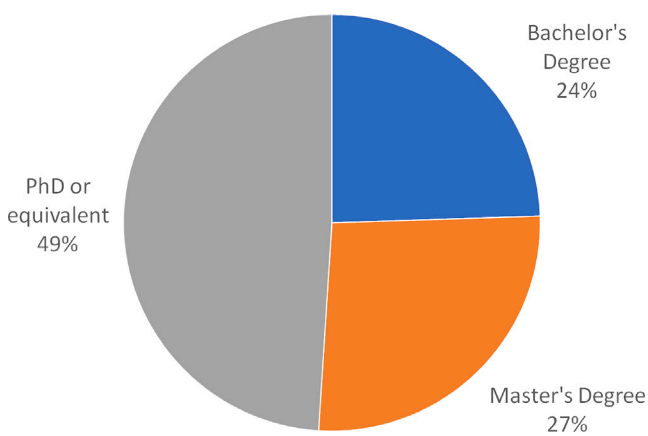


Fig. 2. The distribution of the participants' highest level of education.

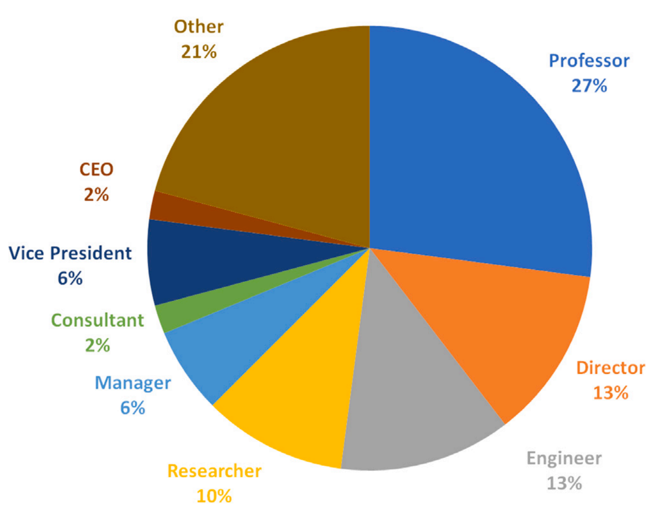


Fig. 3. The distribution of the participants' positions within their organizations.

to identify the general areas in which they observed a knowledge gap, where all responses are reported in Table 2. The most frequently perceived areas of deficiency were: translating their knowledge to practical solutions, system-level thinking, state-of-the-practice tools and technologies, working with data in practice, and theoretical foundations.

The next question more specifically targeted the CAV sector as the participants were asked to identify the knowledge gaps related only to CAVs. Table 3 displays all areas that were reported to that question.

Among these areas, connectivity between vehicles, infrastructure, and other road users was the most frequently selected option, followed by infrastructure support for CAVs, human factors with CAVs, testing and evaluation of CAVs, and finally, travel behavior in the context of CAVs. These areas collectively helped us form the main four themes of the workshop, as mentioned earlier.

As the last question of the survey, we asked the participants to choose the key ways to enhance the skill set of transportation engineering graduates, and thereby, fill in the existing knowledge gaps. Table 4 shows all noted options to fill the knowledge gaps, where the most frequently selected options are certificate programs with short modules, either in person or online, while the least suggested options are those pertaining to traditional degree programs.

The survey provided numerous insights that contributed to the design of the workshop. First, it enabled us to pinpoint four key themes related to CAV education for our workshop. The survey participants highlighted these gaps as the areas with the most significant knowledge gaps within the existing workforce. In designing the workshop curriculum using a backward design approach, our primary goal was to bridge the knowledge gaps within these identified themes. Second, in shaping the workshop structure, we used the survey outcomes to prioritize the exploration of areas perceived as lacking in knowledge and aligned with the preferred educational formats highlighted by the survey participants.

4. Workshop discussion results

In the following subsections, we summarize the outcomes of the discussions on the four themes related to CAV education. Each subsection is further divided into three steps, which correspond to the three steps for backward design. More specifically,

- *Learning Objectives* outlines the desired goals and objectives from curriculum redesign, with goals serving as broad and inspirational statements to motivate students, and objectives are specific, actionable elements that guide teaching and evaluation;

Table 2
The distribution of the general areas with perceived knowledge gaps.

Area	Responses
Translating their knowledge into practical solutions.	32
System-level thinking.	29
State of the practice tools and technologies.	28
Working with data in practice.	23
Theoretical foundations.	11
Emerging transportation technologies and impacts.	1
The behavioral, socio-demographic, and societal sides of automated transportation.	1
The breadth of knowledge for the domain space.	1
Networking, cyber security, mobile data architectures, and control systems for safety applications.	1

Table 3
The distribution of the CAV-related knowledge gaps.

Area	Responses
Connectivity between vehicles, infrastructure, and other road users.	31
Infrastructure support for CAVs.	31
Human factors with CAVs.	30
Testing and evaluation of CAVs.	25
Travel behavior in the context of CAVs.	19
Perception, planning, and control systems of CAVs.	19
Machine learning algorithms for CAVs.	15
Modeling and control of CAV systems (with vehicles with varying levels of autonomy and/or other road users).	15
Policies that can improve the likelihood of desirable societal and environmental outcomes with the advent of CAVs (and reduce the likelihood of undesirable outcomes).	1
Traffic control and vehicle control.	1

Table 4
The distribution of the key ways to enhance the skill set of transportation graduates.

Area	Responses
Certificate programs with short, online modules.	32
Certificate programs with short, in-person modules.	31
Case-study-oriented education (similar to MBA degrees).	23
Traditional degree programs with in-person classes.	17
Traditional degree programs with online classes.	12
Grade school introduction to developing skill areas.	1
Interdisciplinary/collaborative projects.	1
Internships, cross-training, collaboration with other disciplines, required short-term job shadowing, collaboration with industry and government on small tasks (funded or non-funded).	1
Practical experience, based on field training together with theoretical foundations.	1
Co-op program.	1

- *Barriers and Proposed Solutions* highlights the challenges in tracking students' learning progress and discusses effective ways for instructors to identify acceptable evidence of learning, which shapes student assessments (Wiggins et al., 2005);
- *Recommended Mode of Teaching* explores methods and modalities to help students meet the learning objectives and how to design engaging learning activities (Wiggins et al., 2005).

4.1. Theme 1: Next generation infrastructure for CAVs

4.1.1. Learning objectives

The next generation infrastructure for CAVs is an interdisciplinary field, drawing knowledge from a wide range of disciplines including civil engineering, mechanical engineering, electrical engineering, and computer science, each with a unique set of perspectives. Considering the involvement of all these domains in the design, deployment, and operation of the next generation infrastructure systems, it is crucial for experts with different backgrounds to have the ability to communicate effectively — a skill set that seems to be missing in current graduates. To address this, undergraduate students should acquire fundamental knowledge in transportation, optimization, data analysis, dynamics, and control. Even though technologies may change quickly, having fundamental knowledge will allow graduates to quickly align themselves with new technological advancements.

For senior-level undergraduate and graduate-level students, they can go beyond acquiring fundamental knowledge in the field. For them, system-level thinking is another skill that would benefit them while pursuing careers in the next generation infrastructure systems. Once graduates enter the field, they will have to partake in large-scale projects that may impact millions of users and require collaboration from multiple stakeholders. As such, having a system-level perspective is one of the greatest advantages of transportation engineers in general. Additionally, since transportation engineering graduates may pursue specific career paths with expertise in a narrow set of sub-fields, they need system-level thinking in order to understand institutional arrangements (government policy, how infrastructures are established, etc.).

Furthermore, all learners must develop the ability to bridge theoretical insights with real-world applications. The ability to self-learn and adapt is particularly important for continuing education, given the rapid evolution of CAV technologies.

Given these circumstances, the learning objectives for students in this field are summarized in Table 5.

4.1.2. Barriers and proposed solutions

To be successful in this field, students must be provided with interdisciplinary knowledge that can prepare them for careers in industry and academia. Although educational materials already exist, they

Table 5
Learning objectives for next generation infrastructure for CAVs.

	Learning objectives	Educational material exists (Y/N)
1	Understand fundamental knowledge of the field such as traffic diagrams, optimization, control, etc.	Y
2	Effectively communicate with people from other fields and reflect on perspectives from experts in other fields.	N
3	Conduct system level thinking in order to understand institutional arrangements.	N
4	Understand the connection between theoretical knowledge and the realities involved in real-world deployments.	N

span a diverse set of fields including transportation, optimization, data analysis, dynamics, and control. As such, a concerted effort needs to be made to package and deliver relevant materials to transportation students in a concise format. As a result, despite the fact that there are no systematic gaps in educational materials, transportation educators are facing a challenge to bring in other disciplines to transportation education, similar to what they have been doing in research. To this end, we need to communicate with domain experts when designing courses in which fundamentals from different disciplines are taught in conjunction with their applications in transportation infrastructure. These courses will enable us to actively integrate the required knowledge into the curriculum.

Additionally, many of the core transportation principles on infrastructure and related topics were created several decades ago, back in the 1950s and 1960s, when data availability was a much more substantial challenge than today. Considering the tremendous amount of data available today compared to six or seven decades ago, and the new advancements in the field of AI, transportation educators are expected to restructure existing courses and revitalize the teaching materials in this field. Moreover, with the rapid pace of technological advancements in transportation infrastructure, educational materials must be continuously and effectively updated to remain relevant and impactful.

4.1.3. Recommended mode of teaching

When it comes to teaching style, active learning is the most useful tool, mostly owing to the fact that students in this field have a diverse set of backgrounds and can learn from each other. An effective active learning task is teaching with projects. Projects will allow students from different backgrounds to interact and view the same problem from multiple perspectives. Other effective active learning tools include watching videos, taking quizzes, and doing different group activities on the same topics but with slightly different focuses. These active learning tasks for students can be best practiced through in-classroom or online courses with a standard university format. For practitioners and researchers working in the industry, however, short courses, half-week summer camps, or certificate programs are more appropriate as they may not have the capacity and time to attend traditional courses that usually take 14 weeks.

Due to the interdisciplinary nature of this field, it may not be appropriate to set a rigid set of prerequisites for courses. Students from different backgrounds may be interested in advancing their knowledge in the field, and rigid prerequisites may stop them from pursuing their interests. Only basic knowledge, such as introduction to transportation engineering, or alternatively, an engineering degree or a certain level of calculus, physics, and algebra may be required. Being familiar with these basics, other domain fundamental knowledge can be taught by instructors in the program.

4.2. Theme 2: Human factors with CAVs

4.2.1. Learning objectives

Human factors is a diverse field. At the undergraduate level, students must understand the fundamental concepts, terminologies, and theories of human factors, so that they can apply them appropriately to the domain of transportation and/or CAVs. Some examples of human factors theories include theories on takeover transition, task switching, and situation awareness.

In a more advanced level, students are expected to learn about the common quantitative and qualitative research methods in human factors. This includes different types of data (e.g., naturalistic driving data, experimental data obtained from driving simulator studies, crash data, and self-reported data), and how they can be collected and used to serve different research purposes. Currently, the main focus of current human factors courses is on quantitative methods (e.g., machine learning methods) and observed data. However, qualitative research methods, such as task analysis and usability studies are also important.

Also, students need to learn about the design of experiments, e.g., the concepts of dependent and independent variables, and how to measure them in the context of transportation and/or CAVs, and are required to understand basic statistical analysis methods and applications. As certain types of research methods may require more training than others to be correctly applied, we must provide courses on both research methods and analytical methods.

For continuing education and industry professionals, it is important to connect human factors principles with real-world transportation system design and policy decisions. This includes interpreting standards such as those from the International Organization for Standardization (ISO) and Society of Automotive Engineers (SAE), while also developing the critical thinking needed to innovate beyond them. Moreover, students from diverse backgrounds (e.g., psychology, urban planning, computer science) must be equipped to communicate across disciplines and apply human factors insights in varied contexts.

Overall, human factors in transportation is an interdisciplinary field, which requires students to be familiar with different applications and terminologies of human factors, e.g., infrastructure design and system design, and link human factors concepts and theories to real-world problems. Finally, transportation engineering graduates are expected to leverage human factors findings to inform system designs in order to improve the interaction between vehicles and humans. The learning objectives for students in this field are summarized in Table 6.

4.2.2. Barriers and proposed solutions

There are a number of reasons behind the existing knowledge gaps. First, human factor is a multi-disciplinary area and traditional silos of academic departments can impede interdisciplinary studies. User-centered design principles have not been traditionally acknowledged in many other fields. Even when transportation educators and students are aware of human factors courses, they may not find the opportunity to take them. The existing curriculum is already heavy, and students in transportation engineering may not be able to fit human factors classes from different departments into their already heavy workload. A possible solution is to review existing classes and create a balance between classes on theories and applications.

Another barrier that transportation educators face is that teaching human factors requires special equipment, tools, and test beds, which often evolve quickly. High level vehicle automation is an emerging technology and active, hands-on learning experiences for CAVs can be difficult to achieve given that CAVs are not yet available. In fact, many people, even practitioners, nowadays may not have any experience

Table 6
Learning objectives for human factors.

	Learning objectives	Educational material exists (Y/N)
1	Obtain a relatively comprehensive knowledge of fundamental theories/ concepts about human factors.	Y
2	Know how to identify and apply appropriate research methods (including both qualitative and quantitative methods) in solving a specific problem.	Y
3	Know how to apply human-centered design methods to develop and evaluate design solutions.	Y
4	Gain knowledge of specific applications of human factors in transportation as human factors is a multi-disciplinary domain.	Y
5	Appreciate the multi-disciplinary nature of human factors needs in automation and transportation.	N

with even SAE definition of L2 or L3 automated vehicles. To overcome this barrier, educators can leverage simulation platforms, virtual reality environments, and remote-access test beds, enabling students to gain practical exposure to automated vehicle concepts and operations even in the absence of physical CAVs.

4.2.3. Recommended mode of teaching

Mode of teaching could vary significantly depending on the purpose of obtaining a degree and the professional background of the students. Certificate programs are a growing need in the industry, but they cannot replace traditional programs, especially for more profound educational purposes. They are, however, appropriate for continuing education purposes for practitioners and professionals already in this field and preparing to work on CAV-related topics. Certificate programs also have advantages in promoting knowledge in human factors as they encourage people to consider human interaction with systems and keep user consideration in the design loop. On the other hand, traditional degree programs are more appropriate for individuals without any human factors training, seeking deeper knowledge in human factors, such as transportation engineering students. For undergraduate students, the focus should be on the physical perspective of human factors, while for graduate students we must emphasize the cognitive perspective of human factors, as well as design and analytical methods.

Regardless, when designing human factor courses for CAVs, we must note the following: (1) Online learning for human factors is possible, but a fully remote degree can be limiting; (2) Courses must include both physical (e.g., inclusive design, motion sickness) and cognitive (e.g., situation awareness, user trust, task switching) perspectives; (3) Active and hands-on learning is important. This could be in the form of lab activities (e.g., on fatigue and eye-tracking), or in a driving simulator. Also, we can provide students with a more immersed experience of concepts and theories through designed course projects. For example, we can let students conduct a crash investigation to identify potential causes behind a car crash in a mock-up or simulated scenario of a real-world situation; and (4) Finally, we must point out that basic human factor courses do not require prerequisite knowledge/courses, but some more advanced topics do. For example, classes on analytical methods could require prerequisite knowledge in mathematics and statistics.

4.3. Theme 3: Modeling, simulation, and testing of CAVs

4.3.1. Learning objectives

In the context of CAVs, modeling and testing are complementary approaches. We need undergraduate students to acquire decent skills on the modeling side to know where to test, and we need decent tests to be able to inform the models. Developing excellent modeling and testing skills requires knowledge of understanding and testing the assumptions of the model, the context in which it is deployed, and the limitations of the model. Additionally, students must be able to communicate with interdisciplinary teams and integrate findings from other domains. This field requires knowledge of computer simulation, human driving modeling, traffic engineering, communications and sensor technology, testing and verification, vehicle technology, and design for safety (software and systems).

Transportation engineering graduates should be able to develop a deeper understanding of modeling errors. They should learn to validate models through a large set of empirical data, integrate simulation results into model improvement, and explore the correlation between simulation and real-world systems. Skill sets such as vehicle dynamics, communication tech, sensor tech, traffic flow theory, probability with respect to the analysis of rare events, global navigation satellite system (GNSS) for positioning and timing, and sensor measurement models could help them in such learning process. Emphasis should also be placed on critical thinking skills, recognizing that models must be treated as hypotheses requiring empirical validation.

Taking a look at the current state of the field reveals that some models are being abused, while many better models are not being leveraged. The main limitation is that the field is still very much at the advanced research and development stage, not deployment/practice. As such, designing learning materials for continuing education for this learning objective is particularly challenging. Yet, hardening the modeling foundation for them would be essential, as it would enhance resiliency to rapid changes.

Overall, the learning objectives for students in this field are summarized in Table 7.

4.3.2. Barriers and proposed solutions

Considering the educational outcomes of this field, we face two major barriers. First, training on modeling, simulation, and testing only pertains to Ph.D. level problems, because the models are complicated and the testing is expensive. This implies that it is very difficult to pack the required skill sets into undergraduate education. Secondly, the field is rapidly changing and the introduction of new technology might change what is not known in the field. As such, developing critical thinking skills and lifelong learning skills are going to be really important to tackle the educational gaps.

4.3.3. Recommended mode of teaching

A great deal of content can be covered in a special elective class at the undergraduate level. Although this will not cover all the knowledge gaps, it gives space to identify a number of key issues. Also, senior design projects can allow students to get a better feel for the research space and allow the exploration of emerging topics in more detail than a one-size-fits-all class. We must again point out that the field is moving too fast to wait for a student to get a 4-year degree, as by the end the knowledge may already be out of date. As alternatives, we can consider research seminars on emerging topics and certificates that cover core ideas in focused settings.

The prerequisites for training transportation engineering students in this field include elementary physics, introduction to electrical engineering, programming, probability, and statistics. The core courses include vehicle dynamics and control, fundamentals of communication, GNSS, timing and positioning, etc. Let us not forget that there is a wide spectrum of careers in this field, having different requirements and priorities.

Table 7
Learning objectives for modeling, simulation, and testing.

	Learning objectives	Educational material exists (Y/N)
1	Compose CAV modeling components and analyze the components and the whole system for physical correctness with empirical data.	N
2	Design and execute a test to validate or invalidate a model in a specific domain.	Y
3	Learn how to design tests to link empirical testing with modeling concepts.	Y
4	Use models to accelerate real-world testing without introducing modeling biases	Y
5	Have a basic understanding of core components that underpin the field.	Y
6	Identify most important areas of impact and timeline to get there for potential benefits and perils of CAV deployments at scale.	N

Table 8
Learning objectives for travel behavior analysis in the context of CAVs.

	Learning objectives	Educational material exists (Y/N)
1	Understand basics of what drives behavior, and factors that influence traveler decision-making (long-term and short-term), given CAV context.	Y
2	Master basic modeling approaches and have foundations for learning advanced modeling techniques in depth; choice models, foundational econometrics, ability to derive composite models/model structures.	Y
3	Identify and critique various data streams available to study CAV systems and describe use cases.	N
4	Demonstrate the ability to manage and process traditional (survey-based, experiment-based) and passive data streams.	Y
5	Apply foundational knowledge in travel behavior and CAV technologies to design and development of research questions, hypotheses, measurement instruments, and analysis plans.	N

4.4. Theme 4: Travel behavior in the context of CAVs

4.4.1. Learning objectives

The educational needs in travel behavior modeling are centered around two main pillars: a methodological core and a behavioral core. The methodological core includes foundational knowledge such as statistics, econometrics, and programming, which are essential not just for travel behavior analysis but for a broad range of transportation topics, and can be taught at the undergraduate level. However, current curricula often lack the breadth needed to address emerging trends, and the inclusion of more advanced subjects is warranted. The behavioral core, on the other hand, directly addresses the study of travel behavior and emphasizes topics like microeconomic principles, travel behavior data, and the fundamentals of discrete choice and activity-based models. These topics can be handled at the graduate level for more advanced and pinpointed instruction. Discrete choice modeling remains essential, serving as a key tool for understanding how system changes impact user decisions.

The rise of CAVs introduces new challenges and opportunities for travel behavior modeling. Shared autonomous services, such as driverless taxis or household AVs, change how vehicles are used and necessitate new modeling approaches, particularly regarding the modeling of empty vehicle trips and repositioning behavior. These behaviors are not yet well captured in existing regional travel demand models. To address these complexities, optimization methods and game-theoretic frameworks may become increasingly relevant, particularly to understand intra-household vehicle negotiations and fleet management strategies. Incorporating these tools into educational programs will be critical for preparing students to analyze and model these evolving dynamics effectively.

Additionally, CAVs are expected to produce large volumes of passive data, opening new possibilities for data-driven travel behavior analysis. Historically, travel demand modeling has relied on survey data, but the shift toward passive data sources demands a new methodological emphasis. Students must be trained in data mining, including skills in data cleaning, integration, validation, and machine learning, to effectively handle and analyze big datasets, These skills, while essential for understanding CAV-related behavior, are also broadly applicable across transportation engineering (West et al., 2021). As such, they should become a standard part of the methodological core. These shifts in the field can also be covered in continuing education to prepare the current workforce for the new technologies.

Overall, five learning objectives for travel behavior and its application to CAVs were identified, as summarized in Table 8.

4.4.2. Barriers and proposed solutions

As Table 8 demonstrates, one of the barriers to preparing transportation engineering curricula for teaching travel behavior analysis in the context of CAVs is that the educational material for two of the learning objectives presently does not exist to the best of the workshop participants' knowledge. For two further learning objectives, materials exist in general, typically in other courses that are taught outside of transportation engineering programs, but they are often not specifically focused on the needs of transportation engineering programs. Finally, there is a lack of openly available CAV data for teaching purposes, especially pre-processed data that can help transportation educators to teach fundamental concepts and models of data mining in travel behavior analysis. Furthermore, even when some CAV data is available, the rapid pace of technological advancement often renders them outdated before they can be fully integrated into teaching materials.

4.4.3. Recommended mode of teaching

Much of the foundational material, especially pertaining to the methodological core, could be generally taught in self-contained online courses. However, in courses pertaining to the behavioral core, especially those covering the design of travel behavior studies and hands-on analyses of behavioral data, students can benefit strongly from in-person interaction with an instructor and with classmates, and hence, they are not suitable for self-contained online instruction. The workshop participants noted that travel behavior courses do not necessarily have to be only lecture-focused, and that some learning objectives could also be achieved through applications-focused instruction and hands-on learning in case studies or projects.

5. Conclusion

In this section, we first discuss the implications stemming from the *Autonomy in Transportation Education* workshop. We also elaborate on limitations of this workshop, i.e., crucial points that have not been addressed during the workshop that could be discussed in the future. Following this, we provide a comprehensive summary of the paper, distilling its essential points to offer a clear understanding of the workshop's outcomes. Additionally, we outline post-workshop outcomes that have emerged from this collaborative endeavor.

5.1. Workshop evaluation

To underscore the workshop's contributions and establish a link with the existing body of literature, we examine the prevailing literature on transportation education curricula. By comparing these curricula with the key insights derived from the workshop discussions, we aim to highlight the workshop's findings within the context of established educational frameworks.

Sinha et al. (2002) provide an overview of which topics have been instructed in traditional transportation education curricula. The topics span from design, construction, and maintenance of facilities to planning, financing, operations, and logistics of the transportation system. However, they acknowledge many transportation engineering programs lack IT-related depth which is critical in the next generation of the domain. As such, incorporating CAV-related technologies in transportation engineering courses would improve the curricula, as suggested in workshop discussions.

Hurwitz et al. (2016) further review the literature on the history of transportation education curricula. They recommend several considerations to improve the course materials, such as anticipating the job market and employer expectations for the graduates and regularly revising the course offerings and modality to match the needs in engineering education and practice. The workshop tackled such considerations by including practitioners and educators from both industry and academic disciplines, where they discussed the importance of inducing CAV-focused topics in the new curricula and the pathways through which subsequent course designs could take place.

West (2018) emphasizes the importance of active learning to evoke students' interests in transportation engineering. She notes that this change needs to take place in an inter-institutional effort to facilitate collaborations and exchanges of data and teaching aids. The workshop commenced this effort by hosting scholars from different locations and sectors. The workshop also highlighted the importance of active learning during the discussions to highlight the importance of creating opportunities for students to engage and participate in the classroom.

To summarize, the workshop congregated a number of transportation experts who are involved in CAV-related research or professions. In one voice, they highlighted the need to renovate the transportation curricula in higher-level education to accommodate the changing workforce needs. Educators in different institutions may leverage the workshop outcomes to evaluate their existing curricula and amend them to more future-oriented ones. The adoption of CAVs is inevitable in transportation engineering and in our societies, and therefore this change should take place collectively across institutions.

5.2. Workshop limitation

We acknowledge that this one-time workshop does not fully encompass the breadth of topics necessary for reimagining transportation engineering curricula in the context of emerging CAV technologies. One important limitation is the lack of a detailed implementation and evaluation strategy to accompany the proposed learning objectives. While the workshop successfully identified relevant competencies and key barriers, further effort is needed to establish concrete and systematic methods for assessing student learning outcomes. To address this gap, we propose the integration of both direct and indirect assessment tools, such as embedded assignments, capstone project evaluations, alumni and employer surveys, student self-assessments, and ongoing feedback mechanisms. These tools can support iterative curriculum development, ensure alignment with educational goals, and help determine whether students are effectively acquiring the intended knowledge and skills.

Another important area not explicitly addressed during the workshop is the growing role of AI in transportation engineering education. Recent advances in AI tools, such as intelligent tutoring systems (Maity and Deroy, 2024), automated feedback (Messer et al., 2024), and generative content (Qadir, 2023), can support student engagement, active learning, and the rapid development of instructional materials. These advances are particularly useful in emerging areas like CAVs, where educational content may be limited or quickly outdated (Pirat, 2023; Ruben, 2023; Nantoi et al., 2025). Future efforts to redesign transportation engineering curricula should explore how AI can be integrated to enhance teaching effectiveness and fill gaps in course content.

5.3. Post-workshop outcomes: Launch of the connected and automated transportation (CAT) certificate program

Following the April 2022 *Autonomy in Transportation Education* workshop, a key recommendation was to develop flexible, targeted educational programs to address critical skill gaps in connected and automated transportation. In response, CCAT launched the fully online CAT Certificate Program[6] in November 2024. The program is open to students across CCAT consortium institutions, and is designed to deliver rigorous, application-oriented content.

The CAT Certificate directly addresses high-priority areas identified during the workshop. It consists of five online modules, each combining foundational theory with applied learning:

1. **Fundamentals for CAV Modeling** — examines key aspects of automated vehicle technologies, starting with an in-depth exploration of three foundational components: sensing, trajectory planning, and vehicle control.
2. **Automated Vehicles and the Law** — examines how the U.S. legal system shapes and responds to automated vehicle deployment, covering dispute resolution, regulatory authority, and federal-state-local dynamics. It then explores key legal areas such as liability, insurance, data privacy, licensing, operational rules, and surveillance, before comparing approaches in other jurisdictions, including the EU and China.
3. **Cybersecurity for CAVs** — covers security and safety in CAVs, including AI roles, cyberattacks, defense strategies, connectivity technologies, standards, and emerging research on protecting cooperative driving systems.
4. **Dynamics and Control of Connected Vehicles** — introduces core AV technologies, including sensing, trajectory planning, and control, as well as connected vehicle systems, operations, and planning. It also addresses related policy issues, aiming to give students foundational knowledge of AV perception, communication, and control, along with real-world application scenarios.
5. **Machine Learning Methods for CAT** — covers machine learning fundamentals with a focus on CAT, exploring supervised and unsupervised methods, practical CAT use cases, and how these techniques drive the development of intelligent transportation systems.

Since its launch, the program has enrolled its first cohort and is now enrolling its second. While a formal longitudinal evaluation is planned, initial participant feedback has highlighted the program's relevance to current industry needs, its accessibility for working professionals, and the practicality of skills gained. Systematic data collection on participants' knowledge acquisition, application of concepts in professional contexts, and career impact is planned, enabling a quantitative assessment of effectiveness in future work.

[6] https://ccat.umtri.umich.edu/education/cat-certificate/

5.4. Workshop summary

This paper investigated potential gaps in transportation education as they relate to CAVs. We examined how transportation curricula can adapt to the interdisciplinary, technological, and workforce challenges associated with emerging mobility systems. Toward this end, a workshop was held in which experts from academia and industry discussed their experiences and observations regarding such educational needs, how these needs can be addressed, what potential barriers exist to transitioning traditional transportation engineering curricula to curricula with a CAV focus, and what the best modes of instruction are to reach the instructional objectives.

Due to the diversity of the field, a pre-workshop survey was used to identify four themes that were the focus of discussions in the workshop: (1) Next-generation infrastructure for CAVs; (2) human factors with CAVs; (3) modeling, simulation, and testing of CAVs; and (4) travel behavior in the context of CAVs. Despite the differences in educational material, and thereby gaps and needs, between the themes, a few common issues and solutions were identified across all themes. There was a consensus that covering fundamental concepts and fostering critical thinking skills and lifelong learning skills in students will ensure that they can contribute to the field throughout their careers, despite the fast advancement of technology. Combining theoretical foundations with practical training through projects and other means of active learning was also universally identified as a critical component in training future transportation engineers.

In addition to these broad-based findings that are universally relevant across all themes, a number of theme-specific learning objectives were identified. These included a list of core concepts, methodologies, and data requirements for each theme. Some of the obstacles that were identified included a lack of access to high-quality and clean data that can be utilized for teaching as well as a lack of access to test beds, special equipment, and tools. Finally, although it is possible to use online courses or modules to cover some fundamental concepts, workshop participants agreed that in-person classes remain the most effective way of learning, as they allow for hands-on experiences and exchanges of ideas between students with different backgrounds. For undergraduate training, a 4-year degree program may still be the best way to teach fundamental knowledge and concepts. Nonetheless, such a program can offer more practical training through special elective courses and senior-year projects. CAV-focused seminars would also provide means to keep students informed of fast-paced technological advancements in the field. On the other hand, short certificate degrees can help professionals to stay up-to-date with technology.

Overall, through a survey and multi-stakeholder workshop involving academia, industry, and government experts, this study explored how transportation education can better support future transportation practice, policy implementation, and workforce preparedness in the era of connected and automated transportation. We acknowledge that the workshop has not covered all relevant topics in transportation engineering pertaining to CAVs. Consequently, we intend to plan future workshops that will concentrate on other specific areas within the realm of CAV technologies. Furthermore, we will strive to broaden our reach and invite a more diverse group of stakeholders for future workshops. Indeed, our study approach is generalizable to other disciplines, such as supply chain, logistics, or business management, through the use of a structured process in which academic leaders or domain experts initiate a dialogue around a predefined agenda. This agenda can be informed by survey responses collected from a broad cross-section of the professional community. The success of such an effort hinges on coordinated organizational support – such as that provided by CCAT in our case – as well as active engagement from the broader community. This model can be adapted to facilitate focused discussions, generate consensus on curricular priorities, and guide program development in various fields beyond transportation engineering.

Another promising direction for future work is the development and evaluation of educational content targeted at the existing transportation workforce. As connected and automated transportation technologies continue to evolve, current transportation professionals in public agencies, consulting firms, and industry will also increasingly require continuing education opportunities to remain current with emerging technologies, operational practices, and policy considerations. Future studies may therefore examine effective approaches for professional development, such as certificate programs, short courses, workshops, and online learning modules targeted at professionals currently in the field, as well as evaluate their effectiveness in supporting adaptation to CAV-enabled transportation systems.

CRediT authorship contribution statement

Jisoon Lim: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Amirmahdi Tafreshian:** Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Neda Masoud:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Henry X. Liu:** Investigation, Formal analysis, Conceptualization. **Andre Carrel:** Investigation, Formal analysis. **Shan Bao:** Investigation, Formal analysis. **Daniel Work:** Investigation, Formal analysis. **Gábor Orosz:** Investigation, Formal analysis.

Declaration of Generative AI Use

During the preparation of this manuscript, the authors used a generative AI tool (GPT-5.5) to assist with language refinement and editorial improvements. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was supported by MCity as well as CCAT (the USDOT Region 5 University Transportation Center). The authors would also like to acknowledge the organizing committee of the workshop, including Henry Liu, Neda Masoud, Siqian Shen, Gábor Orosz, Debra Bezzina, Amirmahdi Tafreshian, and Calvin Tuttle. The authors also thank Yiyang Wang, Ethan Zhang, Hao Wang, Jisoon Lim, Dania Ammar, and Huizhong Guo from the University of Michigan, George Gunter from Vanderbilt University, and Christina Gore from Ohio State University for taking notes in the breakout sessions.

Data availability

The data that has been used is confidential.

References

Abbasnejad, B., Soltani, S., Wong, P., 2023. A systematic review of online learning and teaching strategies during the COVID-19 pandemic: implications for the construction management sector. Smart Sustain. Built Environ. 13 (4), 934–959.

Ambrose, S., Bridges, M., DiPietro, M., Lovett, M., Norman, M., 2010. How Learning Works: Seven Research-Based Principles for Smart Teaching. Jossey-Bass.

Bach, S., Haynes, P., Smith, J., 2007. Online Learning and Teaching in Higher Education. McGraw-Hill.

Baker, D., Briant, S., Hajirasouli, A., Yigitcanlar, T., Paz, A., Bhaskar, A., Corry, P., Whelan, K., Donehue, P., Parsons, H., 2023. Urban freight logistics and land use planning education: Trends and gaps through the lens of literature. Transp. Res. Interdiscip. Perspect. 17, 100731.

Bisht, L.S., 2025. Frameworks for capacity development and road safety curriculum design for road safety professionals in India. Transp. Res. Interdiscip. Perspect. 34, 101767.

Bruner, J., 1996. Frames for thinking. Modes Thought: Explor. Cult. Cogn. 93–105.

Covey, S., 2006. Habit 2: Begin With the End in Mind. FranklinCovey.

Dewey, J., 1923. Democracy and Education: An Introduction to the Philosophy of Education. macmillan.

Do, W., Rouhani, O.M., Miranda-Moreno, L., 2019. Simulation-based connected and automated vehicle models on highway sections: a literature review. J. Adv. Transp. 2019.

Doering, A., Veletsianos, G., 2008. Hybrid online education: Identifying integration models using adventure learning. J. Res. Technol. Educ. 41.

Ersal, T., Kolmanovsky, I., Masoud, N., Ozay, N., Scruggs, J., Vasudevan, R., Orosz, G., 2020. Connected and automated road vehicles: state of the art and future challenges. Veh. Syst. Dyn. 58 (5), 672–704.

Farley, I.A., Burbules, N.C., 2022. Online education viewed through an equity lens: Promoting engagement and success for all learners. Rev. Educ. 10 (3).

Feng, Y., Yu, C., Xu, S., Liu, H.X., Peng, H., 2018. An augmented reality environment for connected and automated vehicle testing and evaluation. In: 2018 IEEE Intelligent Vehicles Symposium. IV, IEEE, pp. 1549–1554.

Fisher, D.L., Horrey, W.J., Lee, J.D., Regan, M.A., 2020. Handbook of Human Factors for Automated, Connected, and Intelligent Vehicles. CRC Press.

Galvis, Á.H., Carvajal, D., 2022. Learning from success stories when using elearning and blearning modalities in higher education: a meta-analysis and lessons towards digital educational transformation. Int. J. Educ. Technol. High. Educ. 19 (1).

Garcia-Alberti, M., Suarez, F., Chiyon, I., Mosquera Feijoo, J.C., 2021. Challenges and experiences of online evaluation in courses of civil engineering during the lockdown learning due to the COVID-19 pandemic. Educ. Sci. 11 (2), 59.

Garrison, D.R., Anderson, T., Archer, W., 1999. Critical inquiry in a text-based environment: Computer conferencing in higher education. Internet High. Educ. 2 (2–3), 87–105.

Ge, J.I., Avedisov, S.S., He, C.R., Qin, W.B., Sadeghpour, M., Orosz, G., 2018. Experimental validation of connected automated vehicle design among human-driven vehicles. Transp. Res. Part C: Emerg. Technol. 91, 335–352.

Gregg, A., Dabbagh, N., 2023. Engineering education and online learning. In: Nternational Handbook of Engineering Education Research. Routledge, pp. 479–500.

Gunter, G., Stern, R., Work, D.B., 2019. Modeling adaptive cruise control vehicles from experimental data: model comparison. In: 2019 IEEE Intelligent Transportation Systems Conference. ITSC, IEEE, pp. 3049–3054.

Hendrickson, C., 2017. Some thoughts on the future of transportation engineering. J. Transp. Eng. Part A: Syst. 143 (11).

Hung, Y.-H., Proctor, R.W., Chen, Y., Zhang, J., Feng, Y., 2022. Drivers' knowledge of and preferences for connected and automated vehicles. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 66, (1), SAGE Publications Sage CA: Los Angeles, CA, pp. 1457–1461.

Hurwitz, D., Sanford Bernhardt, K., Turochy, R., Young, R., 2016. Transportation engineering curriculum: Analytic review of the literature. J. Prof. Issues Eng. Educ. Pr. 142 (3), 04016003.

Ivanov, V., Augsburg, K., Blundell, M., De Nijs, W., Desmet, W., Ferrara, A., Kanarachos, S., Kiele-Dunsche, M., Klomp, M., Metzner, S., et al., 2018. Development of multi-actuated ground vehicles: Educational aspects. IFAC-PapersOnLine 51 (9), 236–242.

Jiang, L., Molnár, T.G., Orosz, G., 2021. On the deployment of V2X roadside units for traffic prediction. Transp. Res. Part C: Emerg. Technol. 129, 103238.

Karimi, A., Mao, S., Lotto, G., Lee, J.J., Bassani, M., 2026. Drivers and automation: a systematic review on road suitability for assisted and partially/conditionally automated vehicles. Transp. Res. Interdiscip. Perspect. 37, 101986.

Kothari, C., O'Brien, W.J., Khwaja, N., 2022. Transportation programs under financial uncertainty: Identification of needs for future research. Transp. Res. Interdiscip. Perspect. 16, 100684.

Kröger, L., Kuhnimhof, T., Trommer, S., 2019. Does context matter? A comparative study modelling autonomous vehicle impact on travel behaviour for Germany and the USA. Transp. Res. Part A: Policy Pr. 122, 146–161.

Lau, E., Lei, C.-U., Ng, J., Lui, K.-S., Lam, K.H., Hew, T.K., Tam, V., 2020. Designing an autonomous vehicle system design course for COVID-19 remote learning under first principles of instruction framework. In: 2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering. TALE, IEEE, pp. 460–466.

Lavieri, P.S., Garikapati, V.M., Bhat, C.R., Pendyala, R.M., Astroza, S., Dias, F.F., 2017. Modeling individual preferences for ownership and sharing of autonomous vehicle technologies. Transp. Res. Rec. 2665 (1), 1–10.

Liu, L., Feng, S., Feng, Y., Zhu, X., Liu, H.X., 2022. Learning-based stochastic driving model for autonomous vehicle testing. Transp. Res. Rec. 2676 (1), 54–64.

Liu, S., Gaudiot, J.-L., Kasahara, H., 2021. Engineering education in the age of autonomous machines. Computer 54 (4), 66–69.

Liu, Y., Tight, M., Sun, Q., Kang, R., 2019. A systematic review: Road infrastructure requirement for connected and autonomous vehicles (CAVs). In: Journal of Physics: Conference Series, vol. 1187, (4), IOP Publishing, 042073.

Lopez, G., Ramos, D., Rivera, K., del Valle, K., Rodriguez, A., Rivera, E.I.O., 2015. Micromouse: An autonomous robot vehicle interdisciplinary attraction to education and research. In: 2015 IEEE Frontiers in Education Conference. FIE, IEEE, pp. 1–5.

Mahdavian, A., Shojaei, A., Oloufa, A., 2019. Assessing the long-and mid-term effects of connected and automated vehicles on highways' traffic flow and capacity. In: International Conference on Sustainable Infrastructure 2019: Leading Resilient Communities Through the 21st Century. American Society of Civil Engineers Reston, VA, pp. 263–273.

Maity, S., Deroy, A., 2024. Generative AI and its impact on personalized intelligent tutoring systems.

Masoud, N., Jayakrishnan, R., 2017. Autonomous or driver-less vehicles: Implementation strategies and operational concerns. Transp. Res. Part E: Logist. Transp. Rev. 108, 179–194.

Merrill, M.D., 2002. First principles of instruction. Educ. Technol. Res. Dev. Vol. 50 (43–59).

Messer, M., Brown, N.C.C., Kölling, M., Shi, M., 2024. Automated grading and feedback tools for programming education: A systematic review. ACM Trans. Comput. Educ. 24 (1), 1–43.

Miranda, M., 2023. Autonomous Vehicles and their Potential Impacts to Transportation Engineering. https://www.texasce.org/tce-news/autonomous-vehicles-and-their-potential-impacts-to-transportation-engineering/. Accessed 30 August 2023.

Molnár, T.G., Ji, X.A., Oh, S., Takács, D., Hopka, M., Upadhyay, D., Van Nieuwstadt, M., Orosz, G., 2022. On-board traffic prediction for connected vehicles: Implementation and experiments on highways. In: 2022 American Control Conference. ACC, IEEE, pp. 1036–1041.

Morariu, A.-R., Tsvetkova, A., Hellström, M., Bolbot, V., Virtanen, S., 2025. Investigating educational solutions in the field of autonomous shipping at finnish universities. Transp. Res. Interdiscip. Perspect. 31, 101402.

Nantoi, V., Nantoi, D., Ceban, D., 2025. Challenges and solutions for integrating artificial intelligence into transportation engineering education. J. Social Sci. 7 (4), 64–95.

Pariota, L., Coppola, A., Di Costanzo, L., Di Vico, A., Andolfi, A., D'Aniello, C., Bifulco, G.N., 2020. Integrating tools for an effective testing of connected and automated vehicles technologies. IET Intell. Transp. Syst. 14 (9), 1025–1033.

Peine, M., Coleman, L., 2010. The phenomenon of waiting in class. J. Educ. Gifted 34 (2).

Pirat, A., 2023. Autonomous vehicles and AI-powered logistics: Transforming smart transportation systems and education through classroom management and adaptive learning.

Qadir, J., 2023. Engineering education in the era of ChatGPT: Promise and pitfalls of generative AI for education. In: 2023 IEEE Global Engineering Education Conference. EDUCON, IEEE, pp. 1–9.

Ruben, M., 2023. Revolutionizing traffic management and education: The impact of AI on autonomous vehicles and personalized learning systems.

Rubin, J., 2016. Connected autonomous vehicles: Travel behavior and energy use. In: Road Vehicle Automation 3. Springer, pp. 151–162.

Saeed, T.U., Alabi, B.N., Labi, S., 2021. Preparing road infrastructure to accommodate connected and automated vehicles: System-level perspective. J. Infrastruct. Syst. 27 (1), 06020003.

Samak, T.V., Samak, C.V., Xie, M., 2021. Autodrive simulator: A simulator for scaled autonomous vehicle research and education. In: 2nd International Conference on Control, Robotics and Intelligent System. pp. 1–5.

Sanusi, F., Choi, J., Kim, Y.H., Moses, R., 2022. Development of a knowledge base for multiyear infrastructure planning for connected and automated vehicles. J. Transp. Eng. Part A: Syst. 148 (4), 03122001.

Sarker, A., Shen, H., Rahman, M., Chowdhury, M., Dey, K., Li, F., Wang, Y., Narman, H.S., 2019. A review of sensing and communication, human factors, and controller aspects for information-aware connected and automated vehicles. IEEE Trans. Intell. Transp. Syst. 21 (1), 7–29.

Scheffe, P., Maczijewski, J., Kloock, M., Kampmann, A., Derks, A., Kowalewski, S., Alrifaee, B., 2020. Networked and autonomous model-scale vehicles for experiments in research and education. IFAC-PapersOnLine 53 (2), 17332–17337.

Sharma, A., Ali, Y., Saifuzzaman, M., Zheng, Z., Haque, M., et al., 2017. Human factors in modelling mixed traffic of traditional, connected, and automated vehicles. In: International Conference on Applied Human Factors and Ergonomics. Springer, pp. 262–273.

Shock, L., 2023. Employers of CEE Graduates. https://cee.engin.umich.edu/undergraduate-studies/careers-in-cee/employers-of-cee-graduates/(Accessed 30 August 2023).

Sinha, K., Bullock, D., Hendrickson, C., Levinson, H., Lyles, R., Radwan, E., Li, Z., 2002. Development of transportation engineering research, education, and practice in a changing civil engineering world. J. Transp. Eng. 128 (4).

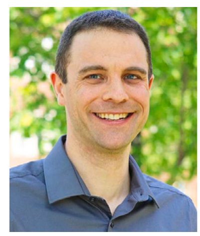
Stern, R.E., Cui, S., Delle Monache, M.L., Bhadani, R., Bunting, M., Churchill, M., Hamilton, N., Pohlmann, H., Wu, F., Piccoli, B., et al., 2018. Dissipation of stop-and-go waves via control of autonomous vehicles: Field experiments. Transp. Res. Part C: Emerg. Technol. 89, 205–221.
Sun, H., Feng, S., Yan, X., Liu, H.X., 2021. Corner case generation and analysis for safety assessment of autonomous vehicles. Transp. Res. Rec. 2675 (11), 587–600.
U.W. Civil & Environmental Engineering, 2023. Transportation Engineering Master's Degree Program. https://www.ce.washington.edu/future/grad/masters/transportation#:~:text=People%20with%20advanced%20degrees%20in,agencies%20and%20non%2Dprofit%20organizations. (Accessed 30 August 2023).
Vygotsky, L.S., Cole, M., 1978. Mind in Society: Development of Higher Psychological Processes. Harvard University Press.
Wang, S., Li, M., Yu, B., Bao, S., Chen, Y., 2022. Investigating the impacting factors on the public's attitudes towards autonomous vehicles using sentiment analysis from social media data. Sustainability 14 (19), 12186.
Wang, S.-H., Lin, C.-X., Tu, C.-H., Huang, C.-C.J., Juang, J.-C., 2020. Autonomous vehicle simulation for Asia urban areas with a perspective from education. In: 2020 International Computer Symposium. ICS, IEEE, pp. 454–458.
West, M., 2018. Transportation engineering education in the 21st century: A review of current practices. In: 2018 ASEE Annual Conference & Exposition. ASEE.
West, M.E., Carrel, A.L., Kajfez, R.L., 2021. Future skill requirements in transportation engineering and implications for graduate curriculum design. J. Civ. Eng. Educ. 147 (3), 04021002–1–9.
Wiggins, G., Wiggins, G.P., McTighe, J., 2005. Understanding by Design. Ascd.
van Wyk, F., Khojandi, A., Masoud, N., 2020. Optimal switching policy between driving entities in semi-autonomous vehicles. Transp. Res. Part C: Emerg. Technol. 114, 517–531.
Zhang, E., Masoud, N., 2020. V2xsim: A V2X simulator for connected and automated vehicle environment simulation. In: 2020 IEEE 23rd International Conference on Intelligent Transportation Systems. ITSC, IEEE, pp. 1–6.
Zhang, E., Masoud, N., Bandegi, M., Malhan, R.K., 2022. Predicting risky driving in a connected vehicle environment. IEEE Trans. Intell. Transp. Syst..
Zhang, E., Pizzi, S., Masoud, N., 2021. A learning-based method for predicting heterogeneous traffic agent trajectories: implications for transfer learning. In: 2021 IEEE International Intelligent Transportation Systems Conference. ITSC, IEEE, pp. 1853–1858.
Zmud, J., Williams, T., Outwater, M., Bradley, M., Kalra, N., Row, S., 2018. Updating regional transportation planning and modeling tools to address impacts of connected and automated vehicles, volume 1: Executive summary. Project 20-102 (09).

Jisoon Lim received a B.S. in Industrial Engineering from Georgia Tech, and an M.S.E. in Industrial and Operations Engineering and a Ph.D. in Civil Engineering from the University of Michigan. He is currently a Postdoctoral Fellow at the University of Michigan. His research focuses on developing scalable mathematical frameworks for multi-stakeholder decision-making across multimodal, technology-integrated, and increasingly complex mobility systems.

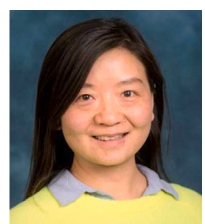
Amirmahdi Tafreshian received a B.S. degree in Industrial Engineering at the Sharif University of Technology, an M.S. degree in Industrial Engineering and Statistics at West Virginia University, and a Ph.D. degree in Civil engineering at the University of Michigan. He was a Postdoctoral Scholar at the University of Michigan as well. His research interest is matching and pricing algorithms for ride-hailing platforms.

Neda Masoud received a Bachelor of Science degree in industrial engineering, a Master of Science degree in physics, and a Ph.D. degree in civil and environmental engineering. She is currently an Associate Professor with the Department of Civil and Environmental Engineering, University of Michigan. Her research interests include devising operational and planning tools to facilitate the transition into the next generation of transportation systems, which are envisioned to be connected, automated, electrified, and shared.

Henry X. Liu received a bachelor's degree in automotive engineering from Tsinghua University, China, in 1993, and a Ph.D. degree in civil and environment engineering from the University of Wisconsin-Madison in 2000. He is currently a Bruce D. Greenshields Collegiate Professor of Engineering with the Department of Civil and Environmental Engineering and the Director of the Mcity, University of Michigan, Ann Arbor. He is also a Research Professor with the University of Michigan Transportation Research Institute and the Director of the Center for Connected and Automated Transportation (USDOT Region 5 University Transportation Center). His research interests include interface of transportation engineering, automotive engineering, artificial intelligence, traffic flow monitoring, modeling, control, and testing and evaluation of connected and automated vehicles. From August 2017 to August 2019, he served as the DiDi Fellow and the Chief Scientist of smart transportation with DiDi Global Inc., one of the leading mobility service providers in the world. He is the Managing Editor of Journal of Intelligent Transportation Systems.



Andre Carrel received an M.S. degree in Civil and Environmental Engineering from MIT and a Ph.D. degree in Civil and Environmental Engineering from the University of California, Berkeley. He is an associate professor of transportation and the director of the Ohio State Travel Behavior Research Group. His research contributes to the forecasting of travel demand trends and has practical implications for designing policies to promote more sustainable travel choices.



Shan Bao received a B.E. degree in Mechanical Engineering from Hefei University of Technology, China, and a Ph.D. degree in Industrial Engineering from the University of Iowa. She is a Professor and Chair of Industrial and Manufacturing Systems Engineering at the University of Michigan-Dearborn. She also has a joint appointment as an Research Associate Professor at the University of Michigan Transportation Research Institute's Human Factors Group. Her research interests focus on human factors issues related to connected and automated vehicle technologies, ADAS system evaluation, and big data analysis.

Daniel Work received the B.S. degree from Ohio State University in 2006 and the M.S. and Ph.D. degrees in civil engineering from the University of California at Berkeley, Berkeley, CA, USA, in 2007 and 2010, respectively. He is a Chancellor Faculty Fellow and a Professor with the Department of Civil and Environmental Engineering and the Institute for Software Integrated Systems, Vanderbilt University. His research interest includes transportation cyber physical systems. He was a recipient of the CAREER Award from the National Science Foundation in 2014 and the Gilbreth Lectureship from the National Academy of Engineering in 2018.

Gábor Orosz received an M.Sc. degree in engineering physics from the Budapest University of Technology, Budapest, Hungary, in 2002, and a Ph.D. degree in engineering mathematics from the University of Bristol, Bristol, U.K., in 2006. He held Postdoctoral Positions with the University of Exeter, Exeter, U.K., and with the University of California, Santa Barbara, CA, USA. In 2010, he joined the University of Michigan, Ann Arbor, MI, USA, where he is currently a Professor in mechanical engineering and in civil and environmental engineering. His research interests include nonlinear dynamics and control, time delay systems, and learning with applications to connected and automated vehicles, traffic flow, and biological networks.