ENGINEERING CHANGE LAB USA

Future of Licensure Experiment

Phase I : Mobility Engineering Licensure System

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BUILD AMERICA CENTER

INNOVATIVE FINANCING AND DELIVERY OF TRANSPORTATION INFRASTRUCTURE

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1. INTRODUCTION

Mobility engineering is a dynamic field that encompasses various areas, such as transportation, autonomous technologies, supply chain, energy, infrastructure, IT, finance, and public policy. As one of the most active research and practice areas in this era, the field demands competent engineers who can design, develop, and implement mobility solutions to meet societal needs. However, despite the demand for mobility engineers in industries, governments, and universities, the lack of a licensure path for mobility engineering poses a challenge that calls for disruptive solutions. An investigation of NCEES products revealed that no engineering licensure exam product has been developed for mobility engineering, highlighting the need for a steering roadmap toward licensure. Without a clear path to licensure, the effectiveness of education and practice in the field of mobility engineering could be undermined. This could result in engineering judgments lacking widely accepted norms and being less disciplined, tracked, or protected, which would potentially lead to adverse impacts on public well-being and the entire engineering community.

To address this challenge, effective licensure design requires a deep and comprehensive understanding of the Mobility Engineering discipline. This report summarizes the findings of a literature survey, education program comparison, job market analysis, and engineering failure investigation on this subject. The report includes collaborative research efforts with the ECL-USA, including a review of Automated Driving System (ADS) technologies, verified mobility engineering failures, relevant education programs from top engineering schools, and qualification requirements for mobility engineering job positions. The report also describes the findings from selected interviews with Mobility Engineering experts, highlighting the importance of personalized career development plans and clear career paths in the field. By examining the challenges and opportunities in Mobility Engineering and analyzing the skills and knowledge required for the profession, this report provides insights into the development of effective licensure pathways for mobility engineers. The enclosed appendix includes typical interview questions that were used to gather insights from Mobility Engineering experts.

2. KNOWLEDGE BASE OF MOBILITY ENGINEERING

We conducted a comprehensive research project to achieve our objectives, utilizing both qualitative and quantitative approaches in parallel to expedite the process. Multiple iterations were executed to ensure the accuracy and reliability of the information gathered from various sources. The following sections detail the methods employed, data collection and analysis, and the results of the review:

2.1. Education Programs Review

In response to the rapid development and integration of autonomous vehicle technologies, many universities and research institutes have been actively developing mobility engineering curricula to prepare engineering students for the evolving industry demands. Our review of top engineering programs in the United States aimed to document the following topics:

- Mobility engineering degree programs
- Mobility engineering professional certificate programs
- Mobility engineering research laboratories and topics
- Mobility engineering core courses

To gather relevant data, we utilized the Google search engine and included keywords such as "mobility engineering degrees" and the names of top engineering schools from the US News Top Engineering Universities list. We also included university acronyms in our search. For instance, to investigate mobility engineering education programs at the University of Maryland, we used search terms such as "mobility engineering and the University of Maryland" or "mobility engineering degree UMD." We further examined the education program information page and identified 22 programs from 18 universities that provide mobility engineering education, as depicted in Figure 1.

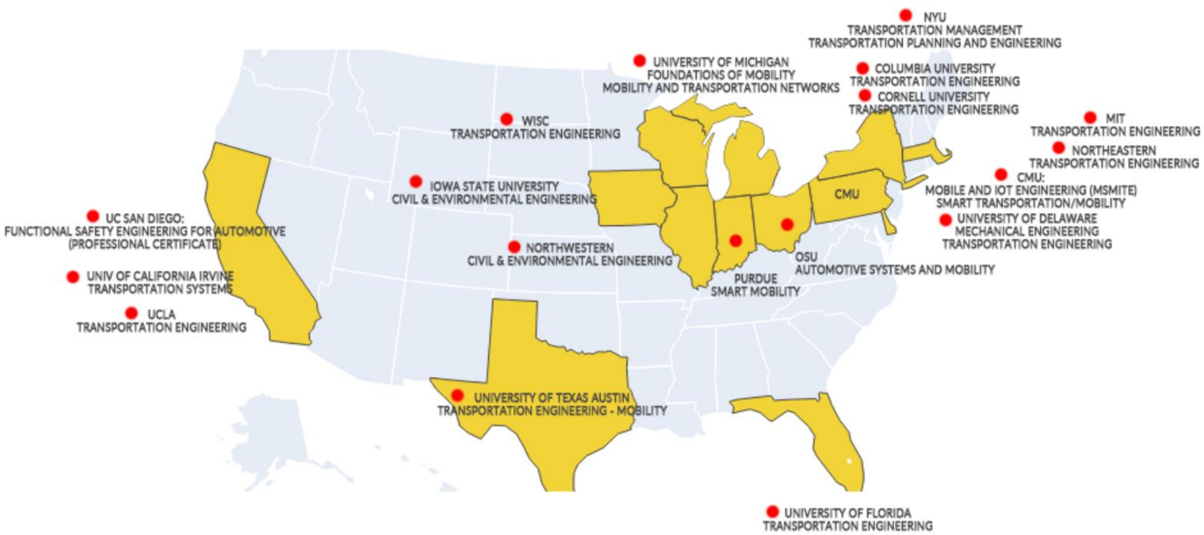

Figure 1: Mobility Engineering Education Programs in the U.S.

Out of the top 52 engineering schools, 18 (34.6%) have integrated mobility engineering into their educational curricula. Some universities offer more than one degree program with mobility engineering components. In total, we identified 21 engineering programs with mobility engineering elements, including two professional certificate programs and 19 graduate-level degree programs.

Among these 21 programs, five have explicitly stated mobility in their program titles or concentration and are designated as independent Mobility Engineering programs. The remaining programs, while covering mobility engineering courses, are traditional engineering programs with mobility engineering components. As shown in Figure 2, these traditional engineering programs consist of transportation engineering (11), autonomous engineering (2), information system engineering (2), and mechanical engineering (1). The following section provides a description of the five independent mobility engineering programs.

- The Smart Transportation Mobility program at Carnegie Mellon University is a Civil Engineering degree program that focuses on transportation systems, mobility services, and public policies.
- The Smart Mobility program at Purdue University is also a Civil Engineering degree program that concentrates on the planning, design, operation, and management of smart mobility systems.
- The Foundations of Mobility program at the University of Michigan is a professional certificate program offered by Engineering Nexus with a multidisciplinary faculty team from transportation, civil engineering, public policy, law, business, and urban planning.
- The Mobility and Transportation Networks program at the University of Michigan is a research-oriented program offered by the Department of Industrial and Operations Engineering that uses data-driven analytics, human-centered design principles, computer simulation models, and experimental studies to design and utilize advanced automation technologies.
- The Automotive Systems and Mobility program at Ohio State University is a graduate specialization program in the Mechanical Engineering Department that focuses on automotive systems and smart mobility.

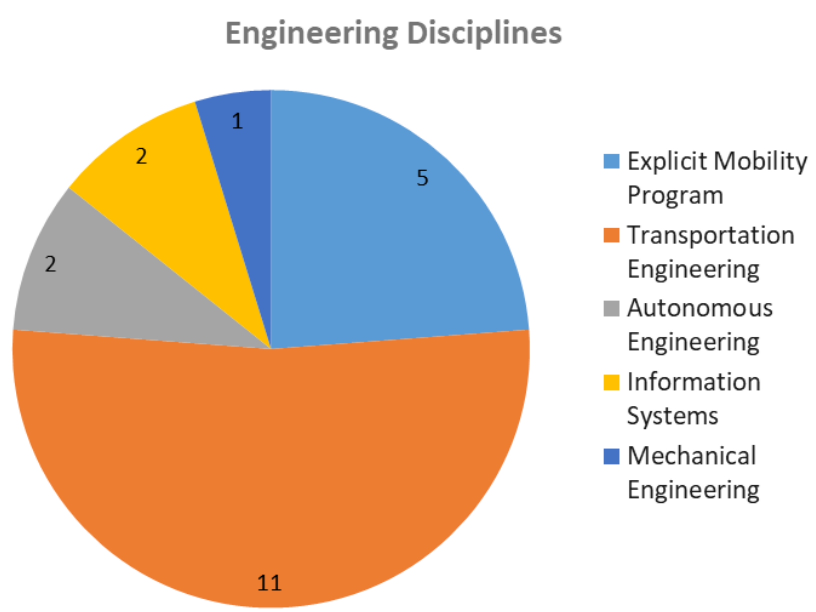

Figure 2: Disciplines Affiliations of Mobility Engineering Education Programs

The Mobility Engineering programs were analyzed in detail to understand their knowledge base, and 72 core courses and related electives were reviewed. A word cloud of the course titles is shown in Figure 3. Research centers and laboratories were also analyzed, with major research areas reflected in Figure 3. Mobility Engineering is a multidisciplinary field with contributions from civil, transportation, system, mechanical, business, law, information technology, and urban planning.

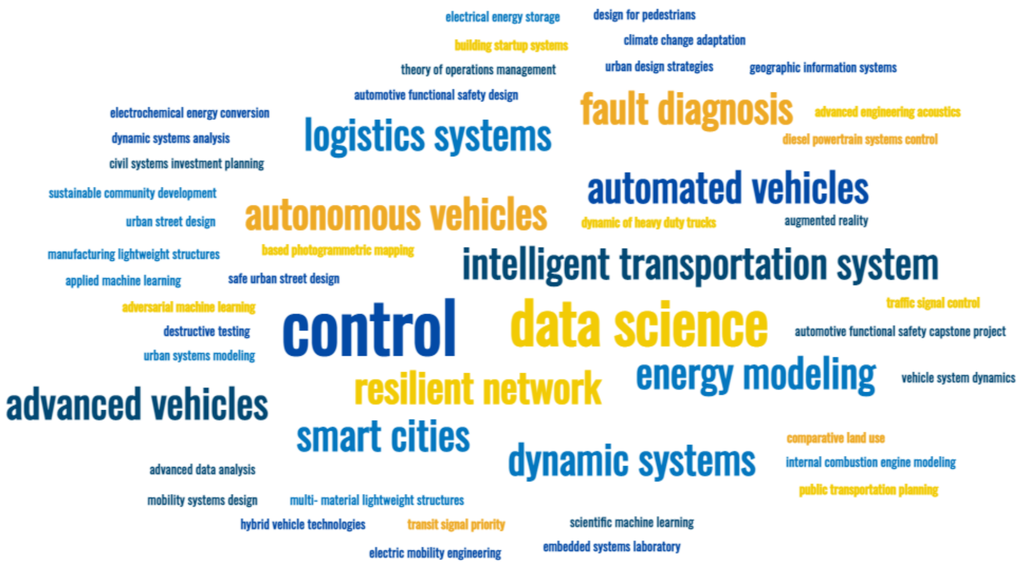

Figure 3. Word Cloud of Mobility Engineering Curricula

In addition, the review of research centers and laboratories highlights several emerging research areas in mobility engineering, such as autonomous vehicles, smart transportation systems, and sustainable transportation. These research areas are driven by the increasing demand for efficient, safe, and sustainable mobility solutions in the face of urbanization, environmental concerns, and technological advancements. The multidisciplinary nature of mobility engineering education and research indicates that addressing these challenges requires collaboration across different fields of expertise and diverse stakeholders.

Overall, the review of education and research programs in mobility engineering provides insights into the knowledge base and research trends in this field. It highlights the need for a multidisciplinary approach to mobility engineering education and research and emphasizes the importance of collaboration and knowledge sharing among different fields of expertise. The findings of this review can inform the development of new mobility engineering programs and research directions and contribute to advancing the state-of-the-art in mobility engineering.

2.2. Job Market Qualifications and Demands

The market analysis was conducted using Indeed data collected in July 2022 with mobility engineering-related keywords to understand industry demand and provide insights into future licensure models. Indeed is the largest job search engine in the U.S., aggregating job listings from thousands of websites. In July 2022, over 15,800 job positions were available for mobility engineers on Indeed, covering areas such as mobility planning, data analysis, automotive safety, traffic optimization, and machine learning. The distribution of mobility engineering jobs is shown in Figure 4.

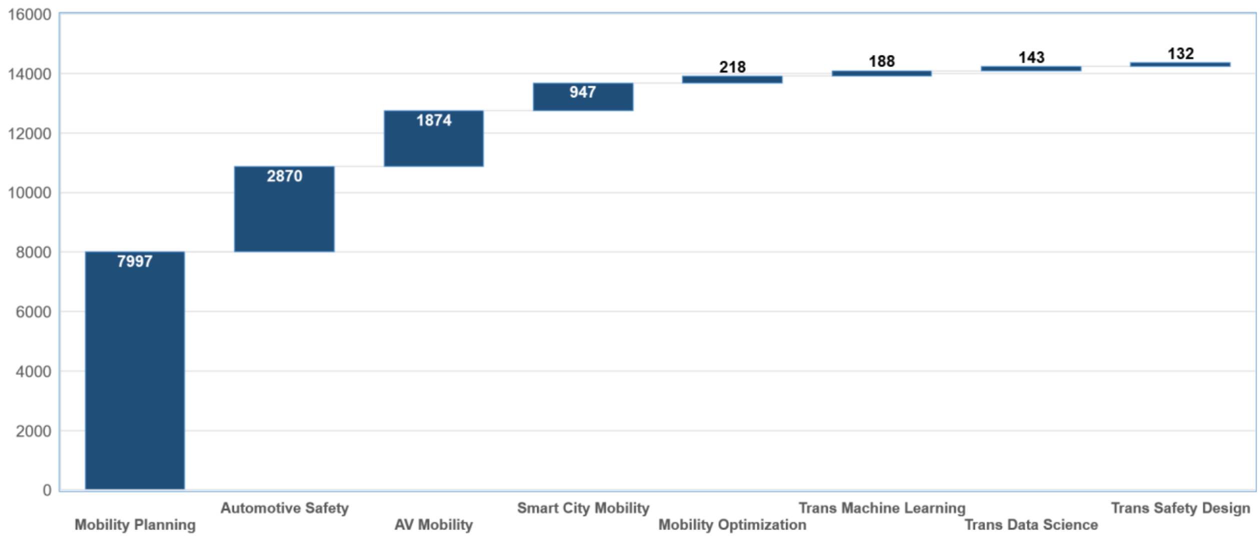

Figure 4: Mobility Engineering Job Positions

Given a large number of job positions available, a selected sample of job descriptions was examined in detail to understand the job responsibilities and required knowledge base and skill set. A content analysis was also conducted to group the job responsibilities and skillsets into 4 categories namely testing, traffic, software and system (Table 1.)

The analysis shows that the mobility engineer position requires domain knowledge from multiple traditional engineering disciplines, including transportation engineering, electrical engineering, mechanical engineering, information system engineering, artificial intelligence, etc. It is interesting to note that data analytics skills are commonly required among all job descriptions in additon to certain levels of programming skills. The need for multidisciplinary engineering knowledge, data analytics skills and programming skills aligns with the findings from the education program review in the previous section. From job market perspective, the knowledge base of mobility engineering centers on the following three fields:

- *Vehicle-centric engineering knowledge*: vehicle design, system design, electrical engineering, etc.
- *Physical infrastructure-centric engineering knowledge*: transportation infrastructure, civil infrastructure, safety, environmental engineering, etc.
- *IT and data analytics skills*: information system engineering, software engineering, machine learning, artificial intelligence, data analytics, etc.

Table 1: Mobility Engineering Job Requirements and Qualifications

Job Position	Job Requirements	Knowledge/Skillset
Test Engineer	Perform vehicle tests; draw electrical and electronic diagrams; program scripts; conduct test analysis, etc.	electrical engineering (vehicle) domain knowledge, mechanical engineering domain knowledge, programming skills, data analytics
Traffic Engineer	Simulate traffic flow and operation; perform safety and capacity analysis; design traffic mesoscopic modeling, etc.	transportation domain knowledge, programming skills (Python), data analytics
Software/System Engineer	Design, implement, tune, and test novel algorithms; design control system software; build and deploy system architecture; generate CAV software documentation packages, etc.	artificial intelligence (machine learning, machine vision), robotics, programming, information system engineering domain knowledge
Electrical Engineer	Develop ADS platform, including power distribution, electrical architecture integration, etc.; Integrate ADS features into CAV vehicles; perform the design and development of embedded electronic control modules; etc.	electrical engineering (vehicle) domain knowledge, mechanical engineering domain knowledge, information system engineering domain knowledge
Safety Engineer	Provide technical expertise of cross-disciplinary research/development team on autonomous certification, passenger-carrying, etc; mentor engineers about safety system engineering industry standards; Apply safety principles to support product investigation, analysis, planning, design, development, testing, evaluation, etc.	Project management knowledge, safety engineering domain knowledge, information system engineering domain knowledge, knowledge of the CAV safety regulation environment (certificates, standards, principles)

2.3. Mobility Technology Systems

To understand the knowledge base of CAVs that are most relevant to public safety, we collected data from NHTSA and reviewed 12 Autonomous Driving Systems (ADS) elements. The data source we consult is NHTSA Automated Driving Systems - A Vision for Safety. We adopted the same content analysis method. Through reviewing the ADS elements, we first identified the key concepts, followed by a classification of the identified concepts into various engineering disciplines, as shown in Table 2.

Table 2: Knowledge Base of Autonomous Driving Systems (ADS)

ID	ADS Elements	Engineer Disciplines	Key Concepts
1	System Safety	System Engineering	system process, reliability
		Safety Engineering	hazard analysis
		Vehicle design	design architecture, sensors, actuators, communication failure, potential software errors, reliability, potential inadequate control, undesirable control actions

		Roadway engineering	knowledge of transportation ecosystem
		Software engineering	development, verification, and validation
2	Operational Design Domain	System Engineering	document process for assessment, testing, and validation, system dynamic change
		Safety Engineering	risky analysis
3	Object and Event Detection and Response	System Engineering	documented process for the assessment, testing, and validation of ADS
		Safety Engineering	crash avoidance capability, pre-crash scenarios analysis
		Software engineering	AI: keep in a lane, obey traffic laws, follow reasonable road etiquette, respond to hazards
4	Fallback	Safety Engineering	minimal risk condition analysis
		System Engineering	system dynamics; documented process for the assessment, testing, and validation of ADS
5	Validation Method	Safety Engineering	mitigate the safety risks; fallback strategies
		System Engineering	deployment, on-road testing
6	Human Machine Interface	Vehicle design	HMI design, level 4 or 5 vehicles;
		Information Engineering	accurately conveying information to the human driver; how the information should be communicate.
		Computer Science	remote dispatcher, central control authority; driver engagement monitoring
		Civil policies	accommodate people with disabilities
		Transportation Engineering	automated delivery vehicles; last-mile special purpose ground drones; automated maintenance vehicles
7	Vehicle Cybersecurity	System engineering	system engineering approach; systematic and ongoing safety risk assessment; cybersecurity considerations; robust document version control environment;
		Vehicle design	broader transportation ecosystem
		Computer Science	
8	Crashworthines s	Safety Engineering	Occupant protection system; geometric and energy absorption crash compatibility
		Information Engineering	sensing technology
		Vehicle design	seating configurations
9	Post-Crash ADS Behavior	Vehicle design	
		Safety Engineering	returning ADS to a safe state immediately after crash
		Information Engineering	vehicle communication technology to reduce harm
		System engineering	documentation that identify the equipment the processes
10	Data recording	System engineering	document process and collect necessary data
		Data science	learn from crash data: personal injury, damages; crash reconstruction
11	Consumer Education and Training	Education, Communication	explicit information on ADS
12	Federal, State, and Local Laws	System engineering	handle foreseeable events safety: temporarily violate laws; process documentation of plausible scenarios; process to update ADS to new legal requirements.

The review of ADS elements is another piece of evidence that supports the multidisciplinary feature of mobility engineering. It reinforces the findings of the underlying engineering domain knowledge, which covers automotive engineering, safety engineering, information system engineering, computer engineering and transportation engineering. Also, programming and data skill is a common requirements for mobility engineers to perform ADS engineering practices.

One should note the availability of other ADS guidelines from the National Institute of Standards and Technology (NIST), NHTSA, SAE International, the Alliance of Automobile Manufacturers, the Association of Global Automakers and the Automotive Information Sharing and Analysis Center (Aauto-ISAC). As the guides from these organizations provide recommendations on standard procedures rather than strict regulations, the review of such guides was not included in this study.

2.4. Lesson Learned from Mobility Engineering Failures

Engineering practice must demonstrate the highest standard of competence to ensure the protection of public health, safety and well-being. Learning from failed engineering practices helps understand the knowledge and regulation gap and therefore improves the creditability of engineering licensure. Engineering failures related to autonomous vehicles were collected from Tesla accident statistics, NHTSA case collections, sporadic news on autonomous vehicle accidents,and other sources. In particular, NHTSA accident cases were used for in-depth review due to detailed failure descriptions and analysis as well as verifiable information. Six CAV failures are listed in Table 3.

The following common safety issues and regulatory gaps are identified related to CAV features and mobility engineering practices:

- Limitation of system capabilities
  SAE International has defined 6 categories of autonomous vehicles based on the automation level. Level 0 is the lowest and Level 5 is the highest, representing no automation at all to full automation respectively. For now, the highest consumer vehicle in the US market is Level 3, which is conditional automation. Under conditional automation, the driver is not required to monitor the environment but must be ready to take control at all times for unforeseen circumstances. Some accidents were caused by the limitations of the partial automation system, including:
    - Lack of capabilities on ADS elements.
    - Lack of complete and systematic documentation on the design, test and approval of ADS elements. For example, Case 1 triggered a nationwide recall of Tesla due to lack of documentation.
    - Insufficient intelligence of AI technologies. Evidence could be Cases 5 & 6. In these accidents, the CAVs had detected the collision before it happened, however, the system did not know how to perform under unforeseen conditions.

Table 3: CAV Engineering Failure Examples

Case	Location	Time	Briefing
1	Williston, FL	May 7, 2016	Collision Between a Car Operating With Automated Vehicle Control Systems and a Tractor-Semitrailer Truck
2	Culver City, CA	January 22, 2018	Rear-End Collision Between a Car Operating with Advanced Driver Assistance Systems and a Stationary Fire Truck
3	Delray Beach, FA	March 1, 2019	Collision Between Car Operating with Partial Driving Automation and Truck-Tractor Semitrailer
4	Mountain View, CA	March 23, 2018	Collision Between a Sport Utility Vehicle Operating With Partial Driving Automation and a Crash Attenuator
5	Las Vegas, NV	November 18, 2017	Low-Speed Collision Between Truck-Tractor and Autonomous Shuttle
6	Tempe, AZ	March 18, 2018	Collision Between Vehicle Controlled by Developmental Automated Driving System and Pedestrian

- Data issues
  Data collection methods aiming to monitor driver engagement, driver distraction and environmental data is a common major failure as supported by multiple cases. It caused overreliance on the automation of CAVs. When accidents happened the drivers had no time to react. Besides driver monitoring, there are no clear standards on the requirements of data recording and its ethical use. What should CAVs collect under considerations of public safety? How to use the data as an instant-driven force for a safe operation still remains unclear.

- Ethics issue and public policies
  The accidents in Case 6 happened on a CAV which was performing the ADS testing tasks. Besides insufficient ADS capabilities, it reflects the gap in regulating ADS testing procedures. For example, safety risk assessment procedures should be implemented before the testing phase by leveraging regulatory tools. Also, the company's safety culture contributed to the failures. Insufficient oversight was enforced as well as the driver’s carelessness in the driving tasks was not monitored or assessed in a timely manner. We consider that to protect public safety and save lives, it is important to build up a culture of ethical practice led by the regulatory agency.

2.5. Mobility Engineering Knowledge Base: A Summary

In conclusion, from the literature review and analysis of the education programs, job market, ADS technologies and engineering failures in autonomous vehicles, we summarize the following key findings:

- Mobility engineering roots from multiple traditional engineering disciplines. Fields like transportation engineering, electrical engineering, mechanical engineering, software engineering and data science are some of the key disciplines that make up mobility engineering. Mobility engineering education programs across the country are typically housed in one engineering department but integrated with a variety of course requirements from other engineering disciplines.
- The job market indicates the need for mobility engineers are multi-facet, including electrical engineers, safety engineers, transportation engineers, etc. It is a loose correlation to the education programs from different traditional perspectives.
- The ADS technologies for the 4th and 5th SAE International automation level show the trends in autonomous vehicle safety features. It requires knowledge from system engineering, transportation engineering, AI, software engineering, safety engineering, etc., which is a continuation of the knowledge base reflected in mobility education programs and the corresponding job market.
- From the review of engineering failures, we found there are limitations of the current CAV system capabilities, including insufficient implementation of safety features, non-regulatory documentation process and lack of AI-related capabilities. Data issues and ethics concerns are also nontrivial contributors to severe accidents.

From the above finding, we conclude the following implications:

- Education programs in mobility engineering are driven by market needs. They started from traditional engineering disciplines and are growing towards a mature and independent discipline. This implication is evidenced by the 5 well-established education programs and the link between core courses and the job market. However, compared to traditional engineering education, there is no licensure stewardship provided in mobility engineering.
- Since the knowledge base of mobility engineering is widely and deeply rooted in traditional engineering disciplines, the current PE exam from NCEES of each engineering specialty could partially meet the needs of mobility engineering. To fit the needs of mobility engineering, knowledge from multiple specialties should be further integrated and tailored. However, mobility-specific knowledge requires new development, such as big data analytic skills.
- With the incoming maturity of SAE Level 4 and Level 5 automation, more ADS features would be implemented to achieve the objective. However, there is a gap in regulating the implementation process of these safety features to protect public safety.
- There is no explicitly authoritative agency to guide and ensure the ability development and ethical commitment of a mobility engineer. Also, no licensure stewardship is provided to protect the public by regulating the CAV providers. We consider they are necessary for public safety.

3. INTERVIEW

Personal interviews were conducted to collect experts' opinions on mobility engineering knowledge base and licensure issues. During the interview process, we aimed to identify the knowledge base in support of the sound functionality of mobility engineering, investigate key stakeholders involved in the mobility engineering industry, evaluate the current regulatory environment and locate regulatory challenges to proceed with mobility engineering, and then determine the transformable knowledge base from traditional engineering to mobility engineering.

3.1. Questions Design and Interview Implementation

Candidates for the interview were selected with the principles of maximizing representation as well as reducing selective bias. To achieve this goal, we determined a candidate pool of size 60 with sound considerations from multiple mobility-related industries, including automobile manufacturers, the government, academia and engineering consulting firms. Virtual conferencing was employed as the interview method. From October 2022 to November 2022, the research team sent out invitations to the potential candidates via email and LinkedIn and received six acceptance. The interviews were implemented during the same period. Each interview last approximate one hour to collect experts' insights in alignment with the pre-determined objectives. A list of the roles of the interviewees is provided in Table 4.

Table 4. The Role of Interviewees

No.	Title	Type of Organization
1	Senior Vice President and Principal	Engineering Consulting
2	Co-founder	Engineering Consulting
3	Distinguished Professor	Academia
4	Technical Manager	Auto Maker
5	Program Manager	Auto Maker
6	Co-chair of CAV Program	Government

Before the interview, semi-structured questions were designed, reviewed, revised, and approved by the ECL-USA. Questions weresent to the interviewees together with the invitation, which helped to determine if the audient possess the right knowledge for the question. Interviewees could also prepare themselves in advance and therefore leading to more productive interviews. The interview questions covered two major perspectives towards mobility engineering, the Connected and Autonomous Vehicle (CAV) perspective, and the Intelligent Transit System (ITS) perspective, as well as miscellaneous questions. There were about 5-7 questions under each category. The wording of the interview question was written in an easy-to-understand way to avoid miscommunications. The sample interview questions are in Appendix A.

In the implementation phase, the interview was structured into three sections. First of all, the PI introduced the background and the goal of the study, and let all participants share their professional background and expertise. Second, the PI led to general questions such as *how do you define the term mobility engineering? What's the difference you envision between mobility engineering and traditional engineering?* Third, the PI navigated the discussion to specific questions pre-determined. Depending upon the types of toles of interviewees, selected specific questions were asked and discussed for extensive data collection. For example, if they were from the CAV industry, specific questions would have an emphasis on connected vehicles. On the contrary, if they were working for the government or transportation sector, the specific question would be around infrastructure and policy. To better document, the research team asked permission from the interviewees to save captions for information-compiling purposes. Two team members were taking notes as a validation measure.

3.2. Major Findings From the Interview

The research team collected and analyzed data to confirm and complement the knowledge base observed in the literature review phase. Also, challenges were identified in current mobility engineering practices. Since the mobility industry was a highly multi-disciplinary field, key stakeholders and the team collaboration mode were also covered. In the end, in particular of data, issues were compiled.

- **Confirmation of the Knowledge Base**

The interview result confirmed that the knowledge base of mobility engineering was clustered at three centers: vehicle, infrastructure, and technology. The industry development is driven by the advancement in these three footings of knowledge and their collaborations. However, the industry is still in its infancy stage. Partial reasons should be attributed to the uneven growth of the three footings. The autonomous vehicle is ahead of the supporting infrastructures. It was evidenced by the comments that "*Autonomous without that infrastructure is where we are now*." The interviewee further explained that the mobility industry is "*populated by people that are experts in the private sector of the cars, or the vehicle itself. And all the technology for making the vehicle smarter, but not as many people are experts at the infrastructure. These two worlds are not merging together very well.*"

A granular view of the key technologies that drive the development of the physical bodies was collected, including both vehicles and infrastructures. On the vehicle sides, technologies are focusing on batteries, electric drivers, AI and software, cybersecurity and motor power electronics. To connect with the traditional engineering disciplines, they matched the knowledge taught in mechanical engineering, software engineering and electric engineering. On the infrastructure side, technologies were expected to improve pavement markings, stripping, smart traffic signals and roadside units. To achieve better performance traffic signal control centers, designated smart lanes and adaptive message signs stay in need. The knowledge required to build smart infrastructure is grown out of traditional disciplines of transportation engineering, system engineering and safety engineering. The collected information above confirmed that mobility engineering is a multi-disciplinary field.

We have also collected opinions on the establishment of a mobility engineering degree. Due to its multidisciplinary attributes and the fast-changing environment, opinions from academia are conservative. They considered that the "*Mobility engineering degree itself may not be resistant to industry recession*." They worried "*Students with a single mobility engineering degree cannot get any jobs other than the automotive industry when it goes through a recession.*" As a solution to fill the gap between industry needs and education programs, they prefer to offer certificates and courses to students within traditional engineering disciplinary. They commented that "*Certification and additional courses provided based on traditional engineering discipline are considered robust.*" The opinion from academia is a confirmation of our review of education programs in mobility engineering. Those education programs are typically rooted in one of the traditional engineering programs, with additional courses or certificates on mobility.

- **Industry Challenges**

From the interview, challenges and barriers in mobility engineering were collected. Lack of data, lack of cross-disciplinary expertise and lack of specialists of human factors were major concerns pointed out. Evidence to support and explain these industry challenges was compiled.

First of all, "*the biggest problem for the industry is lack of data, especially for small companies.*" The interviewee explained that, "m*any of the companies that are developing both hardware and software are small companies, and most of the rare incidents are in the tails of their distributions. However, it is very difficult for particularly smaller companies to have access to databases established by big companies like Tesla.*" For those big companies, it has been observed that they are under pressure to protect their intellectual property. Therefore, as a solution, the interviewee from academia brought up the necessity to start a public database. The public database was described as "an *Independent body should start a database that everyone contributes to, as long as it is anonymous.*" Since other industries, like ecology and environmental, had built such public databases, they anticipated a similar one in mobility engineering led by the government.

Second, there is a lack of experts who know multi-disciplinary interface collaborations. The interviewee from the government sector in charge of infrastructures said, "w*e had struggled with hiring people when we put in the skill sets or work responsibilities. They have to be a blended person with all these skills. It was really hard to find what we call those unicorns who could literally do it all.*" Because of the lack of cross-disciplinary expertise, instead, they have to hire professional engineers, software programmers, AI specialists, and others, to work as a team. However, in the government sector, this team strategy made them less competitive in the job market when compared to the private sector. The interview results implied that mobility engineers with the cross-disciplinary background may take over multiple roles to reduce human capital costs and promote efficiency in collaboration.

Third, the lack of human factors and ethical specialists was another major challenge. Responses supported this statement were saying "*I think it's good to bring in the human factor side in the curriculum so that when engineers were trying to solve a problem, they actually understood why they're trying to solve the problem.*" The interviewee who brought this concern up gave a concrete example in mobility engineering by asking "*As an engineer, I can do the civil parts, perform the calculation, get to know how the vehicles are driving and know the frictions, but am*

"I actually moving people? That's a different approach to solving the problem." In terms of the gap between solving a pure engineering problem and actual human problems, the interviewee commented that "*I see people read the problem statement that they're given, and they don't expand on it, which is necessary to solve real problems.*" An interviewee with a PE license recalled his/her own education path on the human factor and said "*I took one of those electives, which was a human factor class. It gave me a different perspective on how a human interacts with the roadway to trigger the design. Another one was about transportation law, which forced me out of the classroom environment into the real transportation world. As I got into the industry, these courses are helpful because no one engineering solution fits all real problems.*" Besides the contradictions of insufficiency and the necessity of integrating human factors and ethics into mobility engineering education, other issues were also brought up. An interviewee from the industry pointed out the dilemma in engineering practice: who should lead and be responsible for ADS technologies and related safety issues? It was described as *"a huge debate over who is responsible for leading in order to get technology out on the roadways and within the vicinity so that we significantly reduce the death and serious injuries."*

- **Licensure Issues**

In our study, special attention was given to the licensure issues implied by the challenges identified from the interview. They are concluded below.

- There is no particular engineering licensure provided to govern the design and building of CAV-supportive infrastructures. As a lack of infrastructure was identified as the bottleneck for the advancement of the mobility industry, a lack of governance or guidance for industry practice may lead to safety risks.
- There is no team-based engineering licensure model to facilitate multidisciplinary collaborations to deliver safety products. This implication is supported by the observation that it was unrealistic to have one kind of professional engineer to meet all needs. The safety product must be the outcome of cross-disciplinary collaborations.
- There is a lack of regulation in ethics for the practice of mobility engineers. As pointed out, traditionally trained professional engineers were likely to have a built-up mentality in solving engineering problems but is different from solving real-world problems. When it comes to safety-related ethics, such as liability dilemmas, they may be incapable to make a deliberate decision or bear any consequences.

- **Team Composition and Collaboration**

Considering the team composition and collaboration, different descriptions were collected from interviewees with different roles in the industry.

- **Industry perspective**

Successful delivery of safe vehicles requires the collaboration of internal and external teams in charge of different modules. Various kinds of interfaces are existing depending on the parts and feature a particular team delivers, including in-house and external suppliers. Each functional team, follow certain standards to meet safety requirements. In regard to the issues between these teams, the interviewee pointed out that "*collaborating across multiple teams and even external teams, they may not be on the same schedule.*" Besides being out of sync, effective communication is another major barrier. "*There are issues where requirements are not very clear* *on the external sides. They may interpret our requirements differently on the external side.*" To mitigate communication confusion, the industry teams "*have regular collaboration meetings, design meetings, and developed an agile process where they are able to develop codes.*" In particular of the role of the AI scientist, the interviewee said it was a decision to make on partnering with external agencies, such as Google, or training their own model. A lot of discussions would take to clarify the details of requirements, because "*the original requirement will drive how the AI development proceeds*". To discuss the government's role, the interviewee stated that there is a designated organizations from the corporate to look at regulations, laws, and guidance from the government. Their understanding will report to the senior management, and then finally be distributed to individual groups.

Another interviewee from the industry thought the future of collaboration in mobility engineering could be in the mode of public-private-partnership. He/she thought "*Private sectors expect the public sector to define the standards*" and *"The public sector should take a major role to deliver a safe product because the private sector is protective of information."*

- **Academia perspective**

The interviewee from academia thought that *"Universities have the advantage to bring multi-disciplinary expertise into the team, which favors innovation."* Therefore, the interviewee considered universities serve as the role to inspire future technological advancement. To implement, the future suggestion includes,, *"universities would possess the IP and have multiple collaborations with the industry."* Regarding the safety liabilities, he/she thought, *"the automaker itself who tests the vehicle takes ultimate safety liability."*

- **Government perspective**

As a response to this question, the interviewee who is serving as a government official described a real-world scenario in incident management to deploy mobility solutions. When there was a crash, their responsibility was to know what they need to do. In this process, they worked closely with the local emergency responders, local counties, municipalities and FHWA. If they decided a solution, such as a camera, was needed, it was their job to make every stakeholder or team member be on the same page for "*How do we clear the road? How do we monitor the road to be safer? How do we inform the public about a situation that is happening?*" To handle this, they had to manage different contracts with consultants who provided technical solutions that may be AI backed in information distribution and analytics.

Besides proactive collaboration to promote roadway safety, the interviewee also provided insights on the liability dilemma for incidents. They considered standards or regulations of vehicle safety should be made at the Federal level. They said that "*emerging technology vehicles would be new and different, and it would probably be best looked at as a national level*." For safe operations, they considered that "i*t is actually more in the local motor vehicle administration.*" When the end drivers register the vehicle they self-certifying with the safety features equipped.

- **Data Consideration**

Considering that data plays a predominant role in the AI-powered industry, we solicited opinions on data issues in mobility engineering and concluded as below:

- Politics and the bureaucracy's impact on data. An interviewee commented, *"most parts of western Europe are advancing smart mobility faster than the US. What are the system issues? The politics and bureaucratic issues that are slowing down the advancement."*
- Data protection, segregation and public acceptance. The industry practitioners considered, *"the private industry is too protective of information, I just don't see it being a true leader in the sense of advancing everybody."* Both the interviewees from the industry and academia thought the government should take a leading role in data collection. However, government officials envisioned that "*the public is more afraid of us collecting data, and that is a bigger barrier than the private sectors don't want to share data.*" Therefore, the method to ensure data communication, security and transparency remains as debate under the current regulatory environment.
- Environmental data collection. Besides vehicle data, environmental data collection, including infrastructure data, are critical to ensure safety. We collected several supporting pieces of evidence, *"the quality of environmental data connection and accuracy of data flow are essential for AI to make decisions."* In addition to infrastructures, *"when talking about mobility in the next phase, we have to think about not just the grounds, which everyone used to, but we have to think about air and water as well".*

4. LICENSURE SYSTEM FRAMEWORK

Based on the literature review and interviews, the multi-disciplinary nature of the emerging field of mobility engineering does not align with any existing PE licensure model. As a result, there is a growing interest in exploring team-based licensure frameworks for mobility engineering. In this section, we will examine some examples of proposed team-based licensure frameworks.

4.1. Existing team-based licensure framework

- **ISO Certificate Program**

The ISO Certificate is a valuable tool to demonstrate that a product or service meets customer expectations and, in some industries, is a legal or contractual requirement [1]. The ISO governance structure involves several entities, including ISO, external certification bodies, the ISO Committee on Conformity Assessment (CASCO), the International Accreditation Forum (IAF), and the International Laboratory Accreditation Cooperation. Certification is granted to companies or teams, but not individuals. The certification process involves building and implementing a quality management system in accordance with ISO 9001 standards, undergoing an audit by a Certified Body, and recertification every three years. The ISO certificate program covers various standards, including ISO 9001, which provides a framework for quality management systems, and ISO 14001, which provides a framework for environmental management systems. Other standards are focused on specific industries or sectors, such as ISO/TS 16949 for the automotive industry and ISO/IEC 27001 for information security management systems.

There are three major steps to get ISO certified. First, an organization builds and implements a quality management system in accordance with the principles of the latest ISO 9001 standard. Second, the organization have an audit performed by a Certified Body (CB or Registrar) to assess the performance of its QMS against the latest ISO 9001 standard. Third, after a successful auditing, the certificate will need to be recertified after three years (and every subsequent three years) to make sure the organization is still up to standard as well as any new changes to the standard [2]. Obtaining an ISO certification can bring numerous benefits to an organization, such as increased credibility and trust among customers, improved efficiency and productivity, and better risk management. It can also help the organization meet legal and regulatory requirements and enhance its competitiveness in the market.

Overall, the ISO certificate program is a well-established and recognized system for certification and accreditation of conformity assessment bodies, providing a valuable tool for organizations to demonstrate their compliance with international standards and best practices.

- **DBE Certificate Program**

The Department's Disadvantaged Business Enterprise (DBE) program is designed to remedy ongoing discrimination and the continuing effects of past discrimination in federally-assisted highway, transit, airport and highway safety financial assistance transportation contracting markets nationwide. The primary remedial goal and objective of the DBE program is to level the playing field by providing small businesses owned and controlled by socially and economically disadvantaged individuals a fair opportunity to compete for federally funded transportation contracts [3]

U.S. Department of Transportation (DOT) is in charge of developing regulations 49 CFR Part 26 and/or 49 CFR Part 23 and issuing DBE certificates. However, USDOT does not review DBE applications. The state Unified Certification Program (UCP) allows applicants for the Disadvantaged Business Enterprise (DBE) program to apply only once for a DBE certification that will be honored by all recipients in the state. The DBE certification process includes the following steps:

Step 1: Timely processing of a firm’s application is critical to ensuring that qualified DBEs.

Step 2: A recipient or UCP must advise each application within 30 days from receipt of the application whether the application is complete and suitable for evaluation.

Step 3: A recipient is considered complete when a UCP has received the Uniform Certification Application Form.

Step 4: If the UCP’s staff determines that an application is not complete, it should, within 30 days from receipt of the application, under 49 C.F.R. § 26.83(1), record the date on which it reached that determination for tracking purposes and notify the applicant about the additional information or actions that are required to complete the application.

Step 5: Once the UCP’s staff determines that the application is complete, it should record the date of that determination for tracking purposes and notify the applicant that its application is complete.

Step 6: For in-state applications, the 90-day deadline does not prevent certifying staff from requesting the applicant to provide additional information at a later time, as may be required to clarify information or to answer reasonable questions that may arise during the review process.

Step 7: UCP will make a decision of the certification.

4.2. Mobility Engineering Licensure System: Critical Issues

From the review of existing licensure models, we identified critical considerations to define the framework of mobility engineering licensure:

- **Individual vs. Organization** (or team). An individual regulatory model is designed to evaluate the skills and competence of a candidate to perform specific tasks or deliver services. This model is particularly useful for tasks that have clear knowledge boundaries and can be accomplished independently. For instance, the traditional PE licensure model focuses on individual competence in a specific engineering discipline. On the other hand, an organizational model favors the delivery of a product or service that requires collaborative efforts from multiple individuals with different expertise. In the case of the mobility engineering industry, the safety of products such as autonomous vehicles involves a wide range of disciplines, including mechanical, electrical, and software engineering, as well as data science, cybersecurity, and ethics. Therefore, the organizational model is better suited to regulate and evaluate the safety of these products. It considers the collaboration and coordination between different teams and disciplines, which is essential to ensure the safety of the final product. Furthermore, the organizational model also provides more flexibility in terms of adapting to changing requirements and regulations. Since safety standards and technologies are constantly evolving, an organizational regulatory model can be more adaptable and responsive to these changes. This is in contrast to individual regulatory models, which may become outdated and less effective over time.
- **License vs Certificate**. Licensure and certificate programs differ in terms of the authority that issues them, the industry standards they adhere to, and their professional reputation [4]. Licensure, typically regulated by a state or national board, evaluates the capability of the licensee to ensure public safety. On the other hand, certificates are issued by educational institutions and are not legally required. While licensure is preferable due to the serious nature of protecting public safety, the uncertain liability of CAV-related accidents in the current regulatory environment makes it riskier to develop a license than a certificate. The lack of clarity around CAV-related accidents poses a challenge for regulatory bodies. Developing a licensure program for mobility engineering may be challenging, as it requires defining the scope of regulations and ensuring the competence of the licensee to operate safely. Additionally, since the technology and regulations in the mobility engineering industry are still evolving, a certificate program may offer greater flexibility to adapt to changes. Therefore, a certificate program may be a more suitable option for regulating the mobility engineering industry until the liability of CAV-related accidents becomes clearer.
- **Exam vs Peer Review**. The current NCEES PE licensure process requires both an exam and peer review to obtain licensure. The exam consists of two parts: the Fundamental Exam (FE) and the Professional Exam (PE), while peer review is based on working experience under licensed professionals and reference letters. This combined approach is considered robust in assessing a candidate's knowledge and practical experience. It is recommended to continue this mechanism and conduct exams and peer reviews in line with traditional disciplines. However, before implementation, the scope of knowledge and practice should be rigorously defined.

- **Process based vs. Performance based**. Based on the review, the current NCEES adopted both a process-based approach and a performance-based approach. It requires the candidate to accumulate a certain amount of working experience, as well as successfully pass the exams. In addition, continuing education is required after licensure. In comparison, certificate programs, such as ISO and DBE programs, are less rigorous. ISO certificate is developed to evaluate, manage, and control the process [5]. Recall the evidence from the review of ADS and engineering failures, documenting the process is critical to prevent, analyze and diagonalize accidents. We consider it necessary to evaluate the process to deliver mobility products. For DBE certificates, which goal is to provide a fair opportunity for disadvantaged businesses to compete for public jobss [6]. Therefore, it could be inappropriate to certify a business based on its business process. When it comes to mobility engineering, the performance of CAV would be directly related to public safety. Also, it is the direct reflection of ethical practices during the process. Evaluating the performance should be a critical need, too. Considering the above, it is ideal to secede from the mechanism of the current NCEES PE licensure model, which is a combination of process-based and performance-based regulatory systems.
- **Local vs National/International**. The management of the current NCEES PE licensure is divided into two tiers: state level issuance and management of licensure, and national-level governance of the PE exam. This division is due to the varying socioeconomic and geographical features of projects that require a unique emphasis on specific engineering knowledge in each state. While this mechanism ensures the competence of licensees to solve engineering problems, it can be costly. In contrast, ISO and other certificates are managed internationally, with standards less constrained by geographical environment, which benefits regulatory agencies by opening up a larger market. For mobility engineering, we consider the core technologies transferable between geographical regions, favoring national or international scope. However, policies around CAV and infrastructure technologies may differ geographically, necessitating further investigation to define the scope of mobility engineering regulations.
- **Product vs. Organization**. In terms of product versus organization regulation, the 12 ADS safety products reviewed cover a broad range of best practices in processes, technologies, and communication, making regulation of the final product difficult, even with clear standards. Given the broad scope and rapid innovation of ADS products, it is anticipated to require tremendous effort to update regulations. In contrast, regulating the organization instead of the product could make the regulatory process more straightforward.

Considering the unique features of mobbilities engineering knowledge and practice, it seems at this initial evaluation that mobility engineering licensure model may be an organizational based national certificate, combining both exam and peer review processes, integrating both business practice and performance, and focusing on organization instead of final product. The detailed justification and viability deserves further exploration and analysis in the next step.

4.3. Team-based Mobility Engineering Licensure System: A Conceptual Framework

To ensure a functional regulatary system for mobility engineering, four-pillar framework should be considered namely knowledge base, team composition, certification process and continuous education (Figure 5).

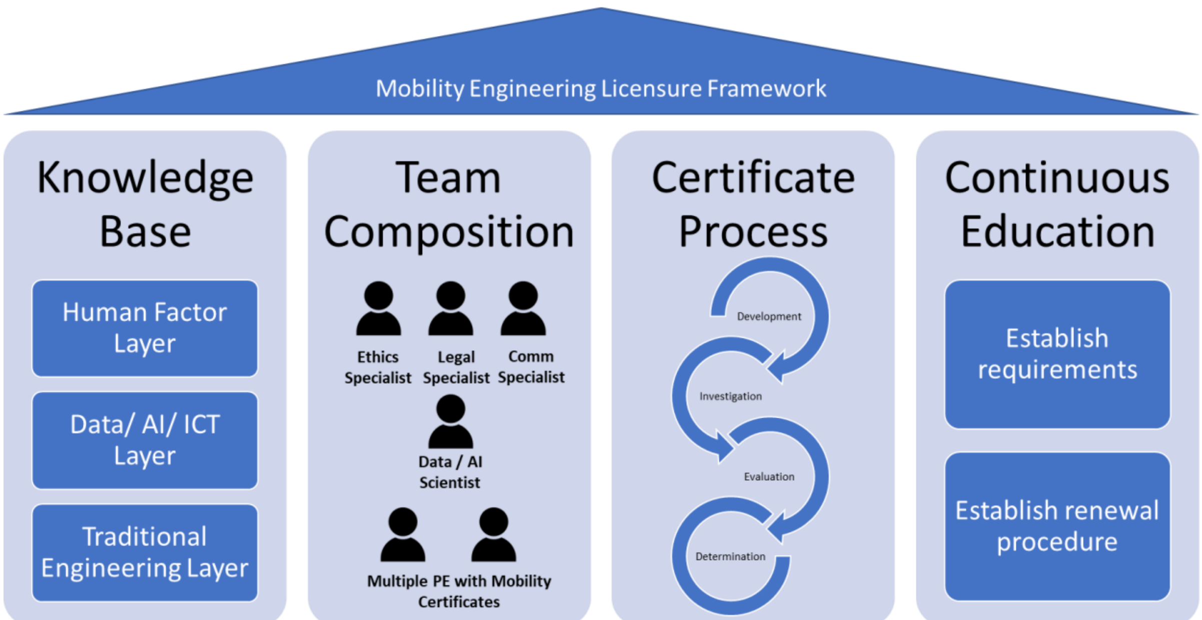

Figure 5: Conceptual Framework for Mobility Engineering Licensure

- Knowledge Base.

The pillar of knowledge base in mobility engineering consists of three essential layers. The first layer is the traditional engineering layer, which serves as the foundation of mobility engineering. Our study shows that competence in traditional engineering disciplines is necessary for a mobiilty enginieerinig team, covering both transportation and ITS knowledge. Given the direct correlation between traditional engineering and public safety, we recommend team members hold a PE license. The second layer is the emerging knowledge requirements of data analytics, artificial intelligence, and internet communication technologies, which are critical for a mobility engineering professional. Finally, the third layer is the human factor layer, which encompasses ethics, law, public communication, and other competencies. This layer guides and evaluates the design of AI features, interprets regulatory requirements, and communicates and educates the public. Together, these layers constitute the necessary knowledge base for mobility engineering practitioners to ensure the safe and effective deployment of new technologies.

- Team Composition

In terms of team composition, we propose roles corresponding to the three layers in the knowledge base pillar. For the traditional engineering layer, we recommend project engineers from traditional engineering disciplines with additional knowledge of mobility engineering to design, develop, test, and implement safety products. The second layer requires professionals with expertise in data analytics, artificial intelligence, and ICT technologies. The third layer, or the human factor layer, requires specialists in ethics, law, and communications. Team members in each layer should provide support and deliver value to other layers internally, as well as collaborate with external counterparts to ensure the safe delivery of products. This composition ensures a diverse set of skills and competencies necessary for effective and safe mobility engineering practices.

- Certificate Process

To ensure the safety of mobility engineering products, we propose a team-based certificate process with four phases: development, investigation, evaluation, and determination. This process will be implemented after publishing the code of compliances by the regulatory entity. In the development phase, the licensee team will be responsible for developing their approach and demonstrating compliance with the codes. The regulatory committee will execute the investigation and evaluation phases to inspect and ensure the safety of the developed process. After examination, the committee will determine whether or not to certify the process. To prepare for implementing the certification process, safety codes for mobility engineering need to be developed, and a regulatory committee must be established. This process will ensure that safety measures are taken into consideration and will enhance public safety in the mobility engineering field..

- Continuous Education

Based on our analysis, it is essential to implement a continuous education mechanism in the mobility engineering industry to keep licensed engineers updated with the latest developments. To achieve this, we propose the adaptation of the continuous education mechanism from traditional PE licensure while incorporating mobility engineering-specific standards. This framework involves two critical steps: setting the necessary requirements and defining the renewal procedure. By implementing this continuous education mechanism, mobility engineers will be equipped with up-to-date knowledge and skills, leading to improved safety and innovation in the industry.

5. CONCLUSION AND NEXT STEP

Mobility engineering is an emerging engineering field driven by rapid advancement in CAV and ITS technologies. Currently, no licensure has been offered to provide both technical guidance and ethics education in protecting the public. To get a better understanding of the knowledge base required by mobility engineering practitioners and the gap in the current regulatory environment, the BAC team conducted research to collect and analyze relevant information. To meet the objective, we reviewed the knowledge base from mobility engineering and conducted interviews to collect insights into the licensure issues of mobility engineering. In the review tasks, four aspects were taken into consideration, which is the education programs, job markets, safety technologies and engineering failures. Major findings are summarized below:

- Mobility engineering is a field that draws from multiple traditional engineering disciplines, so education programs in this field are often hosted in one traditional engineering department with additional certificates and courses in mobility engineering.
- The job market demands a broad range of expertise in mobility engineering that has a loose correlation with traditional education programs from different perspectives.

- Autonomous Driving Systems (ADS) technologies, designed to ensure public safety, reflect the knowledge base of mobility education programs and the corresponding job market.
- Insufficient implementation of safety features, non-regulatory documentation processes, and lack of supporting infrastructure and AI-related capabilities are identified as bottlenecks to achieving optimal safety, according to engineering failures and interviews.
- Data issues and ethics concerns are also significant contributors to severe accidents.

Further research is needed to refine licensure models and examine their viability. Specifically, various licensure and certificate models should be reviewed, and their transformation potential to the field of mobility engineering should be explored. The proposed conceptual model in this report requires further refinement to specify team roles, product delivery workflows, collaboration mechanisms, liabilities and authorities, risks, etc. A quantitative and qualitative analysis is necessary to determine the value, benefits, and barriers of the licensure system as a regulatory policy to ensure public safety and wellbeing in mobility engineering practice. Lastly, industry acceptance and market prospects should be explored to create a strategic implementation plan.

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APPENDIX: INTERVIEW QUESTIONS

Overall Objectives

- Identify knowledge base in support of the sound functionality of mobility engineering.
- Investigate key stakeholders involving mobility engineer professionals.
- Review and evaluate the current regulatory environment and locate regulatory challenges to proceed for mobility engineering.
- Explore education programs in mobility engineering.
- Determine the transformable knowledge base of traditional engineering licensure model into mobility engineering.
- Develop detailed scope, milestones, and budget estimates for Phase 2 Prototype Development efforts.

I. CAV Perspective

1. For CAVs, what emerging technologies/functions do you consider as effective to protect public safety? E.g., Electrification vehicle systems; Autonomous transportation systems; Vehicle connectivity systems, such as V2V, V2I, V2N, and etc.; Shared mobility and integrated transportation systems; Smart infrastructure systems; Mobility safety systems: Autopilot
2. Describe a CAVs technology failures-caused crashes. How could the technology get improved to avoid this?
3. What are the bottlenecks to widely adopt these technologies in everyday life?
4. What are the business pipelines in your organization to deliver the CAV specific safety product?
5. Since the development of CAVs is a cross-disciplinary effort, such as system design, mechanical engineering, data analysis, etc. what knowledge areas do you consider are in key needs to drive the industry?
6. Is there any standardized process to define the scope of knowledge needed to fill in an engineer position?
7. How does your organization regulate the technology in order to get aligned with the Vision Zero Network? (For US interviewees)

II. ITS Perspective of ITS

8. What are the key technologies that have been leveraged by current ITS?
9. What functionalities/features do you consider that future ITS would add?
10. How is ITS in collaboration with CAVs?
11. What are the challenges to implement a better ITS? Such as data insufficiency, unreliable technology, policy issues, public acceptance, etc.
12. What is your approach/vision to transform existing infrastructure to ITS?
13. Besides the knowledge in traditional domains, such as transportation, city planning, etc, what do you consider as ITS specific expertise?

III. Other Objectives

14. To nurture a CAVs feature from start to finish, who are the key stakeholders to drive the project to final success?
15. For your product, how do you manage/regulate the engineer's capability to ensure QAQC, reduce rework, reduce cost and mitigate future risks?
16. Who are the regulatory authorities for CAVs?
17. What CAVs regulations/standards are currently implemented in the industry?
18. How does your organization ensure compliance with it?
19. What is the role of the regulatory authorities in the product life cycle? Set standards? Guide the process? Assess/test the framework?

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