National and State Level Approaches to Automated Vehicle Certification




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National and State Level Approaches to Automated Vehicle Certification

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16. Abstract

Automated vehicles (AVs) are transitioning from experimental pilots to limited real-world operation across several U.S. states and international authorities. As deployment expands, transportation agencies face growing questions regarding how AVs are approved for public use, how safety is monitored over time, and how regulatory responsibilities are shared among manufacturers, operators, and public authorities. In the United States, vehicle safety oversight is led federally by the National Highway Traffic Safety Administration (NHTSA) through a self-certification framework, while states retain authority over operational permissions, resulting in diverse regulatory approaches nationwide. This technical assistance project, conducted by North Carolina State University for the North Carolina Department of Transportation (NCDOT), reviews current AV certification, authorization, and post-deployment oversight practices in selected U.S. states and international contexts with active testing or deployment. Drawing on peer-reviewed research, state regulations, federal guidance, and practitioner sources, the study examines key issues including safety assurance, operational approval, software updates, data reporting, and incident response. The synthesis identifies three representative state-level certification models: (1) baseline legal compliance relying on existing registration, insurance, and self-certification requirements; (2) administrative self-certification frameworks incorporating safety documentation, reporting, and ongoing oversight; and (3) permit-based authorization programs requiring formal agency review and approval prior to testing or deployment.

The report synthesizes these findings into a structured, comparative framework that clarifies how certification models differ in regulatory involvement, administrative workload, and institutional capacity requirements, and applies this framework to assess North Carolina's current position and potential future pathways. By translating diverse state practices into representative regulatory models, the study provides a practical decision-support tool for policymakers to evaluate tradeoffs between safety assurance, governance complexity, and deployment flexibility as AV operations expand.

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EXECUTIVE SUMMARY

This report examines how automated vehicles are being authorized, regulated, and overseen across the United States and selected international contexts, with a particular emphasis on the role of state governments. As such vehicles transition from experimental testing to real-world operation, traditional certification frameworks—originally designed for human-driven and mechanically oriented vehicles—are no longer sufficient. The integration of software-intensive systems, artificial intelligence, sensor fusion, and continuous updates introduces new aspects of uncertainty in expected safety performance, including decision making, cybersecurity, operational risks, and interactions with human-driven vehicles. Our findings suggest that certification should shift from a periodic approval process to a continuous lifecycle-oriented model that uses continuous monitoring, scenario-based validation, and ongoing oversight.

Within the United States, the regulatory environment is characterized by an organically evolving partnership between federal and state governments. Federal oversight, led by the National Highway Traffic Safety Administration (NHTSA), presently relies on a self-certification framework under vehicle safety standards that do not explicitly address fully autonomous systems. NHTSA presently provides guidance and exercises post-deployment authority through requirements recalls, investigations, and crash reports. States are responsible for governing the operational aspects of automated vehicles, including testing permissions, roadway use, insurance requirements, and enforcement. This style of collaboration has resulted in a fragmented regulatory landscape, with significant variation in how different states approach automated vehicle authorization and oversight.

To encourage uniformity and consistency, this report suggests structured frameworks that categorize state-level practices into three representative models based on the level of regulatory involvement and administrative complexity. The first model relies on baseline legal compliance, where automated vehicles are permitted to operate if they meet existing requirements related to registration, insurance, and adherence to traffic laws. This approach involves minimal regulatory intervention and does not require dedicated automated vehicle programs. The second model introduces administrative self-certification, in which states establish formal processes for submitting safety documentation, plans for law enforcement interaction, and operational information, along with requirements for ongoing reporting and oversight. The third model involves permit-based authorization, involving formal approval from a state authority prior to testing or deployment, often supported by detailed application processes, operational restrictions, and extensive reporting obligations. These models reflect increasing levels of regulatory oversight, institutional capacity requirements, and administrative workload, with more elaborate systems providing greater safety assurance and accountability at the cost of increased complexity.

The report further analyzes differences among current state practices within these models, highlighting the substantial variation that exists in how requirements are structured and enforced. Some states adopt highly detailed and prescriptive frameworks with clearly defined operational phases, reporting requirements, and agency responsibilities, while others implement more flexible and less detailed authorization processes. These differences illustrate that regulatory design is not only a matter of choosing a model but also determining the degree of elaboration and stringency to be followed within that model. The report emphasizes that these choices have direct implications for institutional capacity, inter-agency coordination, and the ability to respond to emerging safety and operational challenges.

In addition to the U.S. analysis, the report places these findings within a global context by comparing regulatory approaches across major regions. Internationally, there is a trend toward more centralized and

structured certification systems, particularly in Europe and China. For example, the European Union employs a type-approval framework supported by harmonized regulations, scenario-based testing, and mandatory requirements for cybersecurity and software updates, resulting in a highly coordinated and transparent system. China adopts a centralized and technically detailed approach with mandatory scenario testing, real-time data access for regulators, and rapid deployment through designated pilot zones. Japan follows a cautious and safety-focused model centered on operational design domain-specific approval and detailed safety-case documentation. Other regions, like Australia and Singapore, are developing frameworks that emphasize safety-focused case study testing, simulation-based validation, and integrated national oversight. Despite these differences, it does seem that there is convergence toward common principles such as scenario-based testing, lifecycle oversight, cybersecurity assurance, and the use of operational design domains to define system boundaries.

The report highlights that the United States differs from these international models due to its decentralized governance structure, which presents challenges in developing a unified certification framework. While this situation fosters innovation and flexibility, it also creates challenges related to consistency, safety assurance, and public trust. The absence of standardized validation methods and national-level certification processes complicates cross-state deployment and raises questions about the adequacy of current oversight mechanisms as automated vehicle operations expand.

From the perspective of North Carolina, the report describes the policy presently in place: a baseline legal compliance approach, relying on existing federal and state laws without implementing dedicated automated vehicle programs or permitting frameworks. This structure minimizes administrative burden and allows for flexibility in deployment, but it may not provide sufficient oversight as automated vehicle technologies advance toward widespread driverless operation. The report suggests that moving toward a more elaborate regulatory framework, which might be prudent, would involve expanding the state's role in operational governance. This would include establishing clearer operational rules, implementing administrative processes for authorization, enhancing incident response capabilities, and developing mechanisms for data access and transparency. It would not necessarily involve vehicle testing.

The report also emphasizes that transitioning to a more involved regulatory model would require significant institutional readiness. This includes developing technical and policy expertise related to automated vehicle systems, cybersecurity, and safety assurance; strengthening coordination among state agencies and with federal authorities; and preparing public communication strategies to address transparency and trust. Additionally, North Carolina would need to consider how automated vehicles interact with existing transportation systems, including infrastructure requirements, traffic management strategies, and the coexistence of automated and human-driven vehicles. These considerations extend beyond regulation to broader planning and operational responsibilities, highlighting the need for a comprehensive and integrated approach to automated vehicle governance.

Overall, the report concludes that the central role of state governments is likely to involve managing the operational aspects of automated vehicles, even in the absence of formal certification authority. The three model options provide a practical tool for understanding regulatory implications and evaluating trade-offs between safety assurance, administrative complexity, and economic impact. As automated vehicle technologies continue to evolve, states must determine the appropriate level of oversight that balances innovation with public safety, while aligning with their institutional capabilities and legal authority. The findings underscore the importance of adaptive, lifecycle-oriented governance systems that can respond to the dynamic and uncertain nature of automated driving technologies.

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Chapter 1. Introduction

1.1 Background and Motivation

According to the National Highway Traffic Safety Administration (NHTSA), automated driving systems (ADS) refer to autonomous vehicles (AVs) at SAE automation Levels 3 and above (NHTSA, 2021; SAE International, 2021). Automated driving systems (ADS) that can operate with limited or no human driver involvement have created issues for certification and regulatory mechanisms. Existing vehicle and driver approval pathways are not well suited to the emerging needs, as those are designed for human drivers and mechanical-electrical systems which assume that safety depends primarily on the vehicle integrity and human driver competence.

As ADS development progresses, driving responsibility increasingly shifts from the human driver to a computer-based driver, and in some cases eliminates the human driver entirely. The traditional role of the human driver is replaced by an integrated suite of hardware and software with complex architecture with heavy use of artificial intelligence (AI) models. Such a new paradigm introduces new safety risks and verification challenges (Baldini, 2020). New testing procedures are needed for the software-intensive system components, including AI models used in the autonomy pipeline, sensor fusion processes, cybersecurity protection, and remote connectivity systems, which all continuously evolve over time. As such, traditional static certification approaches do not adequately capture the operational variability, emergent failure conditions, or risk management needs associated with ADS. Particularly, the wide use of AI in ADS (e.g., AI-based perception and decision-making modules) creates new risks related to model generalization, dataset limitations, susceptibility to adversarial perturbations, and performance degradation over time. The literature emphasizes that machine learning and deep learning components require specialized verification methods, including robust testing, scenario coverage metrics, and systematic evaluation of edge cases, as well as ongoing testing throughout the operational lifecycle (Baldini, 2020). Cybersecurity threats add an additional dimension, affecting both safety-critical and non-safety-critical functions. Regulatory bodies therefore require manufacturers to implement cybersecurity management systems, continuous vulnerability monitoring, supply-chain controls, and secured update processes (UN R155/R156). Given these evolving challenges, there is growing consensus among regulators, technical agencies, and researchers that AV certification must transition from one-time approval to a structured, multilayered, and lifecycle-oriented assurance model (Baldini, 2020).

Stakeholders across the globe recognize the limitation of the existing homologation procedures. The Joint Research Centre of the European Commission notes that AVs require scenario-based testing, AI robustness evaluation, cybersecurity assurance, and lifecycle oversight because they operate in an effectively unbounded set of real-world situations that cannot be exhaustively enumerated through conventional test methods (Baldini, 2020). Similarly, U.S. federal guidance acknowledges the fundamental limitations of existing practice and emphasizes the need for simulation evidence, functional safety analysis, and continuous monitoring to address the probabilistic nature of ADS performance (USDOT/NHTSA guidance 2016; U.S. Department of Transportation, 2025).

For the U.S., a further complication is the fragmented regulatory landscape. There is no unified federal regulation framework for ADS. Federal authorities are presently relying on self-certification under the Federal Motor Vehicle Safety Standards (FMVSS), while operational permissions for testing and

deployment are determined by individual states. State-level requirements vary widely with respect to permit structures, reporting obligations, driverless operation rules, insurance thresholds, remote operation legality, and safety plan expectations (Regulations in U.S. States, 2025; IIHS, 2026). Abroad, other paradigms are emerging. European countries have chosen to operate within the United Nations Economic Commission for Europe (UNECE) framework, where type approval is mandatory and supported by globally harmonized regulations on cybersecurity (UN R155) and software updates (UN R156), supplemented by national laws such as Germany's Autonomous Driving Act and France's LOM framework (UNECE, 2020a, 2020b; European Commission, n.d.; Bosch Engineering GmbH, n.d.). These differences between the U.S. and Europe underscore the lack of an internationally unified certification pathway and complicate cross-jurisdictional deployment of AVs.

The Autonomous Vehicle Industry Association (AVIA, 2025) emphasizes that the absence of a unified national framework has become a barrier to deployment. In a 2025 survey, more than 93% of AV CEOs stated that the single most consequential action needed to advance safe deployment is the establishment of a federal policy framework for AVs and expressed optimism that national regulatory leadership could resolve current inconsistencies. This industry perspective reinforces the structural challenges identified in existing research regarding AV oversight in the U.S.

1.2 Working Scope

In light of the pressing needs surrounding ADS certification, this synthesis is guided by a state regulatory perspective and a practical governance question: when an AV operator seeks to test or operate an ADS within a U.S. state, how does the state regulate that activity, what requirements are imposed, and where do state practices converge or diverge? The answer to this question can shed light on how a state, such as North Carolina, develops or refines its ADS regulation policies.

To answer this question, the synthesis examines state-level mechanisms used to authorize, condition and oversee ADS testing and operation, including requirements imposed prior to and during deployment, such as permitting, vehicle registration, legal compliance, insurance and economic responsibility, safety management plans, reporting obligations, and conditions for suspension or revocation. Because authority over ADS testing and operation resides primarily with individual states, the review is organized on a state-by-state basis.

The synthesis places greater emphasis on ADS at SAE Level 4 and above. In practice, Level 3 deployments remain limited, while most testing and operational activities occur at Level 4, as illustrated by Waymo, Zoox, and May Mobility (AOL, 2025). Because Level 4 ADS increasingly enables driverless operation, the systems raise more complex safety and oversight considerations, and state certification or authorization processes are therefore typically more stringent and elaborate. In the remainder of this report, the term *autonomous vehicles (AVs)* refers to ADS at SAE Levels 4–5, which are often described in state statutes and guidance as *"fully autonomous vehicles."*

The synthesis also compares U.S. regulatory approaches with models used abroad. As the regulatory landscape continues to evolve, this comparison shows the strengths and limitations of different approaches. This perspective is relevant to state agencies because state-level regulation operates within—and adapts to—a broader federal and international context. Understanding alternative regulatory models

helps states place their current practices in perspective and anticipate potential future developments in federal policy and AV governance.

There is no formal statutory definition of *"certification."* In the remainder of this report, the term *"certification"* is used in a broad, functional sense to refer to state practices that permit or constrain ADS testing or operation on public roads. In this usage, the term is often interchangeable with "regulation."

The remainder of this report is organized as follows. The next chapter reviews state-level ADS certification (authorization) practices in the United States and categorizes them into representative regulatory models. This is followed by a chapter on the U.S. federal regulatory framework and other typical frameworks across the globe. The final chapter discusses implications for the findings for North Carolina.

Chapter 2. Practices in the United States

This chapter reviews how U.S. states authorize AVs (Level 4 and above) to operate on public roadways. As clarified in Chapter 1, the term "certification" is used in a broad sense to denote state practices that permit testing or operation of an autonomous vehicle. In most cases, states do not formally define "certification" in statute; instead, authorization is implemented through registration requirements, insurance provisions, self-certification statements, permitting programs, or administrative guidance.

2.1 Federal Level Regulation

At the federal level, the United States does not have a comprehensive or binding statutory framework governing the certification or deployment of autonomous vehicles (AVs). Although several legislative proposals have been introduced in Congress, no unified national AV law has been enacted. Federal authority over vehicle safety is exercised primarily through NHTSA under existing motor vehicle safety law, which was originally designed for conventionally operated vehicles and does not explicitly address fully driverless systems (Congressional Research Service, 2025; Urban SDK, 2025).

In the absence of AV-specific regulations, federal oversight relies on a self-certification model and voluntary guidance. Manufacturers continue to self-certify compliance with FMVSS, even though these standards do not fully align with automated driving architectures. NHTSA has supplemented this framework with non-binding policy guidance outlining recommended safety practices, including system design, operational domains, and cybersecurity considerations; however, these documents do not constitute regulatory approval or a formal certification process (Congressional Research Service, 2025; Urban SDK, 2025).

Federal oversight exists after deployment, through defect investigations, recalls, and mandatory crash reporting for vehicles equipped with automated driving systems. Limited exemptions from FMVSS are available to facilitate testing, but these are constrained and unsuitable for large-scale commercial deployment. As a result, key issues—such as liability, cybersecurity, and operational governance—remain unresolved at the federal level and have largely been addressed by states, contributing to a *fragmented* national regulatory environment (Congressional Research Service, 2025; Urban SDK, 2025).

2.2 State Practice

The National Conference of State Legislatures has been tracking the AV legislation in various states. A of 2020, 21 states and Washington, D.C. had enacted AV-related legislation, and 10 additional states had addressed autonomous vehicles through executive orders as of February 2020 (NCSL, 2020). The Conference continues to monitor these actions, but no summary exists. Considerable variation exists across states. Accordingly, certification practices also vary across states. Since state practices vary widely and continue to evolve, this synthesis focuses on representative certification models rather than an exhaustive scan, with the goal of providing insight into regulatory design choices relevant to North Carolina.

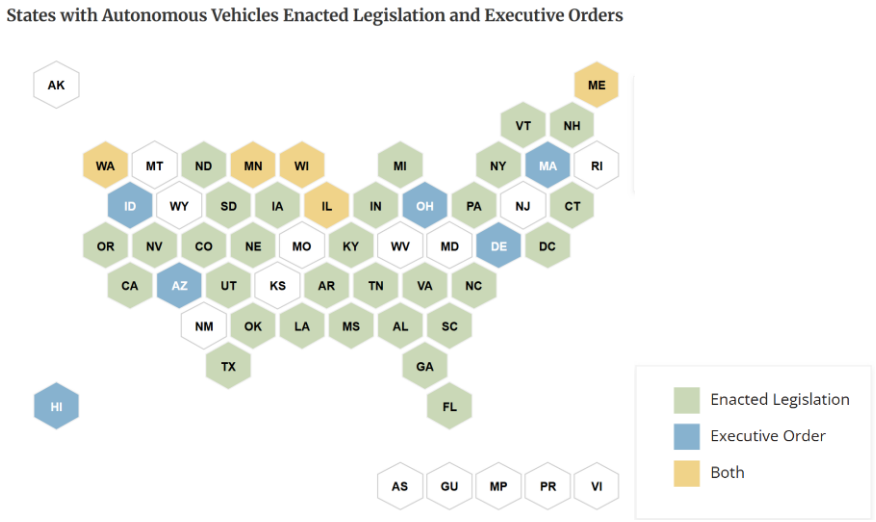

Figure 2-1: AV Legislation Status across Various States in the U.S. as of February 2020 (NCSL, 2020)

2.2.1 Methodologies

To support a systematic review of state AV certification or authorization practices, the research team developed a set of analytical questions, aiming to clarify how certification is defined, implemented, and enforced (Table 2-1). These questions cover key dimensions, including scope and operational conditions, governance and oversight, evidence requirements, and interaction with federal policy.

The synthesis is based on a review of publicly available materials (e.g., state statutes, administrative rules, agency guidance documents, and official websites) and insights from interviews with agency representatives that were conducted in January and February 2026 for a complementary NCDOT-supported technical assistance project (Jing et al, 2026).

2.2.2 Outcomes: Different Models of AV Certification

The detailed synthesis of all these outcomes is in Appendix A.

Based on the synthesis, the research team grouped the certification and authorization practices into three models, corresponding to different tiers of requirement; see results in Table 2-2. The requirements can be categorized into three tiers, reflecting increasing levels of regulatory involvement and administrative workload. Higher tiers generally incorporate the requirements of lower tiers.

- Tier 1: Baseline legal compliance. Tier 1 consists of baseline legal requirements applicable to AV operation, usually including self-certified compliance with applicable federal requirements (e.g., FMVSS issued by NHTSA) and state traffic laws, vehicle registration as a fully autonomous vehicle, and liability insurance.

- Tier 2: Administrative oversight and self-certification on official platforms.
  Tier 2 adds explicit administrative and safety-related requirements. Common elements include safety management plans (e.g., law enforcement interaction procedures), self-certification of

compliance with federal and state laws in an authority-designated platform, and post-deployment reporting requirements (e.g., crash reporting).

- Tier 3: Authority-issued permit or authorization. Tier 3 includes an explicit permit or authorization issued by a public authority prior to AV testing or operation. This entails a review process of the authorization conditions.

Table 2-1: Questions Used to Review State AV Certification Practices

Category	Question ID	Question
A. Scope and Operational Conditions	A1	What certification or authorization model is used (e.g., self-certification, submission-based approval, authority-issued permit)?
	A2	Does certification or authorization differentiate by AV vehicle type or use case?
	A3	Is certification or authorization tied to specific operational phases (e.g., testing, pilot, deployment)?
	A4	Is certification or authorization explicitly conditioned on an Operational Design Domain (ODD)?
B. Governance, Evidence, and Oversight	B1	Which entity is responsible for issuing AV certification or authorization?
	B2	How are roles and responsibilities allocated between state and local governments?
	B3	What types of evidence or documentation are typically required for certification or authorization?
	B4	Under what conditions is re-certification or renewal required?
	B5	Under what conditions can certification or authorization be suspended or revoked?
	B6	What reporting obligations apply after deployment?
C. Federal Interaction and Portability	C1	Is AV certification or authorization portable or recognized across states?
	C2	How does state certification or authorization interact with federal policy and requirements?
D. Implementation Outcomes	D1	Which AV developers or operators have obtained certification or authorization?

Table 2-2: State Certification Models

Requirement item		Regulatory workload & capacity needs	Group 1	Group 2	Group 3
			GA, NC	AZ, WA	CA, PA, TX, DC
Tier 1	Compliance with federal standards & rules and state laws	Light	Y	Y	Y
	Registration		Y	Y	Y
	Insurance		Y	Y	Y
Tier 2	Law enforcement coordination	Moderate	No	Y	Y
	Self-certify via authority channel		No	Y	Y
	Reporting		No	Y	Y
Tier 3	Permit prior to operate	High	No	No	Y

Based on the requirement levels, state practice mainly falls into three groups:

- Group 1: Minimalist (e.g., Georgia and North Carolina). Group 1 states primarily use Tier 1 requirements. AV operation is permitted once baseline legal conditions are met, without AV-specific administrative programs or permitting frameworks. Authorization is largely *implicit*, grounded in compliance with existing federal and state laws.

- Group 2: Administrative self-certification (e.g., Arizona and Washington). Group 2 states incorporate Tier 2 requirements in addition to Tier 1. These states establish AV-specific administrative processes, such as safety plan submission, self-certification through official platforms, and reporting obligations, without requiring an authority-issued permit prior to operation. Authorization is based on documented compliance and post-deployment oversight.

- Group 3: Permit-based authorization (e.g., California, Pennsylvania, Texas, and the District of Columbia). Group 3 adopts Tier 3 requirements in addition to Tier 1 and Tier 2. These states require an explicit permit or authorization prior to AV testing or operation, typically through a formal application and review process. The permitting frameworks generally impose more elaborate and specified requirements for elements in Tier 2 (e.g., AV-user two-way communication channels as a part of safety management). Additionally, Group 3 states may expand the requirements, such as renewal conditions, operation constraints (e.g., remote operation policies), data retention, and differentiation across permit types (e.g., testing versus deployment, or vehicle seating capacity). Authorization is granted through structured permitting frameworks.

It is worth noting that within Group 3, there is substantial variation in both the level of program elaboration and the stringency of permitting requirements. Although all Group 3 states require authority-issued authorization prior to AV testing or operation, the scope, detail, and procedural rigor of these permitting frameworks differ significantly.

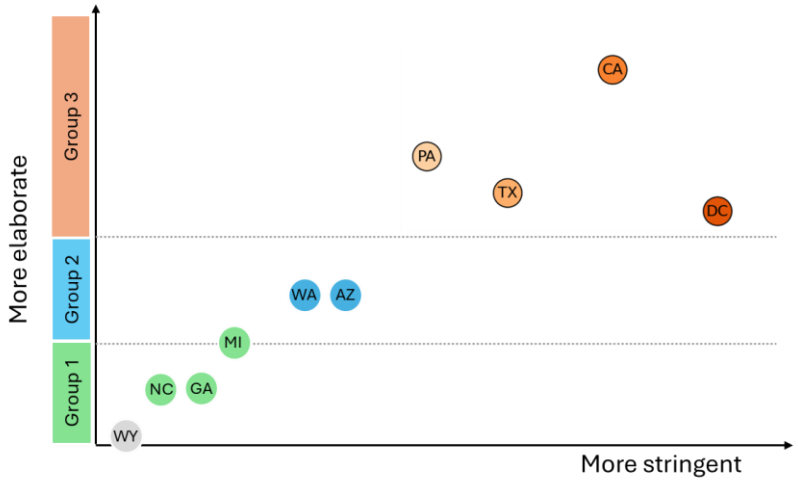

Figure 2-2: Level of Elaboration and Stringency in AV Certification

- California operates the most elaborate and prescriptive program among Group 3 states. Its framework differentiates permits by operational phase (e.g., testing with a safety driver, driverless testing, deployment) and by vehicle type (e.g., seating capacity), and includes detailed reporting obligations and clearly defined renewal and modification conditions. The program reflects a relatively high level of regulatory stringency and well-defined procedures. The program is supported by a distinct regulatory structure involving two primary agencies: the Department of Motor Vehicles (DMV), which handles the technology and vehicle aspects to issue the prerequisite permits, and the California Public Utilities Commission (CPUC), which regulates the commercial service of carrying passengers. Permits from both agencies are required for passenger-carrying operations.

- Pennsylvania also provides detailed certification guidance; however, much of this material is framed as guidance rather than mandates. As a result, while expectations for AV operation are articulated with substantial details, formal permitting requirements are less prescriptive than in California. Overall, the program is less stringent than California's.

- Texas requires authorization for AV operation but maintains comparatively brief statutory requirements. The authorization framework establishes baseline conditions (e.g., presence of a recording device) while avoiding detailed procedural or reporting specifications, resulting in a lower level of elaboration within the permit-based model. Texas only recently adopted a formal permit requirement (effective September 1, 2025), corresponding with increased AV deployment activity and emerging safety concerns (Texas Department of Motor Vehicles [TxDMV], 2025; The Daily Texan, 2025).

- The District of Columbia applies a highly restrictive permitting approach, currently requiring a human safety driver behind the wheel for AV operation. The existing permitting framework is interim. A formal framework addressing operation both with and without safety drivers is anticipated and is likely to involve elaborate requirements and a formalized approval process. The district's permit requirement is also relatively recent, with emergency legislation first enacted in March 2024 (District of Columbia Council, 2024).

The research team positioned the states across the three groups in Figure 2-2 using a 2-dimensional plot to illustrate relative levels of elaboration and stringency. While most states align with one of the three groups, several cases fall between categories. For example, Michigan requires that prior to research testing, manufacturer or upfitter must be recognized and submit proof of insurance to the Secretary of State (Mich. Comp. Laws 257.665 et seq., 2023). However, Michigan has removed permit systems to remain flexible. Thus, Michigan's model shows features spanning Group 1 and 2. Wyoming represents another situation in which AV operations remain unregulated. In Wyoming, AV operators are encouraged, but not required, to notify the Wyoming Department of Transportation and Wyoming Highway Patrol prior to entry. Please note that these positions only reflect the status as of January 2026 and they may change as legislation evolves.

Notably, the different models entail distinct levels of workload and institutional capacity requirements for regulating agencies.

- Group 1 model: Light workload and minimum institutional changes. Implementation is typically embedded within existing regulatory frameworks rather than AV-specific programs, requiring little modification to current institutional arrangements.

- Group 2 model: Moderate workload and institutional complexity. This model introduces Tier 2 requirements, which require regulatory authorities to review submitted documentation (e.g., safety management plans), conduct post-deployment oversight, and exercise regulatory judgment (e.g., suspending or restricting operations when warranted). As a result, additional institutional considerations arise, including which agencies are best positioned to perform these functions and how responsibilities should be allocated. Multiple agencies may be involved as in Arizona, where both the State Department of Transportation and Department of Public Safety are involved. When multiple agencies are designated, inter-agency coordination becomes an important consideration.

- Group 3 model: High workload and institutional design complexity. This model entails formal permitting processes, pre-operation review, and sustained regulatory oversight, placing the greatest demands on administrative capacity and institutional design.

2.2.3 Relevance to North Carolina

At present, North Carolina aligns with Group 1, adopting a regulatory approach similar to Georgia that relies primarily on Tier 1 baseline legal requirements. AV operation is permitted through compliance with existing federal and state laws, without AV-specific administrative programs or permitting frameworks.

If North Carolina were to pursue a more elaborate regulatory approach, it would move toward Group 2 or Group 3, incorporating additional administrative oversight or permit-based authorization. Such a transition would require legislative action and would involve balancing multiple considerations, including

potential public benefits (e.g., enhanced safety assurance), the administrative workload and capacity of regulating agencies, and broader economic implications.

Chapter 3. Global Perspective

It is useful to view the emerging certification vision for the U.S. in a global context. Below is a structured global comparison of how major regions in the world are approaching AV certification. The focus is on regulatory philosophy, testing requirements, certification models, safety cases, scenario libraries, data and cybersecurity, and deployment rules.

An overall view is presented in Table 3-1. These perspectives are described in more detail in the following subsections.

Table 3-1: Perspectives on AV Certification Around the Globe

Region	Main Approach	Style	Key Strength	Key Weakness
U.S.	Self-certification + state permits	Emerging federal model (not yet defined)	Innovation-friendly, flexible	No unified certification test
European Union	UNECE type approval	Formal, test-based, scenario-driven	Most mature and coherent global model	Slower regulatory cycles
China	National technical standards with mandatory scenario testing	Centralized and mandatory	Fast-moving, extensive scenario validation	Opaque decision-making; IP/data access issues

3.1 The United States: An Emerging Hybrid Framework

As of the publication date of this report, the regulatory philosophy of the United States for AVs is self-certification (National Highway Traffic Safety Administration, 2017). The federal government is avoiding the dictation of technology choices (National Highway Traffic Safety Administration, 2020). The states are regulating operation, not design (National Conference of State Legislatures, n.d.). The National Transportation Safety Board (NTSB) is pushing for stronger federal oversight following automated vehicle crash investigations (National Transportation Safety Board, 2022). There is no federal AV certification program; rather, there is a patchwork of permitting systems created by the states (National Conference of State Legislatures, n.d.). To exercise oversight, NHTSA uses recalls, investigations, and voluntary guidance, including Automated Driving Systems 2.0–4.0 (National Highway Traffic Safety Administration, 2017, 2020, 2021).

Strengths of this approach include rapid innovation (Fagnant & Kockelman, 2015) and a high degree of test deployment by developers such as Waymo, Cruise, Aurora, and Kodiak, enabled through state testing permit programs (California Department of Motor Vehicles, 2023). Limitations include uneven safety oversight (National Transportation Safety Board, 2022), no national-level validation tests (RAND Corporation, 2018), and public trust issues after major crash events involving automated driving systems (Litman, 2025).

Potential future direction can include:

- Minimum standards for ADS safety (e.g., fallback behavior, object detection benchmarks, cybersecurity) (Congressional Research Service, 2025; NHTSA, 2017),
- ODD-specific certification (approval only for specific geographies, speed ranges, and conditions) (SAE International, 2021; RAND Corporation, 2018),
- Scenario-based performance tests using a set of nationally prepared required test scenarios,
- Safety-case submission requirement like the UL 4600 and ISO 21448 concepts (Koopman & Wagner, 2017; International Organization for Standardization, 2019; ITF-OECD, 2018); and
- Continuous data reporting and post-market oversight (National Highway Traffic Safety Administration, 2021; National Transportation Safety Board, 2022; ITF-OECD, 2018).

3.2 European Union: UNECE Type Approval with Scenario Testing

The European Union's paradigm involves regulation through a unified framework, like UNECE WP.29 (United Nations Economic Commission for Europe, 2022). It is a highly structured, engineering-driven approach (European Commission, 2022a). It involves mandatory test-based homologation before deployment (European Commission, 2022a; United Nations Economic Commission for Europe, 2021a). Key standards include UN Regulation 157: ALKS (Automated Lane Keeping Systems) (United Nations Economic Commission for Europe, 2021a), UN Regulation 155: Cybersecurity (UNECE, 2024), UN Regulation 156: Software updates (UNECE, 2021b), and EU-specific ODD and scenario requirements (European Commission, 2022b).

The testing requirements involve defined scenario suites for: lane keeping, obstacle avoidance, emergency braking, avoidance of vulnerable road users, on-road and closed-course validation, and simulated performance for corner (edge) cases (United Nations Economic Commission for Europe, 2021a; United Nations Economic Commission for Europe, 2022). Strengths of this approach include the most complete international certification system, high safety transparency, and harmonization across 27 countries (European Commission, 2022a; United Nations Economic Commission for Europe, 2022). Its limitations include slow updates and limited ODD flexibility (only motorway Automated Lane Keeping System, or ALKS, is widely approved) (United Nations Economic Commission for Europe, 2021a).

3.3 China: Centralized Standards with Mandatory Scenario Verification

China's regulatory philosophy is strong national control (China Academy of Information and Communications Technology [CAICT], 2024). It facilitates fast-moving technical standard development (CAICT, 2024; State Council of the People's Republic of China, 2023). The Chinese government views AVs as a strategic industry in which they want to be dominant. Their certification tools include national standards from the MIIT (Ministry of Industry and Information Technology), the MPS (Ministry of Public Security), and experience from the AV Pilot Zones (Beijing, Shanghai, Shenzhen). Mandatory elements include scenario-based testing libraries, closed-course validation combined with simulation and public-road testing, mandatory cybersecurity reviews, data localization requirements, and real-time data access

for regulators (CAICT, 2024; Cyberspace Administration of China, 2021). Strengths of this approach include a fast-moving regulatory environment, deep and technically detailed policy documentation, and the deployment of high-volume real-world autonomous vehicle fleets, including large-scale operations by Baidu Apollo and Pony.ai (CAICT, 2024). Limitations include transparency concerns for external stakeholders, heavy data compliance and burdens of localization, and fragmentation because of the city-based systems (CAICT, 2024).

3.4 Japan: ODD-Based Approval + Safety Case

Japan's certification philosophy is focused on safety. Formal government approval is required for each automated system, and there is a strong emphasis on documenting the ODD (National Police Agency [NPA], 2024; Law.asia, 2024). Honda received approval for its Sensing Elite system in 2021 as a Level 3 automated driving system, which is widely recognized as the world's first commercially available L3 consumer vehicle (Law.asia, 2024). Honda had to provide safety-case documentation, hazard analysis, ODD mapping, redundant hardware validation, and a human-machine interface usability assessment. A strength of this approach is that it is cautious and structured. It also produced the world's first L3 certified vehicle (Law.asia, 2024). It integrates safety cases with performance testing. Among its limitations is the fact that its regulatory processes are slow. Approval of AVs is highly individualized, which may not be scalable. Trend-wise, Japan is moving toward L4 robotaxis in limited zones in the 2025–2030 period (Ministry of Economy, Trade and Industry [METI], 2023). There is close collaboration between the national government and the OEMs, especially Honda, Nissan, and Toyota (METI, 2023; Law.asia, 2024).

3.5 Australia: Proposed National Automated Vehicle Safety Law

The philosophy of Australia's model is centralized national certification. It is safety-case intensive and harmonized across all states and territories (Australian Government, 2023; National Transport Commission [NTC], 2022). The model is still in development. It calls for an AV "safety manager" who would be responsible for AV certification nationally. Stipulations in the certification process include a safety case, a risk assessment, a deploy-and-monitor program, an incident reporting system, and a change-management system (NTC, 2022). Its strengths include a clean-slate regulatory design and a balance between the safety cases and the performance metrics (Australian Government, 2023; NTC, 2022).

3.6 Singapore, Korea, and Others

Other places in the world are also pursuing certification processes. Singapore is pursuing safety-case approval for each ODD and mandatory simulation-based scenario testing. There is a strong emphasis on remote operator elements and fail-safe behavior (Land Transport Authority [LTA] & Singapore Standards Council [SSC], 2021). South Korea has put in place the National AV Act (2020). It combines type-approval with a pilot zone system and cybersecurity and telecommunications integration (Dentons, 2025; World Economic Forum [WEF], 2025). Dubai (the UAE) has the fastest regulatory approval process outside of China. It involves mandatory third-party certification and focuses on fleet-based AVs, particularly in cruise taxis and coordination robots (Government of the UAE, n.d.; Dentons, 2025).

3.7 Summary of the Global Situations

Across the globe, there is convergence toward: scenario-based testing (ISO 34502:2022), ODD-specific certification, safety-case requirements (ISO 21448:2022 – SOTIF), cybersecurity certification (ISO/SAE 21434:2021; UNECE Regulation No. 155), continuous monitoring and post-sales controls, and digital infrastructure integration (e.g., HD maps and V2X) (UNECE, 2022; OECD, 2021; RAND Corporation, 2018). Europe (UNECE WP.29) appears to be the furthest advanced. It has the most complete and harmonized regulatory system (UNECE, 2022; European Commission, 2022). China has the most advanced large-scale scenario-based testing and deployment (CAICT, 2024). Japan has a strong safety-focused program combined with ODD-based processes (METI, 2023). Australia is designing an integrated national model but has not implemented it yet (National Transport Commission, 2022). The U.S. is focusing on technology development, but it lags in unified certification (NTSB, 2022; RAND Corporation, 2018).

Table 3-2 provides a categorical summary of the global situation and

Table 3-3 through Table 3-7 review the certification components from software integrity, data sharing, oversight elements, and reporting requirements.

Table 3-2: Overview of the Strategies across the Globe

Category	United States	Union	China	Japan	Australia
Regulatory philosophy	Industry-led self-certification	Centralized and harmonized	Centralized national control	Cautious, ODD based	Safety-case, performance-based
Main authority	NHTSA + state DOTs	UNECE WP.29 / national ministries	MIIT, MPS, local pilot zones	MLIT (Land, Infrastructure & Transport)	National Transport Commission
Federal/unified rules	✕	✓	✓	✓	✓ proposed
Speed of regulation	Slow	Medium	Very fast	Slow–medium	Medium

* Notation in the table: ✔ = Yes / Mature; ✕ = No / Absent

Table 3-3: Certification Components

Category	U.S.	EU	China	Japan	Australia
Type approval required	✕	✓	● city and national	✓	● proposed
Safety case required	● voluntary (UL 4600)	✓ integrated	✓ required	✓ required	✓ required
Scenario-based testing	● developing	✓ mandatory	✓ mandatory	✓ limited	✓ proposed
ODD-specific certification	● developing	✓ emerging	✓ used in pilot zones	✓ core	✓ proposed
Simulation evidence required	● informal	✓ mandatory	✓ mandatory	✓ used	✓ proposed
Closed-course testing	●	✓	✓	✓	✓
National scenario library	✕	✓ in development	✓	●	●

* Notation in the table: ✔ = Yes / Mature; ● = Partial / Emerging; ✕ = No / Absent

Table 3-4: Software Integrity

Category	U.S.	EU	China	Japan	Australia
Functional safety (ISO 26262)	✔ industry led	✓ required	✔ required	✔ required	✔ required
SOTIF (ISO 21448) integration	●	✔	✔	✔	✔
Cybersecurity certification	● developing	✔ UNECE R155	✔ mandatory review	✔ required	✔ proposed
Software update certification	✘	✔ UNECE R156	✔ required	✔ required	●
HMI and fallback requirements	●	✔	✔	✔	✔

* Notation in the table: ✔ = Yes / Mature; ● = Partial / Emerging; ✘ = No / Absent

Table 3-5: Performance Recording and Data Sharing

Category	U.S.	EU	China	Japan	Australia
Robotaxi deployment approvals	State and local	National	City and national	National	Proposed
Data logging requirements	●	✔	✔	✔	✔
Real-time data access to regulators	✘	✘	✔ required	✘	✘
Remote operator certification	✘	✔ emerging	✔ required	✔	✔
Geographic ODD fencing	●	✔	✔	✔	✔

* Notation in the table: ✔ = Yes / Mature; ● = Partial / Emerging; ✘ = No / Absent

Table 3-6: Review and Oversight Elements

Category	U.S.	EU	China	Japan	Australia
Recalls for AV systems	✓ NHTSA	✔	✔	✔	✔
Mandatory incident reporting	● varies by state	✔	✔	✔	✔
Continuous oversight	●	✔	✔	●	✔ planned
National AV registry	✘	✔	✔	✘	✔ planned

* Notation in the table: ✔ = Yes / Mature; ● = Partial / Emerging; ✘ = No / Absent

Table 3-7: Reporting Requirements

Category	U.S.	EU	China	Japan	Australia
Public reporting of disengagements	● CA only	✘	✘	✘	✘
Required safety reports	✘ voluntary	✔	✔	✔	✔
Required crash reports	✔	✔	✔	✔	✓planned
Testing database access	● NHTSA AV TEST	✔	✔	●	●

* Notation in the table: ✔ = Yes / Mature; ● = Partial / Emerging; ✘ = No / Absent

Chapter 4. A Possible Perspective for North Carolina

4.1 State Role in Certification

Given the evolving national and international regulatory landscape for autonomous vehicles (AVs), an important question for North Carolina is, what role should state agencies play, particularly NCDOT and its Division of Motor Vehicles (DMV)? Even if states do not formally certify AV technologies, state DOTs and DMVs sit at the frontline of AV deployment, with responsibility for testing authorization, operational rules, vehicle registration, enforcement, and coordination with law enforcement and emergency responders (NHTSA, 2017; NCSL, n.d.; AAMVA, 2018). The federal government is unlikely to exercise direct, day-to-day operational oversight of AVs, retaining authority primarily over vehicle design, performance standards, recalls, and post-market safety enforcement (NHTSA, 2017; GAO, 2017).

Based on the division of authority between federal and state government, the state role is best understood as operational governance rather than technical certification. For North Carolina, this implies a focus on authorizing AV use on public roads, setting and enforcing operational conditions, and ensuring public safety through oversight and coordination (NCSL, n.d.; AAMVA, 2018; California DMV, 2022).

State agencies in North Carolina are also likely to coordinate with the federal government and other entities in informing and supporting the development of national-level certification and safety assurance frameworks, should such frameworks emerge (NHTSA, 2017; RAND Corporation, 2018; GAO, 2017). In this context, North Carolina may raise state-specific test cases and advocate for the inclusion of state-based needs and operating conditions in federal frameworks (AAMVA, 2018). Besides, North Carolina can seek transparency, access to results, and advisory participation to ensure that certification and oversight processes meet state needs (RAND Corporation, 2018; NTSB, 2022).

4.2 Implications of a More Elaborate Certification Approach

At present, North Carolina aligns with Group 1 model, adopting a regulatory approach that relies primarily on Tier 1 baseline legal requirements. AV operation is permitted through compliance with existing federal and state laws, without AV-specific administrative programs or dedicated permitting frameworks.

There may be a need to pursue a more elaborate regulatory approach, shifting from a lighter-touch framework toward Group 2 or Group 3 models that incorporate additional administrative oversight or permit-based authorization. If a more formal certification or authorization program were desired, such as the California model, state-designated authorities could be expected to undertake several functions.

- Establishing operational rules: These may include establishing clear operational rules governing how, when, and where AVs are permitted to operate on public roads (AAMVA, 2018; NHTSA, 2017), including specifications for eligible vehicle classes and SAE automation levels, permitted geographies and roadway types, speed limits, and operating conditions such as weather, time of day, and ODD boundaries (SAE International, 2021; AAMVA, 2018).

- Developing and implementing administrative mechanisms for authorization: State authority may need to develop and implement administrative mechanisms for authorization, such as vehicle

registration requirements, insurance and financial responsibility provisions (potentially with higher coverage as in California, Nevada, Tennessee (California DMV, 2022; NAC, 2019)), safety practices (AAMVA, 2018; California DMV, 2022), law enforcement interaction plans, emergency response protocol (California DMV, 2022; NHTSA, 2021), and reporting obligations. For driverless operations in particular, additional requirements related to remote operators will be critical (NCSL, n.d.; California DMV, 2022; Virginia Tech Transportation Institute, 2021), such as operator-to-vehicle ratios and workload limits.

- Updating AV relevant incident response: Among the functions, incident response would be particularly relevant to state DOT and law enforcement due to the public safety concerns. State agencies may need to develop AV-informed incident response and enforcement capabilities, including preparedness for AV-involved crash investigations (NHTSA, 2021). This may involve establishing clear enforcement protocols, guidance for law enforcement interactions with driverless vehicles, and procedures for accessing AV operational data following incidents to support accountability and liability assessment. State agencies may also need to update existing crash and incident reporting mechanisms to account for ADS-specific events (e.g., disengagement, and safety-critical event logs).

- Maintaining AV information for public requests: state agencies may be expected to respond to requests for AV information, such as during crash investigations (NHTSA, 2021). For example, if an AV is involved in a crash, the public may request information like who was operating the AV, what mode it was in, whether it was operating in the approved ODD, and remote operator actions. A key challenge for state agencies is to decide what information should be disclosed and how to obtain or request the data from the AV operator. Addressing this challenge may require the development of clear data-sharing protocols within and across state agencies (AAMVA, 2018).

Notably, a transition to a more elaborate certification program would likely require legislative action and would involve balancing multiple considerations, including potential public benefits (e.g., enhanced safety assurance), the administrative workload and institutional capacity of regulating agencies, and broader economic implications.

4.3 Supporting Capabilities and Institutional Readiness

While the previous sections on regulatory roles and authorization mechanisms, this section discusses the supporting planning, institutional, and coordination capabilities that may need to be implemented to support the more elaborate ADS oversight approach outlined in Section 4.2.

4.3.1 Planning

As a downstream implication of expanded ADS authorization, states may want to integrate AV requirements and accommodation into their planning and capital investment decision-making processes. For example, for work zones, they may want new protocols that accommodate AVs, including machine-readable or consistently signaled work zone layouts (FHWA, 2025). They may need a much richer digital representation of the infrastructure they manage—not HD maps necessarily, but a more up-to-date digital record of lane markings, signage, signage consistency, signal phasing and timing (SPaT), and roadway condition to support broadcast coordination and automated operations (FHWA, 2025; ITF-OECD, 2018).

These considerations align with existing Transportation Systems Management and Operations (TSMO) responsibilities, as AVs are expected to affect congestion patterns and incident clearance times and procedures. Freight AVs will affect truck flow patterns, freight corridors, and support needs such as parking, clearances, and IT support (ITF-OECD, 2018). There may also be significant implications for rural mobility (Litman, 2025).

4.3.2 Policy, Technical, and Legal Expertise

Supporting expanded ADS oversight may require limited but targeted institutional capacity. State DOTs/DMVs may wish to create and maintain a small but capable AV unit (AAMVA, 2018; FHWA, 2025). They may want to identify the skill areas needed, such as traffic engineering for AV behavior, ADS safety concepts (e.g., ODD definition and risk minimization), simulation-based scenario understanding, cybersecurity basics, AV-related legal considerations, insurance and liability frameworks, and public communications (AAMVA, 2018; ITF-OECD, 2018). They may want to integrate AV issues into their training for law enforcement, field crews, motor vehicle inspectors, and incident responders (Virginia Tech Transportation Institute, 2021).

4.3.3 Public Communication and Transparency

As AV deployment becomes more visible to the public, states may want to prepare public-facing AV dashboards or databases (California DMV, 2023). They may want to incorporate AV sensitivity into communications after incidents, including what occurred and what corrective actions are being taken, and they may want to engage in AV-focused dialogue with cities and local agencies (AAMVA, 2018; ITF-OECD, 2018).

4.3.4 Coordination with Other Governmental Agencies

Expanded ADS oversight would increase the importance of inter-agency coordination. State DOTs may want to be ready to interface on AV-related matters with federal agencies such as NHTSA (vehicle recalls and safety investigations), FHWA (roadway standards and digital infrastructure), the FCC (V2X communications), state public utility commissions (PUCs) overseeing robotaxi or commercial AV services, and neighboring states for freight and autonomous truck corridors (NHTSA, 2017; AAMVA, 2018; FHWA, 2025). This may require the development of shared protocols for investigations, data exchange, and regulatory compliance across agencies (AAMVA, 2018).

4.3.5 Prepare for Mixed Fleets: AVs and Human Drivers

Finally, regardless of the regulatory model adopted, states might want to adjust their rules and procedures to manage interactions between AVs and human-driven vehicles, including encounters with emergency vehicles, traffic stops involving driverless cars, and unusual behaviors such as cautious mergers or narrow gap acceptance (Virginia Tech Transportation Institute, 2021; AAMVA, 2018). AVs are also expected to affect congestion patterns and traffic flow, as well as introduce new operational considerations such as automated truck platoons on interstates (ITF-OECD, 2018). States may therefore want to update driver manuals, training materials, and human-driver-related laws and regulations to reflect mixed-fleet conditions.

4.4 Summary

In summary, from the perspective of a state such as North Carolina, a shift toward more elaborate ADS oversight would primarily expand the scope of operational governance and institutional readiness, rather than introduce technical certification responsibilities. This would involve strengthening authorization and oversight processes, enhancing incident response and data practices, coordinating across agencies and districts, and preparing infrastructure, staff, and public-facing processes to support ADS deployment under mixed-fleet conditions. At the same time, responsibilities such as validating ADS algorithms, certifying vehicle hardware or software, or conducting simulation-based safety testing would remain outside the expected role of state agencies, likely residing at the federal level or with manufacturers and developers.

Chapter 5. Implementation Plan

As with all NCDOT-sponsored research, there is an expectation that a plan for implementation of the results will be provided. In the case of this study, it seems that plan is far reaching. AVs will forever change the way in which NCDOT operates, from the driver and vehicle certification activities of its DMV to the way in which geometric design and construction activities are carried out. AVs will change the way in which the state's highway system functions and the way it interfaces with other systems like transit, aviation, and rail. There will be implications, likely unforeseen, that emerge as the use and operation of AVs increases.

This report could play an important role in helping NCDOT, and the state in general, determine how it wants to ensure the safety, enhanced mobility, and productivity of its citizens as the use of AVs becomes integrated into the fabric of daily life, for both personal and goods transport. The report presents paradigms the state could follow, from simple to more complex, in collaboration with the federal government, which, undoubtedly, will also play a major role.

Moreso than with the current world which relies on licensing for human drivers and physical inspection of vehicles, the complexity of AVs and their use of computer drivers will present challenges for national uniformity of performance certification subject to the wide variations in operating conditions that exist between and within states.

The research team anticipates that the DMV will use this document to deliberate about how "computer drivers" should be tested to ensure they meet state expectations for safe operation; and changes should be made in vehicle inspections. The report should stimulate thoughts about how these roles may be different for AVs and the partnerships that should be forged not only with the Federal government but partner states as well.

Highway designers may want to use the document to stimulate ideas about how AVs should be accommodated; and how their data input needs for safe operation might geometric design standards so the AVs, once certified for operation, do not encounter situations with which they face decision-making dilemmas. An alternate perspective is that NCDOT may want to determine what portions of the state highway network should be able to accommodate AV operation.

Upper level management is also likely to find value in this document because it will stimulate ideas about how the department needs to reshape its administrative structure, internally, and in its interfaces with other state agencies and federal and local (e.g., county and city) partners to ensure that the management of AV operation is seamless and unambiguous. The three models presented, for example, should stimulate discussions about what agencies (or divisions within NCDOT) should have what responsibilities and how those activities should be coordinated. Perhaps more than any other change that has occurred in the past several decades, the introduction of AVs will have a profound effect on how NCDOT operates and invests in its multi-modal transportation system. We hope this document will help that evolution be productive and efficient.

Chapter 6. Conclusions

This synthesis has examined how ADS, particularly SAE Level 4–5 vehicles, are authorized and overseen across U.S. states and compared these practices with emerging regulatory models abroad. Several findings are particularly relevant for North Carolina.

First, state governments play a central operational role in ADS governance, even in the absence of formal "certification" authority. Across the United States, states primarily regulate *operation rather than technology design*, using mechanisms such as registration, insurance requirements, self-certification statements, reporting obligations, and, in some cases, permit-based authorization. Federal oversight remains focused on vehicle design standards, recalls, and post-market enforcement, leaving operational governance largely to states.

Second, state ADS practices cluster into three distinct models: baseline legal compliance (Group 1), administrative self-certification (Group 2), and permit-based authorization (Group 3), with increasing regulatory workload and institutional complexity. North Carolina currently aligns with Group 1, relying on existing federal and state laws without AV-specific administrative programs. This approach minimizes administrative burden but may need refinement for proactive oversight as driverless operations expand.

Third, more elaborate regulatory models do not equate to technical certification, but rather to expanded operational governance. States that adopt Group 2 or Group 3 approaches emphasize clearer operational rules, formal authorization mechanisms, enhanced incident response, structured data access, and defined conditions for suspension or revocation. These measures focus on accountability, public safety, and transparency, rather than validating ADS algorithms or software performance.

Fourth, a transition toward more elaborate oversight would have institutional and planning implications for states, including North Carolina. Beyond authorization mechanisms, such a shift would require readiness in areas such as incident response, inter-agency coordination, public communication, workforce training, and integration of ADS considerations into planning and operations. These supporting capabilities are critical for sustaining oversight.

Finally, international experience provides an interesting context, although direct transferability may be limited. Global trends point toward scenario-based testing, ODD-specific authorization, safety cases, cybersecurity assurance, and lifecycle oversight. However, the U.S. regulatory structure, particularly the federal–state division of authority, means that states will continue to center on operational governance within a fragmented national framework, rather than adopting unified type-approval models used elsewhere.

Overall, the findings suggest that an important question for North Carolina is determining the appropriate level of operational oversight as deployment expands. The Group 1–Group 3 framework provides a practical lens for evaluating future options, balancing safety assurance, administrative capacity, and economic considerations, while remaining consistent with the state's institutional role and legal authority.

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Appendix A. Certification Practice in Various States

The tables below summarize how the reviewed states regulate AVs, particularly fully autonomous vehicles that are Level 4 and above.

Table A1-1: Practice in California and District of Columbia

Question Category	California (CA)	District of Columbia (DC)
A1. Certification model used?	Permit-based	Interim program; moving toward a formal permitting program.
A2. Certification specific to vehicle type?	Yes	Distinguishes between testing and deployment; currently requires in-vehicle safety operators. Focus on Level 3+.
A3. Tied to specific operational phases?	Yes; e.g., there are permits for Driver Pilot, Driverless Pilot, Phase I Driver Deployment, and Phase I Driverless Deployment.	Testing is allowed; deployment legislation and regulations are developing but not yet in place.
A4. Conditioned on ODD?	Yes; authorization is contingent upon the ODD certified.	Uses geofences; retains authority to order vehicles off the road for unique events (e.g., motorcades, inauguration).
B1. Which entity issues approval?	Two primary agencies: DMV and California Public Utilities Commission (CPUC). Authority from both is needed. DMV regulates the technology and vehicle and issues the prerequisite permits. CPUC regulates the commercial service of carrying passengers.	Department of Transportation (oversight moved from DMV).
B2. Role of state vs. local gov?	Regulation is primarily managed by state agencies; local agencies have very limited authority. Local agencies are seeking greater control.	City-state; direct control via Council/Mayor.
B3. Evidence typically required?	Vary with permit type but each has very detailed and comprehensive requirements; e.g., for a deployment permit, it includes (1) core prerequisites (DMV AV Manufacturer's Deployment Permit, prior 30-day testing on CA roads), (2) TCP Authority and Financial requirement, (3) operational and safety documentation (e.g., ODD, proof of training and licensing, passenger notice/consent, law Enforcement and collisions plan), and (4) driverless-specific requirements (e.g., passenger safety plan, Tier 4 advice letter).	Certified driving records for remote operators and training frameworks.

Question Category	California (CA)	District of Columbia (DC)
B4. When is re-certification required?	TCP Permit Renewal every three years. Operational updates (Material Changes) such as ODD updates, material modification, and adding shared rides.	Not mentioned.
B5. When can it be suspended?	Administrative failures, or for extended regulatory review.	Implicit authority to restrict road access for safety/security.
B6. Reporting requirements?	Vary with program types, but are all very extensive; e.g., CPUC requires all reports required by DMV (including collision reports, annual disengagement reports), quarterly reports, and Operational and Financial Reporting.	(Proposed) digital data via Mobility Data Specification (geofence monitoring).
C1. Certification portable across states?	Not addressed.	Not mentioned.
C2. Interaction with federal policy?	FMVSS and NHTSA rules.	Concerns regarding national security involving FBI and Homeland Security.
D1. Certified companies (examples)	Permit holders for driverless testing: Waymo; Tensor Auto; Zoox; R3 Nuro Robot; Apollo Autonomous Driving USA LLC; WeRide Corp DBA WeRide AI.	Waymo, Zoox.
Legislation references	Decision 20-11-046; California Code of Regulations, Title 13, Article 3.7.	D.C. Act 25-674. Autonomous Vehicle Testing Permit Requirement Second Emergency Amendment Act of 2024. D.C. Code § 50-2352.01.
Additional References	California Department of Motor Vehicles. (n.d.). Autonomous vehicle testing permit holders. https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-testing-permit-holders/	

Table A1-2: Practice in Pennsylvania and Texas

Question Category	Pennsylvania (PA)	Texas (TX)
A1. Certification model used?	Self-certification process with elaborate guidelines.	Authorization-based (state authorization/permit required for driverless AVs).
A2. Certification specific to vehicle type?	Applies to "Highly Automated Vehicles" (HAVs) defined as Levels 3-5.	Driverless AVs only (SAE L4–L5).

Question Category	Pennsylvania (PA)	Texas (TX)
A3. Tied to specific operational phases?	Approval is issued in perpetuity unless a material change occurs.	Authorization required prior to driverless public-road operation.
A4. Conditioned on ODD?	ODD is defined by developer; expansion requires re-application.	No state-defined ODD.
B1. Which entity issues approval?	PennDOT.	Texas Department of Motor Vehicles (TxDMV).
B2. Role of state vs. local gov?	Penn DOT is the sole authority for regulating Highly Automated Vehicles (HAVs) on public roads. Municipalities are prohibited from enacting their own regulations. HAV Advisory Committee includes state police and municipalities.	State maintains authorization authority. Texas law (SB 2205) explicitly prevents local governments from outlawing or regulating driverless vehicles.
B3. Evidence typically required?	Safety Management Plan (driver training, response procedures), insurance.	Authorization materials including safety documentation, insurance, recording device, emergency interaction info, FMVSS compliance.
B4. When is re-certification required?	Material changes (ODD expansion, vehicle type change, driverless transition).	No periodic re-certification; updates required within 30 days of material changes.
B5. When can it be suspended?	If a company operates outside the conditions of their self-certification.	Failure to update required info; failure to respond to TxDMV; unsafe operation endangering the public (with notice and opportunity to cure/review).
B6. Reporting requirements?	Crash reporting within 6 hours.	Standard crash reporting; additional reporting may be imposed via authorization conditions.
C1. Certification portable across states?	Inter-state portability is not mentioned, but PennDOT has the authority to negotiate one or more interstate agreements.	Not addressed.
C2. Interaction with federal policy?	Looks to federal reporting data (NHTSA) for crash context.	FMVSS and NHTSA definitions remain baseline.
D1. Certified companies (examples)	Waymo, Zoox, May Mobility.	
Legislation references	Pennsylvania Act 130 of 2022 (Automated Vehicles).	SB 2807; Senate Bill 2205.
Additional References	Pennsylvania Department of Transportation. (n.d.). Publication 950 (Pub 950) [Autonomous vehicle testing guidance]. https://www.pa.gov/content/dam/copapwp-	

Question Category	Pennsylvania (PA)	Texas (TX)
	pagov/en/penndot/documents/public/pubsforms/publications/pub%20950.pdf	

Table A1-3: Practice in Washington and Arizona

Question Category	Washington (WA)	Arizona (AZ)
A1. Certification model used?	Self-certification via the designated channels.	Submission-based via designated channels.
A2. Certification specific to vehicle type?	Applies to autonomous vehicles with automated driving systems (SAE Level 4/5) being tested or operated on public roads.	No. Requirement specified for fully autonomous vehicle (L4 or 5).
A3. Tied to specific operational phases?	Registration is required prior to any Level 4+/autonomous vehicle testing or operation.	No.
A4. Conditioned on ODD?	No state-level ODD specifications; self-certification focuses on ADS performance within its operational limits and compliance with state traffic law.	Implicit only. Operator self-attests safe operation and ability to reach minimal risk condition; no ODD review or approval.
B1. Which entity issues approval?	Washington Department of Licensing (DOL); DOL is designated as the exclusive state agency regulating AV operation.	State does not issue approvals. Department of Transportation and Department of Public Safety are the only state agencies that may implement or enforce laws and rules. ADOT is the primary regulatory body. ADOT manages and responds to the submission process and suspends or restricts operations. DPS develops and maintains the Law Enforcement Interaction Protocol and reviews a company's submitted interaction plan.
B2. Role of state vs. local gov?	DOL is designated as the exclusive state agency regulating AV operation. Any other state agency or local entity is prohibited from regulating or limiting the operation of AVs, automated driving systems, and on-demand AV networks.	ADOT and DPS are the only state agencies that may implement or enforce laws and rules. Local governments (counties, cities, or towns) are prohibited from imposing additional taxes, fees, or requirements on AV systems or operators.
B3. Evidence typically required?	Prior to operating: (1) submit to the State Patrol a law enforcement interaction plan, (2) submit to DOL proof of financial responsibility and the most recent voluntary self-assessment submitted to NHTSA, (3) until 12/31/2028, AV	Initial certification and submission requirements include 2 primary documents: (a) submit a law enforcement interaction plan to both DOT and DPS that is consistent with the Law Enforcement Interaction

Question Category	Washington (WA)	Arizona (AZ)
	operators must notify local law enforcement within 14 days of operation, providing owner contact info and a law enforcement interaction plan. During operation: maintain vehicle registration and title identifying the vehicle as an AV.	Protocol issued by DPS on May 14, 2018; and (b) submit a written statement to ADOT acknowledging that the AV (i) is in compliance with all federal laws and standards, (ii) will achieve minimal risk condition in failures, (iii) complies with traffic laws with a person responsible for traffic citations, and (iv) meets title, registration, licensing and insurance requirements.
B4. When is re-certification required?	Not specified, though mandating annual collision and moving violation report due each year by Feb. 1.	If ADOT determines a vehicle is likely not in safe mechanical condition, the owner must submit a "certification of correction or adjustment" explaining how the identified issues were addressed.
B5. When can it be suspended?	Not specified.	ADOT is required to suspend or restrict registration if a person fails to submit a certification of correction or if that certification is found to be inaccurate. Additionally, a cease and desist can be issued if the initial interaction plan is not submitted.
B6. Reporting requirements?	Until 2028, annual Autonomous Vehicle Collision Report covering reportable collisions and moving violations (due by Feb. 1) to the DOL and relevant municipalities. On-scene accident reporting remains mandatory.	In the event of a crash, the owner or the vehicle itself must promptly report it to law enforcement and provide the owner’s name, address, and the vehicle's registration number to affected parties.
C1. Certification portable across states?	Not mentioned.	Not applicable. No certification.
C2. Interaction with federal policy?	Require compliance with FMVSS standards, including reference to any exemption granted by NHTSA.	Vehicles must comply with all applicable federal motor vehicle safety standards and bear certification labels that include references to any exemptions granted by NHTSA.
D1. Certified companies (examples)	Examples listed by DOL: Waymo LLC, Zoox, Inc., and NVIDIA Corporation.	Waymo; Aurora; May Mobility; Beep.
Legislation references	SB 5594.	Arizona Revised Statutes (A.R.S.) §§ 28-9701 through 28-9702.
Additional References	Washington State Department of Licensing. (n.d.). Registering	Arizona State Legislature. (2021). Summary of S.B. 2813: Autonomous

Question Category	Washington (WA)	Arizona (AZ)
	autonomous vehicles. https://dol.wa.gov/vehicles-and-boats/vehicles/vehicle-registration/register-other-vehicles-and-other-services/registering-autonomous-vehicles	vehicle regulation. https://www.azleg.gov/legtext/55leg/1R/summary/S.2813TAT.DOCX.htm; Arizona Department of Transportation. (n.d.). Autonomous vehicles: Testing and operating without a driver. https://azdot.gov/autonomous-vehicles-testing-and-operating-without-driver; Arizona Department of Transportation, Motor Vehicle Division. (n.d.). Autonomous vehicles: Testing and operating in the state of Arizona. https://azdot.gov/mvd/services/professional-services/autonomous-vehicles-testing-and-operating-state-arizona

Table A1-4: Practice in Georgia and North Carolina

Question Category	Georgia (GA)	North Carolina (NC)
A1. Certification model used?	Self-certification.	Self-certification.
A2. Certification specific to vehicle type?	No specific requirements for vehicle type or use case.	ADS.
A3. Tied to specific operational phases?	No.	No.
A4. Conditioned on ODD?	No; ODD is defined by developer.	No state-defined ODD.
B1. Which entity issues approval?	Dept. of Revenue (registration, an AV should be registered as fully autonomous vehicles in Georgia lawfully registered outside of Georgia); Dept. of Public Safety (enforcement).	No authority-issued permit. Vehicles are required to have registration cards in the vehicle, and so the registration would be handled by the North Carolina Division of Motor Vehicles (NCDMV) although not explicitly clarified.
B2. Role of state vs. local gov?	DOT reviews concept plans on request. Encourages coordination with local cities/law enforcement. Georgia law prohibits the adoption of any new rules or regulations that would further limit the authority to operate fully autonomous vehicles beyond the requirements already established in the current Code.	No authority-issued permit. Local governments are prohibited from enacting laws related to AV operation.

Question Category	Georgia (GA)	North Carolina (NC)
B3. Evidence typically required?	(1) Manufacturer self-certifies that it is in compliance with FMVSS standards and Georgia laws, will perform legal duties after accidents, and achieve a minimal risk condition in failures. (2) Registered as an AV in GA (or in other states). (3) Acquire liability insurance or self-insurance (equivalent to the limits specified in Code Section 40-1-166).	(1) Manufacturer self-certifies that it is in compliance with FMVSS standards and state laws, will perform legal duties after accidents, and achieve a minimal risk condition in failures. (2) Registered as an AV in NC. (3) Acquire liability insurance per G.S. 20-279.21.
B4. When is re-certification required?	N/A.	Not mentioned.
B5. When can it be suspended?	N/A.	Not mentioned.
B6. Reporting requirements?	No.	No.
C1. Certification portable across states?	Yes; AVs lawfully registered in other states can operate in GA.	Not mentioned.
C2. Interaction with federal policy?	FMVSS.	FMVSS and NHTSA definitions remain baseline.
D1. Certified companies (examples)	Senate Bill 219 (SB 219).	
Legislation references		NC Session Law 2017-166 (House Bill 469), which enacted Article 18 of Chapter 20 (G.S. § 20-400 to 403).
Additional References	Yahoo Autos. (n.d.). Self-driving cars in Georgia: What you need to know. https://autos.yahoo.com/ev-and-future-tech/articles/self-driving-cars-ga-know-110000295.html; Georgia General Assembly. (n.d.). O.C.G.A. § 40-8-11: Autonomous vehicles. https://law.justia.com/codes/georgia/title-40/chapter-8/article-1/part-1/section-40-8-11/	

Table A1-5: Practice in Wyoming and Michigan

Question Category	Wyoming (WY)	Michigan (MI)
A1. Certification model used?	Voluntary notification; no state-led certification.	No permit system, but recognition and insurance proof are required by the secretary of state.
A2. Certification specific to vehicle type?	N/A, no certification requirement.	Yes.
A3. Tied to specific operational phases?	N/A.	For research or testing, also for "SAVE projects" (on-demand automated networks) and participating fleets.
A4. Conditioned on ODD?	No; vehicles must simply comply with standard road closures (wind/snow).	Implicit only. Operator self-attests safe operation and ability to reach minimal risk condition; no ODD review or approval.
B1. Which entity issues approval?	N/A.	The Secretary of State is responsible for recognizing "manufacturers of automated driving systems" and "upfitters," as well as receiving required proof of insurance.
B2. Role of state vs. local gov?	Voluntary state notification; locals may draft ordinances.	Undefined.
B3. Evidence typically required?	AV operators are encouraged to notify state DOT and Highway Patrol prior to entry.	Prior to research or testing, manufacturer or upfitter must be recognized and submit proof of insurance to the secretary of state. Proof of insurance is specified under chapter 31 of the insurance code of 1956.
B4. When is re-certification required?	N/A.	N/A.
B5. When can it be suspended?	N/A.	N/A.
B6. Reporting requirements?	No.	N/A; but encourages a close operating discussion with DOT and law enforcement.
C1. Certification portable across states?	N/A.	
C2. Interaction with federal policy?	Relies on guidance from national organizations like NHTSA and AMVA.	Requires non-automakers to pass FMVSS.
D1. Certified companies (examples)		

Question Category	Wyoming (WY)	Michigan (MI)
Legislation references		MCL: Section 257.665; MCL: Section 257.2b.
Additional References	N/A.	N/A.