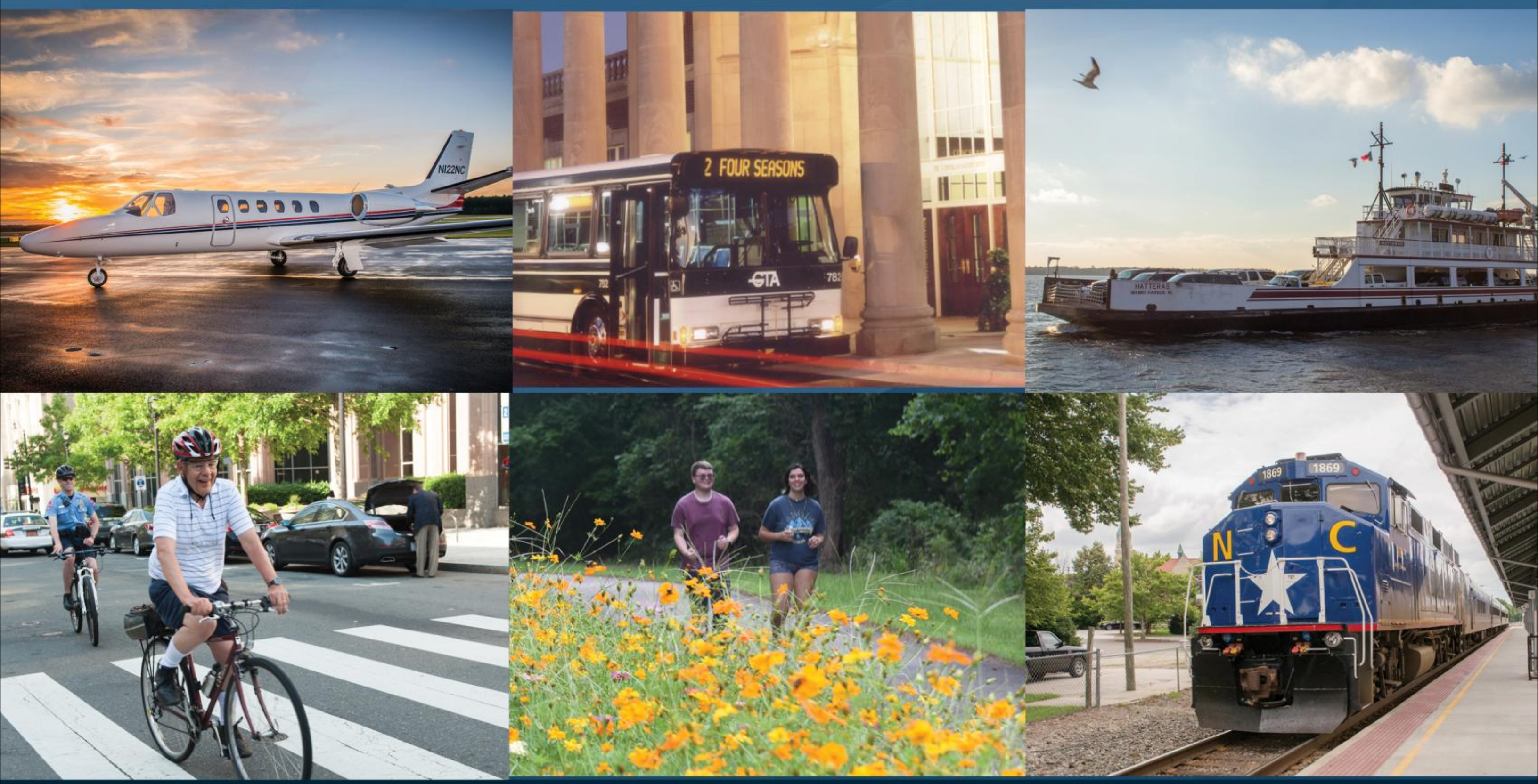
STATE DOT POLICY AND REGULATORY APPROACHES TO ROBOTAXI REMOTE OPERATION



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RESEARCH & DEVELOPMENT

State DOT Policy and Regulatory Approaches to Robotaxi Remote Operation

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16. Abstract
This report reviews the rapid growth of robotaxi services in the U.S. and the emerging role of remote operation in supporting the deployment of robotaxis. A technology scan was conducted to summarize current testing and deployments by major providers, including Waymo, Zoox, and Tesla, and highlight concepts such as remote monitoring, assistance, and, in rare cases, remote driving. The report also documents existing challenges with safety, traffic efficiency, and rider experience. To understand State DOT regulatory approaches, an online survey was conducted, yielding responses from 13 states and the District of Columbia. Findings show wide variations in definitions and oversight, limited remote-operation-specific requirements, and shared challenges related to limited expertise and resources, and operating constraints such as extreme weather and work zones.

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EXECUTIVE SUMMARY

This report examines how different states are approaching the regulation of robotaxis and the remote operation to support the service. As commercial robotaxi services expand, remote operation has emerged as an important operational layer for monitoring vehicles, assisting with unusual situations, and in some cases, enabling limited remote driving. For North Carolina, this creates a timely need to understand how other states are defining, overseeing, and preparing for these technologies to operate on the public roads.

The study combines a technology scan and literature review with an online survey of state Department of Transportation representatives. The technology scan found that companies such as Waymo, Zoox, and Tesla are advancing robotaxi deployment using different vehicle designs, sensing approaches, and remote operation setups. While these services show promise for expanding mobility, recent incidents and operational disruptions highlight continuing challenges related to safety, traffic, rider experience, communication reliability, cybersecurity, and the role of human operator oversight. The literature also suggests that remote operation raises unresolved questions about operator workload, qualification, liability, and system performance, while policy research remain limited.

Survey responses from agencies in 13 states and the District of Columbia revealed substantial variations in regulation approach. Some states have formal definitions and established oversight processes, while others have no specific regulatory framework for autonomous or remotely operated vehicles. Across states, few requirements were identified that are specific to remote operation. Insurance and liability are generally handled through existing legal structures, and human factors and technology requirements are often addressed only at a broad automated-vehicle level. Differential levels of readiness were also observed, with many agencies relying on federal guidance, peer exchange, and emerging standards while facing limited expertise and uncertain use cases.

Overall, the findings suggest that North Carolina could consider a phased approach. Next steps may include further understanding peer models, situating potential approaches with local context, clarifying terminology and agency roles, and developing guidance to support future robotaxi and remote operation oversight.

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Chapter 1. Introduction and Objectives

1.1 Background

Several companies are using highly automated vehicles in commercial taxi or ridesharing services in the United States. Waymo, Zoox, and Cruise have tested their robotaxis in select cities, with Tesla recently announcing its new vehicle and planned service. For Waymo robotaxis, services are offered in Arizona (Phoenix), California (Los Angeles, San Francisco), Florida (Miami), Texas (Austin), and Georgia (Atlanta), and are expanding to California (San Diego), Florida (Orlando), Michigan (Detroit), Nevada (Las Vegas), Tennessee (Nashville), Texas (Dallas, San Antonio), and Washington, D.C..

According to SAE J3016 (2021), robotaxis are classified as Level 4 (high automation), meaning the Automated Driving System (ADS) is expected to perform the entire Dynamic Driving Task (DDT) and the DDT fallback within its Operational Design Domain (ODD) without human intervention in normal operation. If the ADS cannot continue safely (e.g., a sensor failure or leaving its ODD), the system will bring the vehicle to a minimal risk condition (e.g., park-off-lane, or stop-in-lane).

While existing trials demonstrate the technical feasibility of driverless rideshare services and some public adoption, some difficulties with safety, traffic efficiency, and rider experience have been observed. For example, Cruise operations in San Francisco led to collisions and congestion, resulting in significant public dissatisfaction and pullback of business operation (Bellan, 2022; Valdes-Dapena, 2023). Others reported a vehicle getting confused with its path circling a parking lot and a lack of human support to intervene when harassment from other cars took place (Bonos, 2024; Bacon, 2025). Recently, reports of robotaxis' passing stopped school buses with extended stop arms have prompted an active National Transportation Safety Board (NTSB) investigation (Shepardson, 2026).

Further, while Level 4 is not fully driving automation, a remote operator as a safety driver or supervisor is often leveraged. Setups include remote operation centers, where trained remote drivers can monitor, assist, or even take control if a vehicle encounters an unanticipated hazard. Key considerations for the remote operation of automated vehicles include communications reliability, cybersecurity, and operator training.

To prepare for the arrival of robotaxis and ensure their safe operation on public roadways in North Carolina, there is a need to conduct an assessment of regulatory and policy needs for the North Carolina Department of Transportation (NCDOT). A first step is to understand the current robotaxi service and its remote operation, existing research on policy comparisons, as well as other states' current approaches to regulate robotaxi and the use of remote operation for robotaxi services.

1.2 Research Objective and Scope

This research investigates states' approaches to regulating robotaxis and the use of remote operations in robotaxi services. To support this objective, the study includes a technology scan of current robotaxi systems and remote operation practices, a literature review of related policy research, as well as an online survey of state agencies. The survey explores the current definition and operation modes, regulatory approach and oversight structure, safety, human factors, and technical requirements, as well as accountability and readiness. Specifically, the project focuses on the following sets of questions:

1. How does each state agency define autonomous, automated, or remotely operated vehicles, and does it formally distinguish remote operation modes?
2. What is the state's overall regulatory approach toward automated and remotely operated vehicles, and which agencies share oversight responsibilities?

3. What requirements apply to remote operating systems and remote operators in terms of training, qualification, and workload, and how interventions and communications are handled, and what are the minimum safety and operational expectations?

4. How are liability and insurance handled for robotaxi and remotely-operated-vehicle incidents, what steps are the agency taking to prepare for remote operation, what are the current challenges, and what additional resources and guidance are needed?

1.3 Research Approach

The research team used two main methods. First, a brief technology scan and literature review were conducted using publicly available online sources and academic databases to document the current state of robotaxi services, remote operation practices, and key policy and operational issues. Second, an online survey was conducted to gather information from state agencies on their regulatory approaches across the key topics identified, including definitions, oversight, technology and infrastructure, human factors, and insurance and liability.

1.4 Report Organization

The current report is organized into three chapters. Chapter 1 introduces the background, research objectives and scope, and approach. Chapter 2 presents the technology scan and literature review, including current robotaxi deployments, remote operation concepts and practices, and the limited literature on regulatory approaches. Chapter 3 summarizes the survey study and presents findings from agencies in 13 states and the District of Columbia.

Chapter 2. Technology Scan and Literature Review

2.1 Robotaxi

A robotaxi is regarded as a commercial ride-hailing service using vehicles that can drive without an in-vehicle human driver during normal operations, typically within a limited ODD such as specific cities, neighborhoods, roadway types, weather constraints, and time-of-day. In practice, robotaxi systems integrate automated driving software with a sensor suite that includes cameras, radar or lidar, detailed maps and positioning systems, as well as onboard computers to interpret the surroundings and plan actions, as well as built-in safety backups to handle problems safely.

Although Level 4 vehicles (SAE, 2021) do not require a human to drive in normal operation, remote operation in the form of remote monitoring, assistance, or even control is often discussed as a practical operational support layer (Bogdoll et al., 2022; California Code of Regulations §227.02; SAE, 2021). This support is especially considered for edge cases such as when the vehicle encounters an ambiguous road scene or needs help to get unstuck (Waymo, 2024a; Zoox, 2024a; Tesla, 2026).

In SAE International's definition of level of automation, "*Level 4 and 5 ADS-equipped vehicles that are designed to also accommodate operation by a driver (whether in-vehicle or remote) may allow a user to perform the DDT fallback, when circumstances allow this to be done safely, if s/he chooses to do so*" (SAE, 2021, page 11, note 4).

Similarly, NHTSA's report *Automated Driving Systems 2.0* notes that "*In vehicles where an ADS may be intended to operate without a human driver or even any human occupant, the remote dispatcher or central control authority, if such an entity exists, should be able to know the status of the ADS at all times*" (NHTSA, 2017, page 10).

In some states, such as California, regulations and guidance explicitly define and operate the concept of a remote operator, including expectations around supervision and communication (State of California Department of Motor Vehicles, 2026).

Together, these definitions and support concepts provide the context for understanding how robotaxi services are being tested and deployed and why remote operations are emerging as a common component of early deployments.

2.1.1 Current Testing and Deployments

As of January 2026, multiple companies have commercial and pre-commercial robotaxi activities across the US. The scope and operating conditions vary by company and authorities. The following subsections summarize major testing and deployment efforts.

Waymo

Waymo currently operates driverless robotaxi services in Atlanta, Austin, Los Angeles, Miami, Phoenix, and San Franscisco (Waymo, 2026; Figure 1). The technology pairs self-driving software with a sensory heavy approach using multiple cameras, lidars, radars, and audio receivers for perceiving the driving environment (Walz, 2024). It relies on high-resolution pre-mapping of roads and key roadway features (Allon, 2025). Together, the mapped geographical areas, driving conditions and road types define the vehicle's ODD (Waymo, 2017). In November 2025, Waymo announced expansion of service road types from local streets to freeways in select cities (Elias & Kolodny, 2025). When a vehicle encounters unusual situations, Waymo uses a "fleet response" function that remote operators can provide guidance and help coordinate recovery to enable the vehicle continuous operate (Waymo, 2024a).

Waymo is widely adopted in the cities where services are available with ridership estimated to have reached 450,000 weekly paid rides as of the end of 2025 (Wu & Bosa, 2025). Waymo has been regarded as exceptionally reliable (Federal Transit Administration, 2021; Lee, 2026), although incidents and service disruptions have occurred due to technical and operational challenges (Goodwin, 2025; Shepardson, 2026).

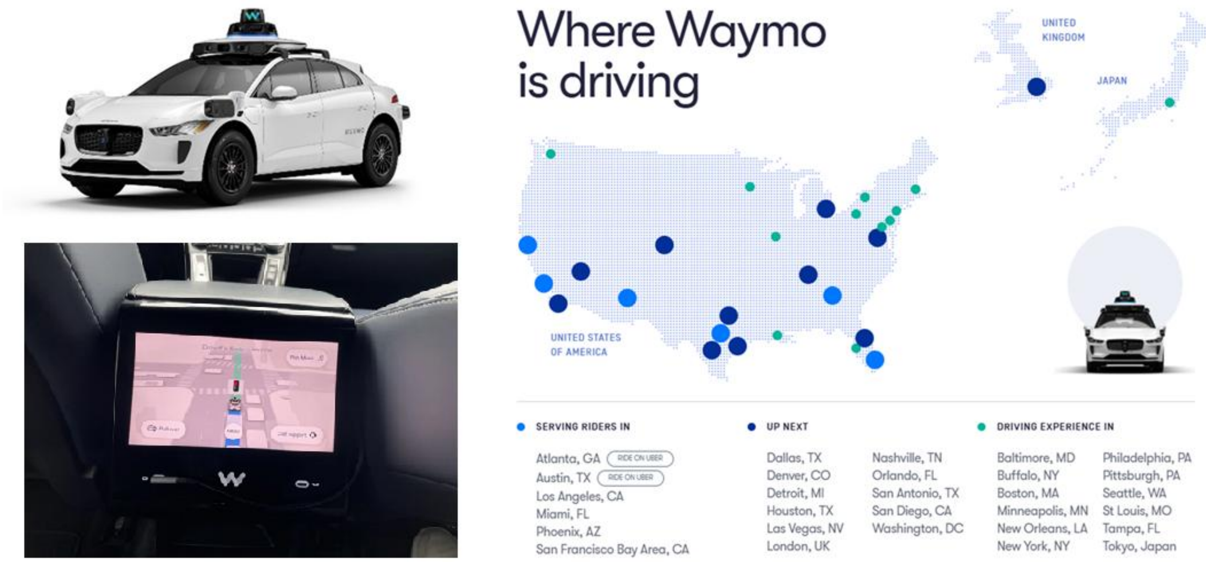

Figure 1.Waymo

(Top left) Waymo vehicle; (Bottom left) Rider in-vehicle display (Ludlow, 2023); (Right) Waymo's service coverage as of January 2026 (Waymo, 2026).

Zoox

Zoox is operating robotaxi fleets in Las Vegas and San Franscisco using its purpose-built vehicles designed specifically for ride-hailing, with services expanding to Austin and Miami (Zoox, 2025a). Media reporting indicates Zoox is testing in additional cities including Seattle, Los Angeles, Atlanta, and Washington, D.C. (Awan, 2025; O'Kane, 2025; Zukowski, 2025). The Zoox vehicles operate within geofenced service areas and operational conditions, and as noted by the company (2024b), expansion is planned to a larger geofence, higher speeds, more weather conditions, and nighttime driving. Inside the Zoox robotaxi, there is no steering wheel or driver's seat. The passengers will sit on limousine-style seats arranged in two rows. The vehicle relies on sensors including cameras, radar and lidar (Figure 2), and pre-mapping of roads. It is supported by connectivity and centralized operations for monitoring and exception handling. As described in public materials about remote assistance, Zoox uses the TeleGuidance system to provide remote assistance when a vehicle encounters a complex scenario. Through this system, remote operators can suggest a path or label objects (e.g., identifying an obstacle), allowing the vehicle to incorporate this as supplemental human sensor data and continue driving (Zoox, 2021, 2024a). Despite rapid progress in technology, there have been challenges with software and operation (Shepardson, 2024, 2025; Zoox, 2025b). For example, in 2025, Zoox recalled 332 vehicles after identifying an issue in its automated driving software that could lead to improper vehicle behavior, such as crossing the yellow centerline or entering an intersection and stopping in the path of oncoming traffic, which prompted the company to release a corrective software update (Shepardson, 2025; Zoox, 2025b).

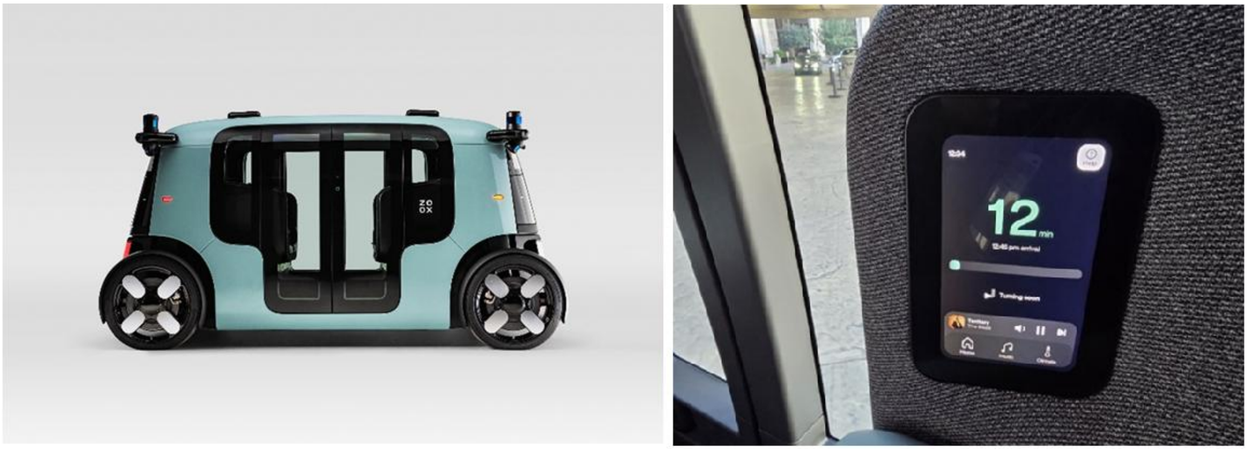

Figure 2. Zoox (Left) A Zoox vehicle; (Right) Zoox's rider in-vehicle display (Hak-jae, 2026).

Tesla

In 2025, Tesla launched early robotaxi operations in Austin with a human monitor seated in the front passenger seat of each vehicle to supervise operations and intervene when required (Shirouzu & Roy, 2025). Recently, in January 2026, reporting indicates Tesla began offering a limited number of rides with no in-vehicle safety monitor in Austin (Hawkins, 2026; Shimkus, 2026). The Tesla Robotaxi uses Model Y vehicles equipped with cameras and its software uses AI trained from large volumes of driving data. Although ODD information on exact boundaries and conditions are not fully public, existing service availabilities suggest operation is only within defined areas and weather conditions (Shirouzu & Roy, 2025; Ellie in Space, 2025). The operation does not seem to require detailed pre-mapping, while online discussion implies the possibility of training AI to memorize the roads and traffic rules (u/Investor3000, 2025). Information based on job posts (u/Diplomat33, 2025; Tesla, 2026) and rider experience (Dirty Tesla, 2025) suggests adoption of remote operation to handle "rare edge cases and challenging environments where human guidance is essential" (Tesla, 2026). On May 8, 2025, in a formal information request, NHTSA asked Tesla to provide a detailed description of its Robotaxi system's ODD, including geofencing, time-of-day, weather conditions, and speed restrictions, as well as how the system responds to ODD exits (NHTSA, 2025).

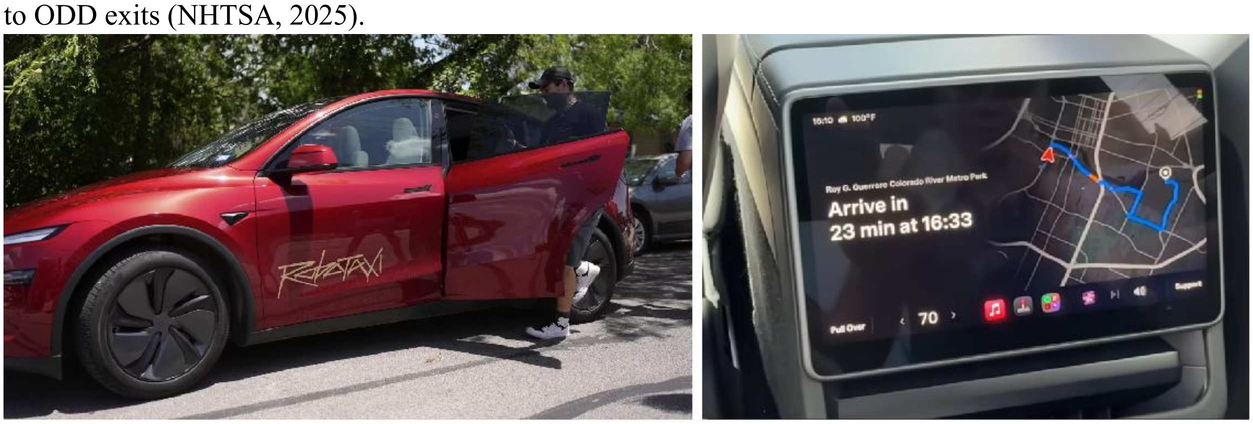

Figure 3. Tesla
(Left) A Tesla Robotaxi vehicle (Gay, 2025); (Right) Zoox's rider in-vehicle display (Hak-jae, 2026).

Lyft and Uber

Several other companies are enabling robotaxi service through technological and operational partnerships. For example, Lyft has started a small pilot through a partnership with May Mobility in midtown Atlanta with trained in-vehicle operators (Lyft, 2025). Uber is taking a similar approach by offering robotaxi rides via Waymo in Austin and Atlanta (Uber Investor, 2024) and has also announced plans for an exclusive robotaxi service using Lucid vehicles driven by the Nuro autonomy platform launching in 2026 (Nuro, 2026).

Figure 4 provides a list of current and upcoming robotaxi services in the United States from Carter (2025) shown below.

Robotaxi services in the US open to the public

CURRENTLY OPERATING	
City	**Operators**
San Francisco	Waymo, Tesla ride-hailing, Zoox via waitlist
Los Angeles	Waymo
Phoenix	Waymo
Austin, Texas	Waymo on Uber, Tesla robotaxi
Atlanta	Waymo on Uber, May Mobility on Lyft (with safety driver)
Dallas	Avride on Uber (with safety driver)
Las Vegas	Zoox
COMING 2026	
City	**Operators**
Miami	Waymo, Tesla
Dallas	Waymo, Tesla
Houston	Waymo, Tesla
San Antonio	Waymo
Orlando, Florida	Waymo
Washington DC	Waymo
Nashville, Tennessee	Waymo on Lyft
Las Vegas	Tesla
Phoenix	Tesla
San Francisco	Nuro/Lucid/Uber service
Los Angeles	Volkswagen on Uber

Figure 4. Robotaxi services in the US open to the public. Figure from Carter (2025). Here's where you can get a robotaxi in the US, and the cities they are coming to next.

2.1.2 Mobility Promises, Challenges, Rider Experience, and Public Opinion

Promises and challenges

Robotaxi services are often promoted to expand transportation access and potentially reduce travel costs for a wide range of users, particularly those who cannot drive or prefer not to (Keeney, 2019; Marshall, 2025). In comparison, Waymo's safety reporting indicates that its robotaxi operations have experienced lower crash and injury rates compared with human-driven vehicles (Waymo Safety Impact, 2025).

Despite encouraging statistics, recent incidents reveal that challenges remain with "edge cases" as robotaxi deployments scale.

Here are some examples.

Waymo:

- The U.S. National Transportation Safety Board opened an investigation in January 2026 after those vehicles were reported to have illegally passed stopped school buses at least 19 times since the school year begin, following a recent software recall affecting more than 3,000 vehicles intended to address this issue (Shepardson, 2026).
- In December 2025, a massive power outage in San Francisco led to Waymo pausing all service with reports of vehicles halted in the middle of city streets and intersections (Goodwin, 2025).

Zoox:

- One vehicle in autonomous operation was involved in a collision with a passenger car, and the software was subsequently updated to address the issue (Zoox, 2025b).
- Other software updates were reported to address unexpected braking, which has caused rear-end collisions (Shepardson, 2024; Bellan, 2025) as well as centerline crossing and stalling in front of oncoming traffic (Shepardson, 2025).

Tesla:

- From July to October 2025, eight incidents were reported for Tesla robotaxis operating in Austin, including collisions with other vehicles, a cyclist, an animal, and fixed objects (Lambert, 2025).

Rider experience and public opinion

A recent survey by Electric Vehicle Intelligence Report (EVIR, 2025) of more than 8,000 consumers found substantial uncertainty about robotaxis. Views on whether robotaxis should be legal were divided, with 32% respondents supporting legality, 20% unsure, and 48% opposing legality. Only 2% reported having ridden in a robotaxi. From the results, about half said they would ride again (1%) and half would not (1%). Given the respondents' limited firsthand experience, and that attitudes about vehicle automation can change with direct exposure (Feys et al., 2021; Liu & Xu, 2020; Zollick et al., 2019), these results should be interpreted cautiously. However, the respondents' hesitation reflects transportation safety concerns as robotaxis expand onto public roads and highlights the need for more consistent policy guidance and more effective public communication.

Among those who have ridden robotaxis, the reported experiences show a mix of excitement and occasional confusion. Many riders noted that trips feel smooth and normal (e.g., Field, 2024; Knizek, 2022; Reiss, 2025). At the same time, media coverage and user-posted videos document awkward non-collision events where vehicles pause, reroute, or appear to be stuck. For example, one ride turned into a vehicle repeatedly circling a parking lot while the passenger tried to reach support (Anguiano, 2025). More broadly, earlier robotaxi deployments (e.g., Cruise in San Francisco) generated rider complaints about vehicles stopping unexpectedly or blocking traffic (Bellan, 2022). These observations highlight that not only collision events, but also non-collision incidents can strongly shape public opinion.

2.1.3 Comparisons and Tracking

There have been several reports comparing Waymo, Zoox and Tesla robotaxis:

- Allon. G. (2025, September 29). Waymo, Zoox, and Tesla: Different approaches and operational implications of self-driving cars. Gas's Newsletter.
- Kolodny, L., Elias, J., & Palmer, A. (2025, December 16). Robotaxi in 2025: Waymo plots global expansion as Zoox and Tesla roll to the starting line. CNBC.

- Jetha. R. (2026, January 7). Waymo has the robotaxi lead. Tesla, Zoox and Uber are coming to the streets. The San Francisco Standard.

Wikipedia has detailed documentation of the history, technology, operational developments, and incidents of these service providers.

- Waymo Wikipedia page: https://en.wikipedia.org/wiki/Waymo
- Zoox Wikipedia page: https://en.wikipedia.org/wiki/Zoox
- Tesla Robotaxi Wikipedia page: https://en.wikipedia.org/wiki/Tesla_Robotaxi

In addition, Robotaxi Tracker (McKanna, 2026) is a real-time tracking tool that provides information on "real-time fleet data, trip logging, and analytics for robotaxis." An evolving list of robotaxi incidents based on NHTSA incident reporting is also available on the site.

2.2 Remote Operation

2.2.1 Definition and Framework

Remote operation

In the context of robotaxis, remote operation refers to using telecommunication to enable remote human operators from a distance to support a driverless vehicle as it may encounter uncertainty or an unusual situation (Lu et al., 2022; Zhang, 2020). It can serve as a critical fallback mechanism and interim solution to bridge the technical gap between current autonomous capabilities and full autonomy (Provost et al., 2025), as well as proactive operational support through human monitoring and intervention (Feng et al., 2026; Bogdoll et al., 2022). Combining the current practical frameworks (SAE, 2021; Bogdoll et al., 2022; British Standards Institution, 2024; DriveU.auto, 2025; California Code of Regulations §227.02), remote operation is categorized into three types:

(1) *remote monitoring*: a human operator monitors vehicle status and the environment,
(2) *remote assistance:* a human operator provides contextual information, verifies aspects of the driving environment (e.g., confirming that an object is an obstacle or that a road is closed), or suggests an action or a path to enable the vehicle to continue to drive,
(3) *remote driving*: a human operator remotely performs some or all of the driving task.

Remote operator

According to the California Code of Regulations (Title 13, § 227.02), a remote operator is defined as: "*A natural person who: possesses the proper class of license for the type of test vehicle being operated; is not seated in the driver's seat of the vehicle; engages and monitors the autonomous vehicle; is able to communicate with occupants in the vehicle through a communication link. A remote operator may also have the ability to perform the dynamic driving task for the vehicle or cause the vehicle to achieve a minimal risk condition.*"

2.2.2 Current Setups and Operations

Robotaxi service is typically enabled with pairing driverless vehicles with remote operation that can monitor fleet health and situations, provide guidance and assistance when the vehicle is uncertain, and in some rare cases, remotely drive in limited circumstances.

Waymo's Fleet Response (Waymo, 2024a; video 1; video 2)

When a usual road situation arises, the vehicle may contact a remote fleet response agent and ask targeted questions (e.g., "Is the emergency vehicle blocking all indicated lanes?"). The agent can review live and recent camera feeds and the vehicle's perception display, then respond by selecting preset answers. The vehicle may ask more questions until the situation is clarified. Through this communication, the agent can supply additional context and provide guidance, such as confirming lane closures, suggesting a specific lane, or even proposing a path, while the vehicle's automated system remains in control of driving (Figure 5).

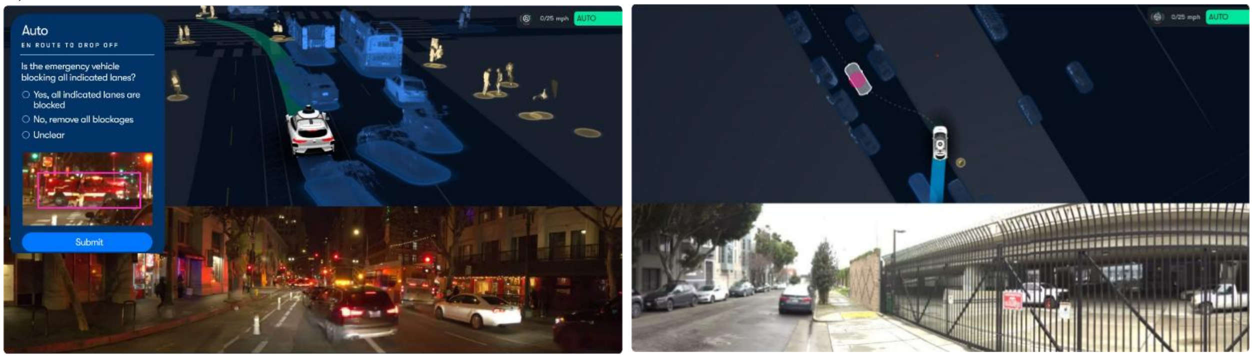

Figure 5. Waymo

(Left) Waymo's question-and-answer remote operation interface; (Right). Waymo's remote operator suggests alternative path by placing a waypoint (Waymo, 2024a).

Zoox's Mission Control, TeleGuidance and Rider Support ([Zoox, 2024a](); [video]())

Mission control operators oversee fleet operation holistically, monitor conditions within the ODD, and can proactively manage the fleet such as by rerouting vehicles around a large parade. When a vehicle encounters a scenario that requires human assistance, TeleGuidance operators can provide guidance by suggesting a path by placing waypoints or inputting human sensor data through labeling a specific object such as a stopped car as an obstacle (Figure 6). Under TeleGuidance, the automated driving system remains in control of vehicle movements and can also make decisions of whether and when to act on guidance. Rider support operators handle rider-facing monitoring and assistance by observing the cabin camera and conduct audio or text communication with the rider when needed, to provide ride status updates, troubleshoot issues, and assist during service disruptions.

Figure 6. Zoox

(Left) Zoox's remote operator suggests a path by placing waypoints; (Right). Zoox's remote operator labels a parked truck in front of the robotaxi as an obstacle (Zoox, 2024a).

Tesla Robotaxi's Teleoperation

There is not much formal information publicly available on how remote operation is performed for Tesla Robotaxis (Kirkham et al., 2025). However, through various sources like media reports (Sanghvi, 2025), job postings (Tesla, 2026), and rider experience (Dirty Tesla, 2025), remote operation is enabled to allow communication with a remote operator from inside the vehicle, and the remote operator can guide or take control of the vehicle. In a video posted by a rider in June 2025, the vehicle encountered an issue after the rider selected the “drop me off now” option, prompting safety driver to contact a remote operator to “resume the ride” (9:55). Tesla’s 2026 job posting (ID 253715) notes that “While our vehicles and robots are designed to operate fully autonomously, there are rare edge cases and challenging environments where human guidance is essential,” suggesting the use of remote operation to handle certain edge cases.

Baidu Apollo Go’s 5G-enabled teleoperation (Baidu, 2020; video)

Apollo Go robotaxis operate in China with planned expansions to Abu Dhabi and Switzerland. While Baidu takes a different remote operation approach than the American companies, their information is included in this technology scan. Their video and reports (Apollo Auto, 2020; Baidu, 2020, 2021) describe remote operation as remote adjustment and control via the 5G Remote Driving Service. A remote operator can press a button to transition between remote driving and autonomous driving.

Figure 7. Baidu Apollo

(Left) Baidu’s remote operation station; (Right). Baidu’s 5G Remote Driving with the autonomous system and the remote operator (Apollo Auto, 2020).

Depending on the type of remote operation, workstation setup can differ significantly. For example, remote monitoring may only require displays with limited control (Bogdoll et al., 2022). Remote assistance can utilize an intuitive touch screen or mouse input interface that allows an operator to answer questions, label objects, or place waypoints (Figure 8, left; Zoox, 2021). Remote driving would require a simulator-like set up with displays, a driving wheel, and pedals (Baidu, 2020). Many remote operators may be sharing the same physical workspace.

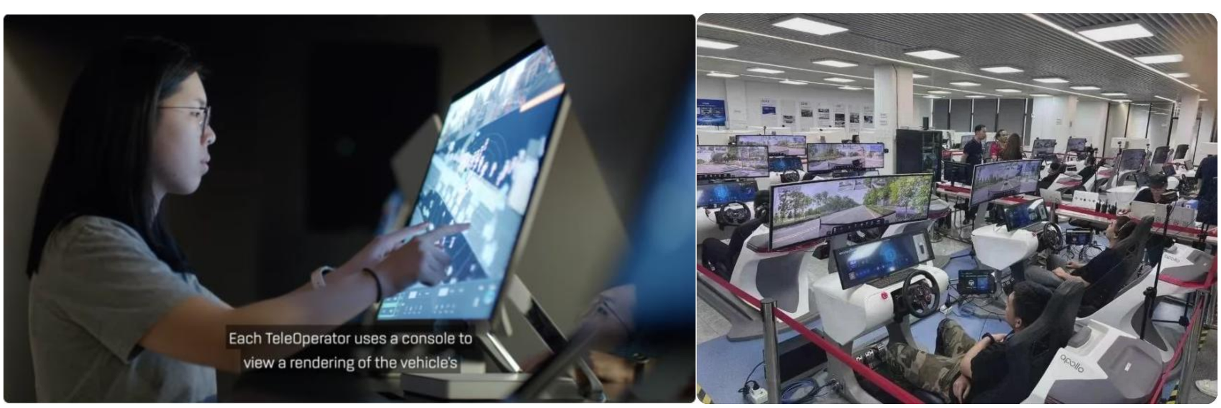

Figure 8. Zoox's and Baidu's remote operation station

(Left) Zoox’s remote operation station (Zoox, 2024a); (Right). Baidu’s remote operation center with many operators (Baidu, 2020).

2.2.3 Technological, Human Factors, and Operational Considerations

Remote operation for robotaxis, whether in the form of monitoring, assistance, or direct control, faces a number of technological challenges.

- **Telecommunication performance** (Neumeier et al., 2019; Podhurt, 2026; Zhang, 2020): Latency and jitter can delay video and control signals, while packet loss and bandwidth reduction can severely impair remote operators' situational awareness, thus making monitoring and guidance stale, and, even worse, making remote driving unsafe.
- **Cybersecurity** (NHTSA, 2022; Hodge et al., 2019): Because remote operation depends on continuous wireless communications, it expands the vehicle's cybersecurity vulnerability. The wireless communication link could be exploited to disrupt service or manipulate data used for operational decisions.

Remote operation poses many human factors challenges as highlighted by researchers, remote operation technology developers, and standards bodies (e.g., British Standards Institution, 2025; Feng et al., 2026; Kettwich et al., 2021; Tener & Lanir, 2022).

- **Remote operation interface** (Feng et al., 2026; Kettwich et al., 2021; Linkov & Vanžura, 2021; Tener & Lanir, 2022): Remote operators are physically separated from the roadway and must build situation awareness from camera feeds, without normal motion and sound cues. Interfaces should support timely perception and anticipation.
- **Operator workload and staffing** (Bogg & Birrell, 2025; Shoffner & Feng, 2024): Staffing should match the remote operation type and avoid overload or underload, since high demand increases errors while low-demand monitoring reduces vigilance. Studies suggest one operator can monitor multiple vehicles. Remote assistance and driving can be scaled better because fewer vehicles need help, but it requires strong queue management and clear intervention procedures.
- **Operator training and qualification** (British Standards Institution, 2025; California Code of Regulations, §227.02): California regulations require manufacturers to maintain a remote operator training program and ensure operators hold an appropriate driver's license.
- **Workspace and shifts**: The setup should minimize interruption and fatigue.

Remote operation also raises practical questions such as where remote operation centers should be located and how liability would be determined when incidents arise.

- **Remote operation center location**: Since remote operation is from a distance, placing centers far from the service area can raise concerns about telecommunication reliability and latency, cybersecurity, and whether operators have sufficient familiarity with local roads and rules.
- **Complex liability**: Remote operation complicates liability as responsibility may be shared among the remote operator, the robotaxi service provider, the automated driving system developer, and the vehicle manufacturer.

2.3 Limited Literature on Regulatory Approaches

Regulatory approaches for the remote operation in robotaxi services remains under examined, largely because deployments are still limited in select jurisdictions. The limited literature points to key considerations. From a general automated vehicle perspective, Cohen & Cavoli (2018) emphasizes regulation in connection with congestion, accessibility, and enforcement challenges. More specifically on remote operation, recent studies highlight unresolved needs around legal accountability, operator training and qualifications, fatigue management, liability during active remote driving, standards and coordination protocol for remote assistance, rider trust, and remote operation center scaling (Goodall, 2020; Hoffman & Prause, 2023; Li et al., 2024; Rudin et al., 2025). No comparative study yet exists, and remote operation oversight also carries major labor implications alongside safety and security considerations.

3 Chapter 3. Survey Study of State DOT Regulatory Approaches

In November 2025, the research team conducted an online survey to examine state DOT policies on the remote operation of automated vehicles (AVs). A summary of the survey study, including the participants, survey questions, and findings, is provided in the following.

3.1 Participants and Recruitment

With fanatical support from NCDOT, the survey was sent to over eighty state DOT representatives across all fifty states and received a total of fifteen responses from thirteen states and one district (Figure 9).

3.2 Survey Questions

Survey questions were organized into five sections: (1) definition and scope, (2) regulation and oversight, (3) technology and infrastructure, (4) human factors, and (5) insurance and liability. The survey questions are listed in the appendix. The survey was administered using Qualtrics.

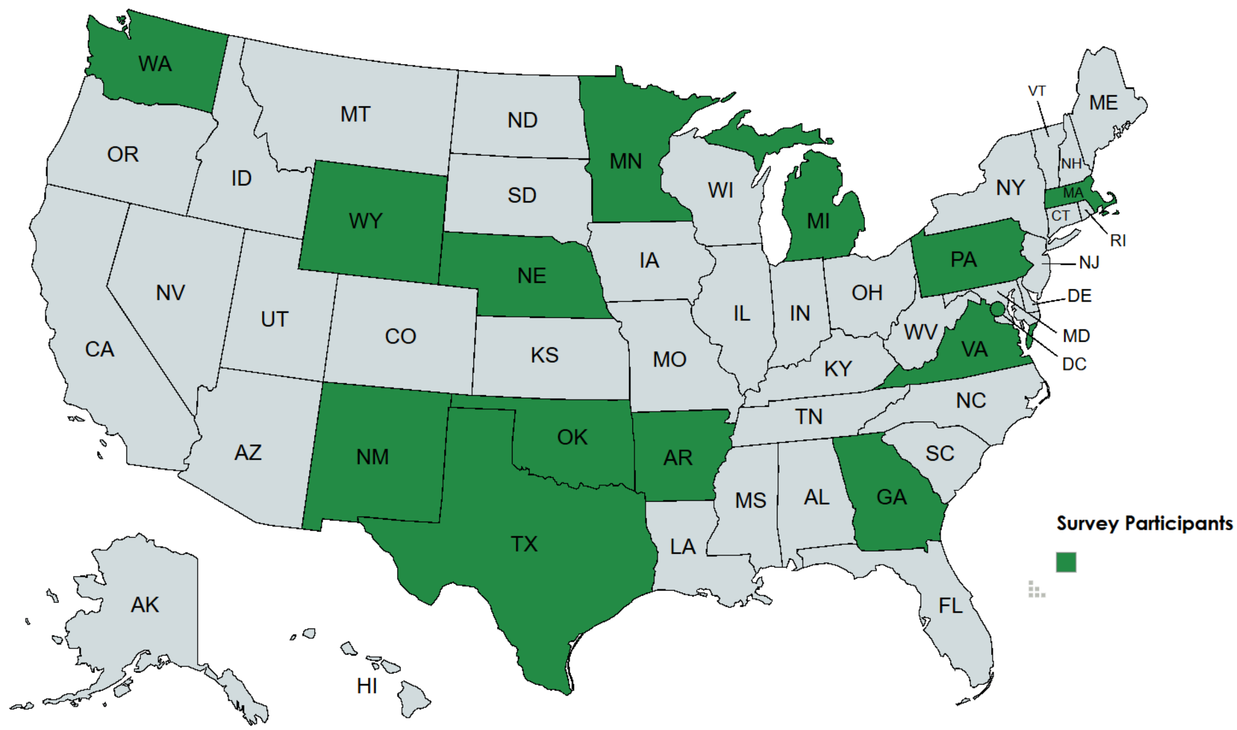

Figure 9. DOT representatives survey participants. DOT representatives from 14 States and District (Washington State, Wyoming, Nebraska, Minnesota, Michigan, Massachusetts, Pennsylvania, Virginia, District of Columbia, Georgia, Arkansas, Oklahoma, Texas, and New Mexico).

3.3 Findings

Highlights:

- **Varying definitions:** State agencies vary in how they define AVs and remote operations, with some establishing rigorous sub-categories while others operate without official policy definitions.
- **Diverse regulatory oversight:** Oversight ranges from permissive "no notification" policies to stringent programs requiring permits and data reporting.

- **Standardized insurance and liability:** States currently apply existing human-driver insurance and liability laws rather than creating unique requirements for remote systems.
- **General human factors guidelines:** Regulations regarding operator workload and fatigue typically apply to AV operators in general without specific provision for remote operation.
- **Limited infrastructure requirements:** Cybersecurity and connectivity requirements are usually addressed through broad safety plans instead of remote-operation-specific mandates.
- **Readiness and challenges:** The readiness of state DOTs varies for remote operations, with some states citing reliance on federal and international standards while facing challenges with limited expertise and access to resources, unclear use cases, latency constraints, and extreme weather and work zones.

Below are more detailed descriptions of findings from each section of questions.

(1) **Definitions and Scope** asked about whether and how the respondent's agency defined autonomous vehicles, remote operation, and types of remote operation. States varied from having no official policy definitions for either automation or remote operation to having rigorous definitions for both. Texas and Virginia formally distinguished sub-categories of remote operation. Notably, Virginia considers remote assistance a separate category from teleoperation altogether.

(2) **Regulation and Oversight** asked the state's overall approach to regulating autonomous vehicles and the organizations sharing oversight of them. Degree of regulation varied from permissive approaches, including no specific regulation for AVs, let alone remotely operated ones, to stringent programs requiring permitting and routine data reports. For instance, in Georgia, there is no requirement for service providers to notify or coordinate with the state DOT prior to testing. Other states, such as Pennsylvania, have a permitting process and a requirement for periodic data reporting from testing organizations.

(3) **Insurance and Liability** asked about insurance requirements pertaining to remotely operated AVs, as well as the allocation of liability among remote operators, technology developers, and service providers. Although some states mentioned unique insurance requirements for autonomous vehicles, there were no unique requirements for remotely operated AVs. For other state DOTs, respondents were unsure how to answer or reported that remote operators would follow the same insurance requirements as in-vehicle human drivers.

(4) **Human Factors** asked about considerations given to the remote operators, such as the management of workload, fatigue, as well as handoff procedures. There were no regulations mentioned that specifically pertained to AV remote operators as such. Of the respondents who provided regulations, those regulations pertained to AV operators in general. For instance, the Massachusetts DOT mentioned a requirement that a test driver must not exceed 8 hours of work in a 24-hour period. When asked about how handoffs should be controlled, there were no state-specific requirements provided by any of the respondents for AV remote operation; the most stringent requirement was for OEMs to discuss the disengagement process within their Safety Management Plan. Several other states mentioned that their DOT either had no specific requirement or such a requirement was outside their scope of authority.

(5) **Technology and Infrastructure** asked about requirements pertaining to safety, connectivity, and cybersecurity, as well as the agency's access to performance data (e.g., crash reports, intervention frequency). As before, respondents reported no unique requirements pertaining to AV remote operation, although some mentioned AV-specific requirements for safety plans that would, in principle, encompass remote operation. Requirements for data reporting ranged from undefined to explicit requirements for crash data reports or routine data reports.

Finally, DOT representatives were asked three additional high-level questions regarding steps their DOT is making to prepare for remote operation, resources they have relied on to inform their policy, and challenges they face in preparation. There was again considerable variation in their stances, ranging from “wait-and-see” to having already established a policy concerning teleoperation. Others mentioned ongoing projects or work groups actively discussing AV testing and deployment. Resources included guidance from the U.S. Department of Transportation, SAE, and ISO, discussions with peer states, and research. Several states mentioned no resources as their agency has not taken an oversight stance. Shared challenges included the lack of expertise on remote operation, the absence of use cases, technological constraints such as latency, and tolerance for unique conditions such as extreme weather and work zones.

Chapter 4. The Next Step and Recommendations

The research team is conducting follow-up interviews with state representatives who agreed to participate to further gain insights into the current and evolving state DOT policies around the remote operation of automated vehicles. These interviews will provide added context to the survey findings by clarifying how states interpret key concepts, structure oversight responsibilities, and respond to emerging operational, legal, and technical issues. They are also expected to reveal lessons learned, implementation challenges, and areas where additional guidance, standards, or interagency coordination may be needed.

Based on the findings of this study, NCDOT could consider a phased implementation approach to prepare for future robotaxi deployment and remote operation in North Carolina. In the near term, this could include building internal capacity to track policy models in other states, compare then with North Carolina's context, and use those lessons to inform its approach. This phase could also include establishing common terminology, clarify agency roles, and reviewing whether current regulations, permitting processes, and reporting requirements are adequate for robotaxi services that use remote operation. In the medium term, efforts can further expand to developing guidance on operator qualifications, communications reliability, incident reporting, cybersecurity, and coordination with law enforcement and emergency responders.

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Appendix A. The State DOT's Regulator Approach Survey

Introduction

We invite your input on your agency's current and emerging approaches to the oversight of teleoperated* vehicles (vehicles operated remotely by human drivers). Our aim is to understand how state agencies are developing policy in preparation for the teleoperation of automated vehicles on public roads.

For each question, feel free to respond at a length that you deem appropriate. While these questions ask about the current regulations and policies in your state, we also encourage you to discuss prospective or anticipated policies, as well as professional views that are shared within your agency on what effective regulation, oversight, and preparation might look like. However, please refrain from sharing your personal thoughts, feelings, or opinions that are unique to yourself and not necessarily representative of your agency.

Definitions and Scope

1. How does your agency currently define or distinguish between autonomous, automated, and teleoperated vehicles?

2. How does your agency currently define or distinguish between different modes of teleoperation (e.g., remote monitoring, assistance, and direct control)?

    2a. If your agency has used formal definitions or guidance documents, please provide references and web addresses for the resources if available.

Regulation and Oversight

3. Please describe your state's overall approach to regulating the teleoperation of automated vehicles (e.g., tight vs. loose oversight/regulation, wait-and-see approach).

4. Which state or federal agencies share responsibility for oversight, and how are those roles divided?

Insurance & Liability

5. How is liability allocated among teleoperators, technology developers, and transportation service providers in your state?

6. How does insurance address incidents involving teleoperated vehicles in your state?

Human Factors

7. What qualifications, training, or workload limits apply to remote human operators in your state?

8. How should teleoperation systems control handoffs to remote human operators or communicate status to passengers and other road users?

Technology & Infrastructure

9. What are the minimum safety, connectivity, or cybersecurity requirements applicable to teleoperated vehicle systems in your state?

10. How are agencies expected or enabled to access and evaluate teleoperation performance data (e.g., crash reports, intervention frequency, signal latency)?

Future Outlook

11. What steps is your agency taking now to prepare for the teleoperation of automated vehicles in your state?

12. What are the main challenges your agency has encountered in preparing for (or during) the teleoperation of automated vehicles in your state?

13. What resources or guidance (federal, interagency, or research) has your agency identified as necessary for planning for the teleoperation of automated vehicles in your state? Please provide references and web addresses for the resources or guidance if available.

Administrative

14. What state does your agency represent?

15. What is your position or title within your agency?

16. Would you be willing to participate in a virtual follow-up interview discussing these topics in more detail?

17. Please provide an email address so that we may contact you to schedule an interview.

*Note: At the early stage of this research, the research team used the terms "teleoperation" and "remote operation" interchangeably. Later, to reduce confusion and maintain consistency, the research team decided to solely use "remote operation." Therefore, "teleoperation" appears in the survey as shown here because it was used in some questions. In the report, "remote operation" refers to the focus of this research, and "teleoperation" was only used if it is in the conventional name of a specific technology.