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Status and Challenges of Level 3 Automated Driving Systems

• Lesheng Hua (PhD) • Jacobo Antona-Makoshi (PhD)
• Luke Neurauter

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EXECUTIVE SUMMARY

This report presents an assessment of the current state of SAE Level 3 (L3) Automated Driving Systems (ADS), highlighting key global regulatory developments, market deployments, and public attitudes, while critically examining the latest safety-relevant scientific evidence and its implications for system design, human interaction, and the continued evolution and deployment of these technologies.

L3 Regulatory Landscape

- The international regulatory framework governing L3 automation has significantly evolved, marked by substantial developments under the United Nations Economic Commission for Europe (UNECE). Regulation R157 on Automated Lane Keeping Systems (ALKS), initially limited to low-speed (60 km/h) and longitudinal-only scenarios, has expanded its scope to cover higher speeds (130 km/h) and lateral maneuvers, including lane changes. This regulatory shift allows for broader operational conditions and supports greater system capabilities but can also bring additional safety challenges.
- In parallel, UNECE is developing a comprehensive regulatory framework for ADS that will impact L3 systems. It includes requirements for *Safety Case* development and *Safety Management Systems*, along with post-deployment reporting obligations. This marks a shift toward more rigorous safety assurance and lifecycle risk management, emphasizing data collection and analysis after deployment. It will also shape the design of pre-deployment research studies and establish clearer expectations for how companies document, monitor, and communicate safety-related information both internally and to regulators or the public.
- In comparison to the UNECE regulations, the United States does not have a federal regulation for ADS, so voluntary industry standards developed by organizations such as ISO and SAE can be expected to play a critical role in guiding system development and informing potential future regulation. For L3 systems, these standards provide essential frameworks for functional safety (e.g., ISO 26262), safety of the intended functionality—SOTIF (ISO 21448), scenario-based testing (ISO 34502), safety case (e.g., TS5083, UL4600), or human-machine interface (HMI) design (e.g., ISO 15007, SAE J3134) to name a few. While this report does not provide a detailed technical review of the relevant standards, it offers a high-level overview of these key standards to support developers and safety professionals in gaining awareness and aligning their research, design, and deployment strategies with current best practices.

Commercially Available L3 Systems

- At the time of writing this report, three companies have commercialized L3 systems: Honda in Japan, Mercedes-Benz in both Germany and select U.S. states, and BMW in Germany. These implementations vary in their supported operational design domains, warning escalation protocols, HMI strategies, and driver monitoring systems. This report provides a detailed comparative analysis of these commercially available systems, focusing on their domain limitations, fallback mechanisms, HMI design, and the degree of driver engagement and awareness. These early deployments offer valuable insights into the practical implementation challenges and design trade-offs shaping the next generation of L3 systems.

L3 Trust and Acceptance

- Research shows that user exposure to L3 systems enhances trust and acceptance, highlighting the value of education and hands-on experience. Trust is shaped by constructs like credibility, reliability, and intimacy, while perceived self-interest can undermine it. Design elements—especially HMI and system behavior—play a key role in influencing user perception. While technical credibility and reliability can be engineered, subtle design cues can affect user confidence and acceptance. This report reviews ongoing L3-specific research on how these human factors interact and how trust on the systems may be strengthened.

L3 HMI

- HMI considerations remain central to L3 safety research, system design, and deployment. HMIs not only convey critical information but also influence user behavior, trust, and readiness to retake control. This report draws on L3-specific user studies and empirical findings to present evidence-based recommendations, emphasizing intuitiveness and minimal cognitive load. The evaluation includes comparative analyses of color schemes, symbol comprehension, message timing, and feedback strategies that can contribute to safer and more effective user interaction.
- A set of recommendations for HMI design include multimodal message (visual, auditory, haptic); continuous system status and anticipatory information; alert intensity and cascade without being a hindrance, distraction, or annoyance to drive; a complete and comprehensive information set; and adjustable amount and complexity of displayed information.
- Mercedes-Benz and BMW vehicles equipped with L3 systems use turquoise lighting on the steering wheel and integrate turquoise-colored marker lights into the vehicle's front and rear lights, consistently with SAE J3134. These implementations reflect a growing effort toward the standardization of visual signals for automated driving.

L3 Transition of Control

- Previous studies suggested that a takeover time of around 7 seconds may allow for safe driver intervention, and UNECE Regulation R157 requires L3 systems to provide at least 10 seconds for the transition of control to ensure optimal performance. However, transitions from automation to human drivers are inherently complex and context dependent. When drivers are engaged in low-cognitive-load, non-driving-related tasks (NDRTs), 10 seconds often provide a sufficient buffer for resuming control. In contrast, high-complexity scenarios—such as sudden obstacles, urban driving, or high-cognitive-load or deeply distracting NDRTs—may demand longer response times.
- There is no universally accepted threshold for safe takeover time. Given the variability in driver readiness, effective transition criteria must remain adaptive, considering the driving environment, the driver's cognitive state, and the nature of the NDRTs. Continued research is essential—not only to refine time thresholds but also to better

understand and enhance the quality of driver responses during transitions, ensuring interventions are both timely and safe across diverse conditions.

L3 Situation Awareness

- In the driving context, the driver's situation awareness is defined as an updated and meaningful understanding of events in the surrounding environment, essential for monitoring traffic and navigating safely. Longer periods of traffic monitoring and more distributed visual attention have been linked to improved overall situational awareness.
- The drivers' situation awareness is a critical factor in takeover performance, functioning both as a key metric and a causal explanation for failures to safely resume control. Understanding how situation awareness interacts with reaction times, and how different warning signals influence this dynamic, is essential for identifying when and where specific signals are most effective, ultimately supporting safer transitions during takeover requests.
- Engagement in NDRTs diverts attention from the driving environment, leading to "out-of-the-loop" issues and potentially impairing the driver's ability to take over control. Further research is needed to examine how the cognitive load of NDRTs affects situation awareness during engagement and to identify effective strategies for enhancing situation awareness in the context of L3 automated driving.

L3 Reasonably Foreseeable Misuse

- L3 systems are designed with the assumption that drivers understand the system's operation, remain alert, and are prepared to take over when needed. However, real-world behavior often contradicts this assumption, with a high likelihood of misuse. Examples include failure to respond to takeover requests, overreliance on system capabilities, or complete disengagement from the driving task. Studies incorporated in this report have documented alarming misuse behaviors, such as sleeping, leaving the driver's seat, or driving under the influence, which are clear deviations from intended use.
- Misuse may result from several factors, including lack of situation awareness, poor trust calibration, over trust and complacency, overestimation of system capabilities, and mode confusion. Cognitive issues such as false recognition, misjudgment, and out-of-the-loop problems also contribute. L3 system developers and regulators should anticipate, to the extent possible, foreseeable misuse scenarios as part of system design and safety assessment. To support this, future research should aim to identify root causes of misuse and evaluate effective mitigation strategies. Standardized frameworks, such as ISO's Safety of the Intended Functionality, have recently been updated to incorporate reasonably foreseeable misuse into safety evaluations and can help guide the safe and responsible deployment of L3 systems.

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ADS	Automated Driving System
ALKS	automated lane keeping systems
HMI	human-machine interface
ODD	operational design domain
TOR	take-over request
NDRT	non-driving-related task
SOTIF	safety of the intended functionality
UNECE	United Nations Economic Commission for Europe

The American Society of Automotive Engineers (SAE J3016, 2014) divides the level of vehicle automation into six levels: No Automation (L0), Driver Assistance (L1), Partial Automation (L2), Conditional Automation (L3), High Automation (L4), and Full Automation (L5).

CHAPTER 1. BACKGROUND AND AIMS

SAE Level (L2) systems are currently offered by most vehicle manufacturers worldwide—global sales reached 11.2 million vehicles equipped with these systems in 2020 and have continued to grow (Canalys, 2021; Pangarkar, 2025). L2 systems initially offered simultaneous steering and acceleration/braking support while requiring full driver supervision and constant driver attention. These systems first targeted highway driving environments, incorporating features such as lane centering and adaptive cruise control. By 2023, L2 systems had evolved to support hands-off driving under certain conditions and were broadly deployed across major OEMs —including Audi (Traffic Jam Assist), BMW (Highway Assistant), Ford (BlueCruise), General Motors (Super Cruise), Hyundai (Autonomous Driving Package), and Tesla (Autopilot). Global sales of vehicles equipped with this advanced type of L2 systems reached approximately 2 million units in 2023, with projections to double to 4.5 million units by 2024 (Liu & Low, 2023), reflecting a clear and accelerating push toward higher levels of driving automation.

At the higher end of the driving automation spectrum, both U.S. and Chinese companies have emerged as frontrunners in the development and deployment of Level 4 (L4) systems. Since the early 2000s in the U.S., major technology and automotive firms such as Google (Waymo), Uber, Apple, Zoox, and the now-defunct Argo AI and Cruise, spearheaded efforts to develop L4 systems and to launch driverless ride-hailing services. This innovation push was enabled by over 20 states allowing the testing of L4 systems on public roads (Othman, 2021). A major milestone occurred in July 2023 when San Francisco authorities authorized large-scale driverless operations by Cruise and Waymo. However, Cruise soon faced public backlash following incidents involving crashes with an emergency vehicle and a pedestrian (ABC7 News Bay Area, 2023; Golson, 2023), leading to the revocation of its permit in October 2023 (Washington Post, 2023). This setback severely impacted Cruise's position, while Waymo strengthened its lead in the U.S. robotaxi market (Tim, 2023). Meanwhile, China has made comparable strides. Baidu's Apollo Go became the first service approved to offer fully driverless, paid robotaxi rides in Wuhan and Chongqing in 2022 (PR Newswire, 2024) and later expanded to Shenzhen in 2023 with a commercial license covering 188 square kilometers (PR Newswire, 2023). By early 2025, Apollo Go had transitioned to fully autonomous services in several urban areas, accumulating over 130 million kilometers of driverless operation (Technology Magazine, 2025). Today, robotaxi fleets without human drivers are actively operating in both the U.S. and China, led by services such as Waymo and Apollo Go.

While traditional automotive manufacturers have been driving the widespread deployment of L2 systems, technology companies have led the development and deployment of L4 services. Amidst these parallel advances, significant developments have also occurred in Level 3 (L3) conditional driving automation systems. L3 systems can fully drive the vehicle under limited and defined conditions, and the driver must be ready to take back control of the system whenever requested. The first-ever United Nations regulation for L3 low-speed Automated Lane Keeping Systems (ALKS) was adopted in 2020 (UNECE, 2021) and was later modified to increase speeds and incorporate lane change capabilities (UNECE, 2022). Following these regulatory milestones, Honda launched the world's first commercially available L3 system, "Honda Sensing Elite," in Japan in 2021 (Beresford, 2021). Mercedes-Benz subsequently launched its L3 Drive Pilot system in Germany in 2022 (Mercedes-Benz Group, n.d.), followed by BMW, which introduced its own L3 system in the German market in 2024 (BMW Group, 2023). As of April 2025, Mercedes-Benz remains the only company offering an L3 system in the U.S. that legally allows drivers to take their eyes off the road under specific conditions, with approvals limited to California and Nevada. Currently, L3 Drive Pilot is available exclusively on the S-Class and EQS models and operates only under defined conditions such as heavy highway traffic at speeds up to 40 mph. Despite uncertainties about market readiness and potentially unresolved safety challenges, vehicle manufacturers are poised to make critical advancements in L3 technology over the next decade, with broader deployment and enhanced system capabilities anticipated.

L3 systems are expected to provide safety improvements by reducing driver errors and minimizing crash risks, as well as other benefits like enhancing convenience, comfort, and efficiency. However, their deployment is not only dependent on technological capability but also a matter of public confidence in Automated Driving Systems (ADS; Autocrypt, 2023). Currently, little is known about the real-world safety performance of L3 systems or their roles in collisions. Failure or low performance of systems can undermine public trust and confidence. The Dutch Safety Board (2019) identified several persistent issues in L3 systems: human factor problems (driver overestimation, misunderstanding, and misuse); systems activated in situations that they cannot cope with; a lack of transparency regarding the design, capabilities, and effectiveness of these systems; questions about regulatory oversight; over-the-air update functionality; and the adequacy of driver training. The Insurance Institute for Highway Safety (IIHS, 2019) highlighted the issue of drivers misinterpreting system messages, particularly when the messages are unclear or misleading. System developers and regulators must collaboratively address these human-centered challenges and enhance the design, implementation, and oversight of L3 systems to ensure safe and reliable user interaction.

The aim of this report is to provide a comprehensive assessment of the status and complexities of L3 systems at the global level. To accomplish this, we compiled information from various publicly available sources, summarizing the international regulations, market offerings, and public acceptance of L3 systems (Chapter 2). Following this overview, we conducted a deep review of critical research issues, including safety challenges, system design, human factors, driver interactions with the systems, and areas with room for system safety improvement (Chapter 3). A discussion of these findings is provided in Chapter 4, followed by a set of final recommendations for L3 researchers, developers, and regulators in Chapter 5. The scope of the report focuses primarily on light motor vehicles and L3 systems, though references to other automation levels and vehicle types are included where relevant.

CHAPTER 2. L3 SYSTEMS OVERVIEW

This chapter provides a high-level overview of the international regulatory and industry standardization landscape, commercial availability, and public acceptance of L3 systems.

2.1. APPLICABLE REGULATIONS AND INDUSTRY STANDARDS

In Contracting Parties to the 1958 Agreement under the United Nations Economic Commission for Europe (UNECE) framework (i.e., countries that have formally agreed to apply UN vehicle regulations), L3 systems are now subject to international regulations that govern safety, design, and technical performance. In contrast to countries that follow UNECE regulations, the deployment of L3 systems in the U.S. heavily depends on state or other regional regulations (Song, 2022).

UNECE R157 is a United Nations technical regulation designed to support the deployment of L3 autonomous technology on public roads, subject to national legislation. This regulation concerns the approval of vehicles equipped with ALKS. ALKS are a component of L3 systems, enabling a vehicle to maintain lane centering automatically while keeping a safe distance from other vehicles. The ALKS regulation covers the various conditions necessary for driving automation and the performance standards. The UNECE R157 recently introduced an update to raise speeds up to 130 km/h on highways and to incorporate lane changes. This shift from the previous 60 km/h limit and longitudinal-only control is a significant development that aligns with global efforts to push for an expansion of L3 systems but can also bring additional safety challenges.

At the time of writing this report, UNECE is actively developing a draft regulation aimed at addressing ADS at L3 and higher (UNECE, 2025). This upcoming regulation marks a significant step forward by proposing a more holistic and systems-based framework for the approval and oversight of higher levels of vehicle automation. The regulation will address higher traffic complexity, including dynamic operational design domains (ODDs), interactions in mixed traffic, urban roads and mixed road users. Notably, it incorporates foundational concepts such as Safety Management Systems and Safety Case approaches, which shift the regulatory focus from prescriptive technical requirements to the demonstration of robust organizational and operational safety assurance processes. The document has also incorporated references to the Safety of the Intended Functionality (SOTIF) framework, which is expected to contribute to addressing misuse. These mechanisms are expected to enhance the industry's ability to manage the complexities and dynamic risks associated with conditional automation, while also providing regulators with structured evidence of safety justifications throughout the vehicle lifecycle. The integration of such frameworks signals a maturing regulatory landscape that aligns more closely with the principles of continuous improvement and proactive risk management essential for L3 deployment at scale.

Industry standards, such as those developed by the International Organization for Standardization (ISO) and the SAE, are voluntary by nature and do not carry the force of law. However, they play a critical role in influencing regulatory frameworks and industry practices, often serving as benchmarks for compliance and product development. Figure 1 presents a schematic illustrating several examples of ADS safety-related industry standards. The standards shown are either currently under development or have been recently published. Each row represents a different level of driving automation, while the columns represent various safety-related domains. L3, which is the focus of this report, is highlighted in bold. For example, ISO provides a foundation for safety assurance through a series of standards, including functional safety (ISO 26262), safety of the intended functionality (ISO 21448), scenario-based test validation (ISO 34502), and safety case development (ISO TS 5083). SAE, UL, and IEEE also offer best practices and standards that may complement, or in some cases, overlap with ISO standards. Examples include SAE AVSC0001-2023-08 on safety criteria, IEEE P2846 on safety metrics, UL4600 on Safety Case, or SAE J3320 on Safety Management Systems. Others, such as SAE J3134 on ADS marker lamps, can support the use of external indicators for ADS. Additionally, ISO 15007 on driver visual behavior and analysis can inform L3 HMI design and assessment strategies.

A summary of some of the most relevant standards is provided below. While an in-depth analysis of these standards is beyond the scope of this report, developers of L3 systems and safety assurance professionals are encouraged to consult the original regulatory texts and supporting guidance documents to support their research, development, and deployment of such systems.

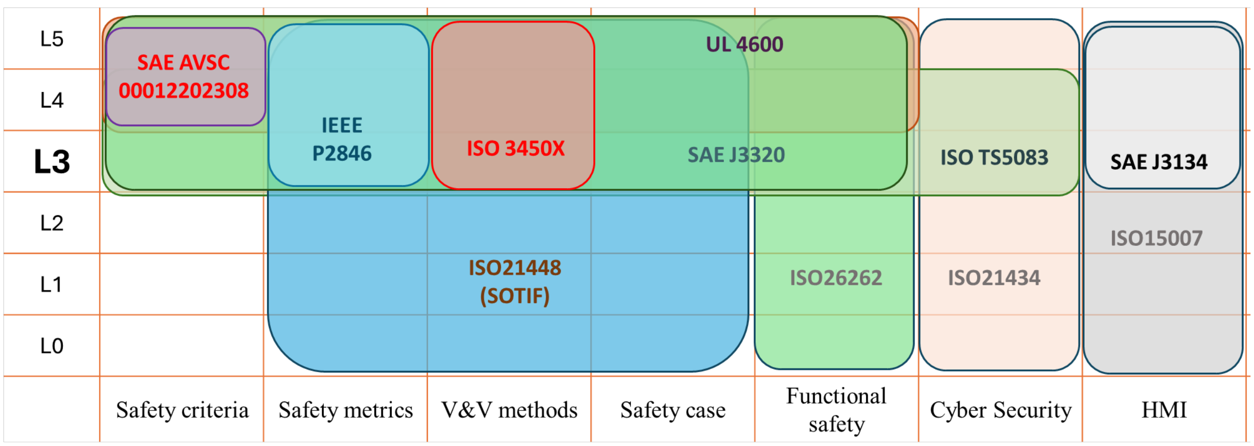

Figure 1. Diagram. ADS safety-relevant industry standards map.

SAE AVSC0001:2023-08 – *Best Practice for Developing ADS Safety Performance Thresholds Based on Human Driving Behavior* – Provides guidance for ADS developers to establish safety performance thresholds by leveraging human driving data, aiming to define safe and competent driving behaviors for ADS-dedicated vehicles.

UL 4600 – *Standard for Safety for the Evaluation of Autonomous Products* – Establishes safety principles, lifecycle risk management, and safety case development guidelines for fully autonomous systems, focusing on the validation of their behavior in the absence of human control.

IEEE P2846 – *Draft Standard for Assumptions for Models in Safety-Related Automated Vehicle Behavior* – Defines a minimum set of reasonable assumptions and foreseeable scenarios to be considered when developing safety-related models used in ADS behavior decision-making, supporting transparency and comparability in system validation.

ISO 3450X Series – *Road Vehicles: Test Scenarios for Automated Driving Systems* – Provides a structured framework for defining terminology, logical scenarios, and concrete test cases to evaluate the behavior and safety of ADS across various operational contexts.

SAE J3320 – *Safety Management System (SMS) Application to SAE Level 3, 4, 5 ADS-Equipped Vehicles and Supporting Systems* – Outlines principles and processes for implementing a safety management system throughout the lifecycle of SAE Level 3–5 ADS-equipped vehicles, including development, deployment, and decommissioning phases (SAE, 2023b).

ISO/TS 5083:2025 – *Road Vehicles: Safety for Automated Driving Systems – Design, Verification and Validation* – Offers recommendations to support the safe development of ADS, covering design, verification, validation, and post-deployment processes necessary to achieve and demonstrate system safety.

ISO 21448:2022 – *Road Vehicles: Safety of the Intended Functionality (SOTIF)* – Addresses potential hazards arising from functional limitations or misuse of road vehicle systems in the absence of hardware or software faults, particularly relevant for driver assistance and automation systems.

ISO 26262 – *Road Vehicles: Functional Safety* – Specifies requirements for ensuring functional safety in the design and lifecycle of electrical and electronic systems in road vehicles, covering hazard analysis, risk assessment, and mitigation strategies across all vehicle development phases.

ISO/SAE 21434:2021 – *Road Vehicles: Cybersecurity Engineering* – Establishes a comprehensive cybersecurity framework for the lifecycle of road vehicle systems, from concept and development to operation and decommissioning, with the goal of mitigating cybersecurity threats and vulnerabilities.

ISO/TR 21959-2:2020 – *Road Vehicles: Human Performance and State in the Context of Automated Driving – Part 2: Considerations in Designing Experiments to Investigate Transition Processes* – Provides guidance for designing experiments to study the human response during control transitions from ADS to manual driving, focusing on performance metrics and test environment variables.

ISO 15007:2020 – *Road Vehicles: Measurement and Analysis of Driver Visual Behaviour with Respect to Transport Information and Control Systems* – Establishes standardized terms and metrics for evaluating driver visual behavior, particularly glance activity, with guidance for both field and simulation-based assessments of interaction with in-vehicle systems.

2.2. COMMERCIALLY AVAILABLE L3 SYSTEMS

In Japan, Honda became the first automaker in the world to sell an approved L3 system: Honda Sensing Elite's Traffic Jam Pilot (Beresford, 2021). This system can drive the vehicle in congested traffic or on highways without requiring the driver to pay attention or keep their hands on the steering wheel. When the proper traffic conditions are met, the Traffic Jam Pilot can be activated by pressing a button located on the right side of the steering wheel, near the right-hand thumb (Figure 2). Upon activation, indicator lights on both sides of the steering wheel's center illuminate. Additional indicator lights appear on the upper part of the navigation screen, and the glovebox also lights blue. When a handover is required, all indicator lights turn orange and begin blinking to signal the driver to take control.

The system activates in heavy congestion, often when speeds drop below 30 km/h, and continues to operate until speed exceeds around 50 km/h, at which point it may prompt the driver to take over. When the system issues an escalating takeover request (TOR) under conditions such as clearing traffic or changing weather, there is no fixed time limit or grace period for the driver to respond. If the driver still does not respond to the request, the vehicle will initiate an emergency stop, making lane changes to the outermost lane or road shoulder when there is a road shoulder. A driver-monitoring camera, mounted on the far side of the center stack's screen, assesses facial orientation, eye openness, and physical movements to determine the driver's ability to respond to handover requests (Honda Motor Co., Ltd, n.d.).

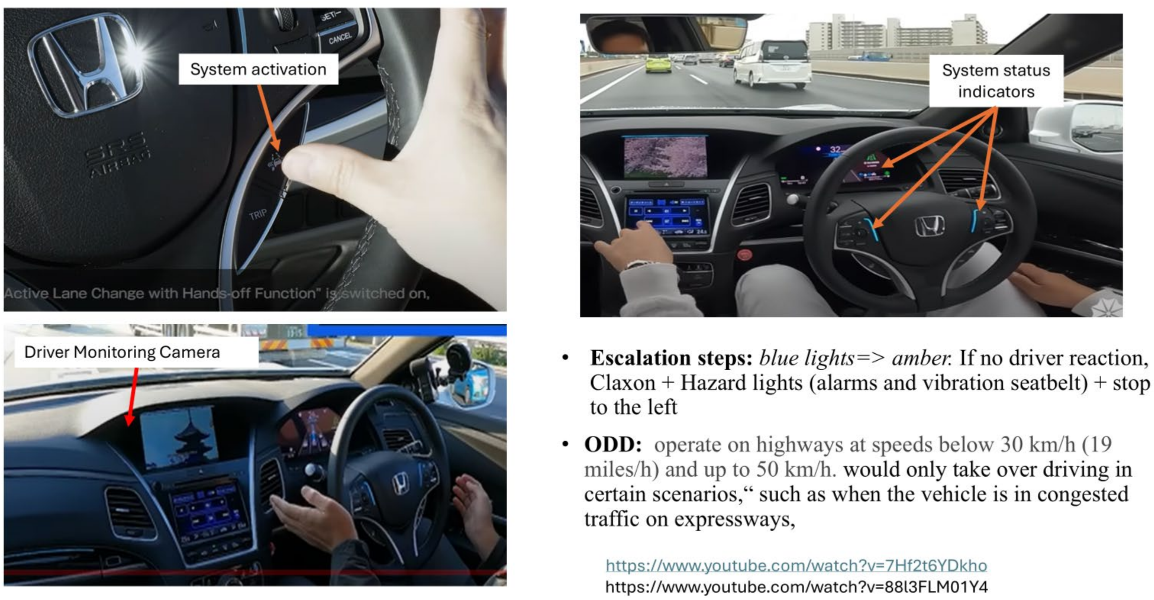

Figure 2. Photos. Honda Legend Traffic Jam Pilot.

According to available online information (AUTOCRYPT, 2023), Mercedes-Benz's "Drive Pilot" met the demanding legal requirements of UNECE Regulation R157 and received approval to release its L3 system in Germany. Additionally, it also received permission for commercialization in the U.S, after a period of testing in Nevada at speeds of up to 40 mph. This system allows for hands-off automated driving in traffic at speeds up to 60 km/h on German motorways and launched in Germany earlier in 2022. To activate the system, the driver presses one of the two identical hard buttons with the system's logo, located at the 10 and 2 o'clock positions on the inner part of the steering wheel rim. The buttons feature slim light strips (Figure 3). Upon activation, the gauge cluster displays a confirmation message indicating that the system is engaged, and the steering wheel rim and column lights illuminate in turquoise to provide visual feedback (Golson, 2023). According to SAE Recommended Practice J3134, turquoise marker lights on the exterior of the vehicle, such as headlights, taillights, and side mirrors, signal to other road users that the L3 system is active. This suggests that Mercedes aligns its internal human-machine interface (HMI) lighting with the external color-coding recommendations outlined in the standard.

The amount of time a human driver has to regain control of the vehicle varies across current L3 systems. The applicable SAE International standard specifies only "at least several seconds." In practice, the Drive Pilot is currently the only commercialized L3 system that explicitly provides a 10-second takeover window for the driver when issuing a takeover request, consistent with UNECE Regulation R157. When a takeover request is issued, a message appears on both the instrument cluster and infotainment screen, accompanied by red lights on the steering wheel, seatbelt tightening, and an audible chime. If the driver does not respond within 10 seconds, the vehicle will activate its hazard lights, come to a full stop in its current lane, and contact emergency services. It currently does not have the capability to automatically pull over to the shoulder or emergency lane. A camera mounted on the upper part of the driver's instrument panel detects the driver's head and both eyes.

Figure 3. Photos. Mercedes-Benz (EQS) Drive Pilot.

BMW was the first automaker worldwide to gain type approval for a system that integrates both an L2 system (the BMW Highway Assistant) and an L3 system (BMW Personal Pilot L3) within the same vehicle (BMW group, 2024). This innovation makes the new BMW 7 Series a milestone in automated driving, providing a unique opportunity to experience the advantages of both systems in a single vehicle. These systems have been available in some of the BMW 7 Series vehicles since March 2024.

To activate the L3 function, the driver must press the designated button located on the left -hand side of the steering wheel (Figure 4). Upon activation and successful transfer of vehicle control, the system notifies the driver that driving responsibility has been assumed. This transition is visually confirmed by turquoise LEDs embedded along both sides of the steering wheel rim. If the driver fails to respond appropriately, the vehicle initiates a controlled in-lane stop and has no shoulder pullover capability. A driver monitoring system (DMS), including a camera positioned in the upper part of the instrument cluster, continuously assesses the driver's alertness, seating position, and seatbelt usage to determine takeover readiness (Bimmer life, 2024). The system combines multiple engagement sensors (e.g., hands-on detection sensor in the steering wheel, steering torque sensor, and pedal position sensors) with video-based tiredness detection to track eye opening, head position, and facial geometry to detect fatigue and engagement conditions.

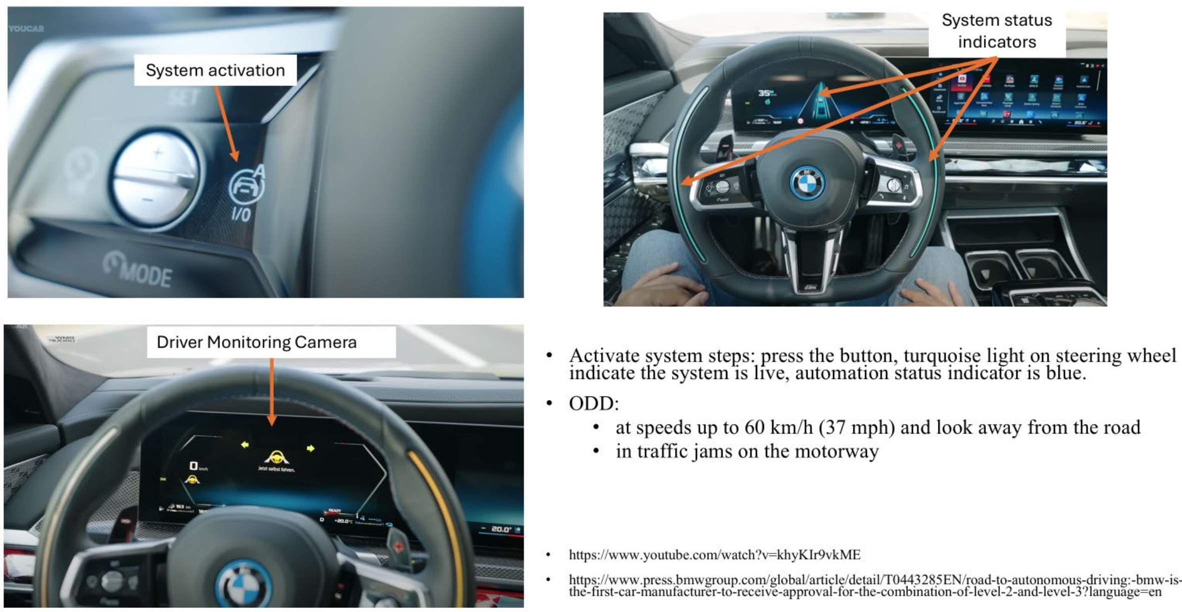

Figure 4. Photos. BMW 7 Series Personal Pilot L3.

The key features of the current three L3 systems are summarized in Table 1. The comparison indicates that these systems are specifically tailored to traffic jam scenarios, likely comply with the UNECE R157 10-second take over time rule, and perform in-lane controlled stop with hazard lights. Honda appears to offer the most conservative deployment. Mercedes-Benz provides the most mature and feature-complete system, with regulatory approval in multiple regions. BMW takes a balanced approach, focusing on premium experience with strong driver monitoring.

Table 1. Summary of three L3 systems.

Feature	Honda Traffic Jam Pilot	Mercedes-Benz Drive Pilot	BMW Personal Pilot L3
Market Availability	Japan only (2021)	Germany (2022), U.S. (California and Nevada from 2023–24)	Germany only (2024)
Model Introduced	Honda Legend Hybrid EX	S-Class, EQS	7 Series (G70), i7
Operational Speed Limit	Up to 50 km/h (31 mph)	Up to 60 km/h (37 mph)	Up to 60 km/h (37 mph)
Road Type	Divided highways in Japan	Pre-mapped, divided highways (Germany, U.S.)	Pre-mapped, divided highways (Germany only)
Takeover Time	Not officially disclosed (estimated 5–10 s)	Up to 10 s (UNECE R157 Rev.1 compliant)	Likely up to 10 s (not officially stated)

Feature	Honda Traffic Jam Pilot	Mercedes-Benz Drive Pilot	BMW Personal Pilot L3
Driver Monitoring	Camera central cluster; must be present; mounted on the far side of the center stack's screen	Eye-tracking DMS (must be awake and visible); mounted on the upper part of the driver's instrument panel	Eye-tracking DMS; must face forward; mounted on the upper part of the driver's instrument panel
Fallback Maneuver	In-lane emergency stop, making lane change to outermost lane or shoulder when there is a road shoulder	In-lane stop with hazard lights and e-call	In-lane stop with hazard lights
External Indicators	None	Turquoise marker lights (legal in CA/NV)	None
System Activation	Auto-activation during congestion	Manual activation via steering wheel buttons	Manual activation via steering wheel button
Activation button	Located on the right side of the steering wheel, near the right-hand thumb	Two identical hard buttons with the system's logo, located at the 10 and 2 o'clock positions on the inner part of the steering wheel rim	Located on the left side of the steering wheel

More manufacturers are expected to adopt L3 systems in the near future. Major OEMs—including Hyundai-Kia, Stellantis, BMW, GM, and Honda—continue to report progress and plans for L3 deployment (AUTOCRYPT, 2023). According to a 2024 report by ResearchInChina, China implemented several policies in 2023 to legally permit L3 and L4 vehicles on public roads. These regulatory advancements are expected to usher in a new phase of competition in intelligent driving. To date, nine automotive brands—Deepal, Avatr, Seres, IM, Mercedes-Benz, BMW, Arcfox, BYD, and GAC—have officially announced that they have obtained licenses to test L3 vehicles on Chinese roads.

2.3. PUBLIC ACCEPTANCE

As major automakers continue developing L3 systems, the industry is steadily progressing toward a future where vehicles can handle complex driving scenarios with minimal human intervention. These systems represent a pivotal shift in automotive technology, allowing drivers to disengage from active control under specific conditions. However, public acceptance of L3 systems hinges on a range of concerns related to safety, liability, trust, and the transition from driver-centric to automated driving. Uncertainty about how reliably these systems perform in unpredictable real-world environments and how well they communicate with drivers contributes to cautious consumer attitude. In particular, if vehicles equipped with an L3 system are involved in an accident, it is unknown whether the system was actively engaged at the time of each incident. News of such accidents can raise public and customers' safety concerns. According to the National Highway Traffic Safety Administration's ADS crash data through June 13, 2025, there are no recorded accidents in the U.S. involving L3 systems like Mercedes-Benz Drive Pilot or BMW Personal Pilot in public crash reports. The reported ADS crashes may be from L2 or L4 test fleets in operation within the U.S. Addressing these concerns will be critical to achieving widespread adoption of L3 technology

In 2015, the Boston Consulting Group and the world Economic Forum conducted a survey dedicated to automated driving among more than 5,500 consumers in 10 countries (2016).

Results showed that half of all consumers do not feel safe in automated vehicles. Consumer trust in traditional automakers regarding automated vehicles was higher in France, Germany, and Japan. Notably, safety and the ability of automated vehicles to avoid mistakes are among the top concerns of people. As automation technology advances, convincing the public of the safety and reliability of automated vehicles will be a challenge for manufacturers. It is expected that the acceptance of automated vehicles will increase over time.

Similarly, AAA's annual automatic vehicle survey in 2019 found that 71% of people fear to drive in highly automated driving vehicles (Edmonds, 2019). The primary reasons for such fears included a lack of trust in technology, reluctance to give up driving completely, and concerns that existing road conditions may not support automation technology. To address these concerns, several factors have been identified as crucial for increasing consumer confidence in automated vehicles (Pangarkar, 2025). These include offering personally testing the automation function to build trust, introducing stronger regulations for automated vehicles, providing more information on the technology, and increasing media coverage of automated vehicle developments. Together, these factors highlight the key consideration that consumers' views are essential for fostering acceptance in automated vehicle technology.

Annually, J.D. Power, in collaboration with the Partnership for Automated Vehicle Education and the Massachusetts Institute of Technology, conducts a survey utilizing the Mobility Confidence Index to measure current public sentiment and readiness to accept automated driving technologies in the U.S. The 2022 and the 2023 reports (J.D. Power, 2022; J.D. Power, 2023) showed that driver assistance and partial driving automation are becoming more widely available and gaining acceptance in the U.S. The 2023 report (J.D. Power, 2023) revealed notably higher comfort levels among those who have experienced a "robotaxi" ride at least once. The growing familiarity with L2 systems and the comfort reported by robotaxi users point to a promising opportunity for L3 systems to gain public acceptance. As drivers become more accustomed to automation and build trust through real-world experiences, L3 systems may represent the next viable step toward broader adoption of automated vehicles.

CHAPTER 3. L3 SYSTEMS DEEP DIVE

When traffic conditions are met and L3 systems are turned on, the vehicle takes over the entire driving task, allowing the driver to engage in non-driving-related activities. Drivers are expected to respond or take over control in a timely manner when the system issues a request to intervene or take over. However, whether drivers can take back control effectively and timely under varying traffic conditions remains uncertain. Specifically, the necessary takeover time for drivers must consider the possibility that drivers might become deeply immersed in their activities during automated driving, potentially compromising their ability to promptly refocus and respond to TORs. To address these considerations and to improve the L3 system in the loop of automated vehicle design, numerous studies have investigated key areas: HMI design, trust and acceptance, transition of control, reasonably foreseeable misuse, and situation awareness. HMI design serves as the primary communication channel between the system and the driver, directly influencing the driver's trust, situation awareness, and ability to manage transitions to manual control. Additionally, successful transitions of control depend on the ability to maintain situation awareness. These topics are interrelated and must be considered in an integrated manner to ensure system reliability and user readiness (Figure 5).

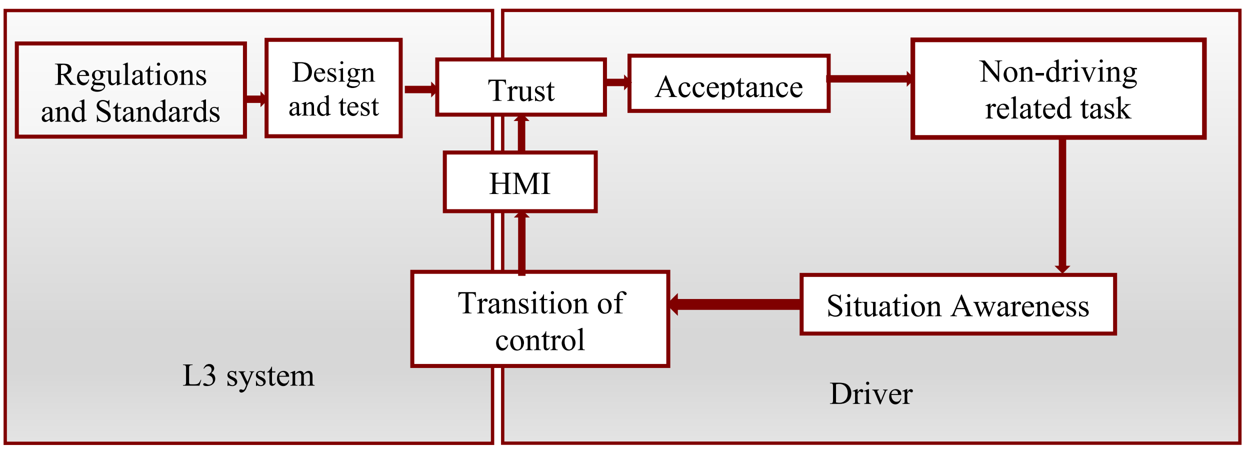

Figure 5. Diagram. Framework of interaction between the L3 system and the driver.

3.1. TRUST AND ACCEPTANCE

Current and future L3 systems must achieve a level of technical maturity to comply with safety standards. Their widespread adoption will depend not only on technical compliance, but also on public acceptance, perceived risk, and trust (Naiseh et al., 2024). Trust in the system's technical ability to safely perform the driving task is a fundamental factor in automation acceptance and reliance (Choi & Ji, 2015), acting as a bridge between drivers' beliefs toward automation and their intention to use it (Nordhoff et al., 2020). When drivers develop trust in an automated system, they are more likely to engage in non-driving-related tasks (NDRTs), such as checking emails or watching videos (Nair et al., 2020). However, trust is multifaceted and exists along a continuum between two extremes: under trust and over trust (Avetisyan et al., 2022; Walker et al., 2023). Over trust can lead to overreliance, misuse, loss of situational awareness, slow or inadequate response during automation failures, falling out-of-the-loop, and activating automation in unsafe conditions, all of which increase the risk of collisions. Conversely, under-trust results in reluctance to use automation, thereby reducing its potential benefits (Walker et al., 2023; Naiseh et al., 2024).

To prevent the risks associated with both under trust and over trust, a substantial body of research has explored various influential factors on trust (Choi, & Ji, 2015; Bauerfeind et al., 2018; Kinnear et al., 2020; Walker et al., 2023; el Jouhri et al., 2023; Naiseh et al., 2024; Schwindt-Drews et al., 2024) and acceptance (Nordhoff et al., 2020; Nastjuk et al., 2020; Othman, 2021; Saravanos et al., 2024). These factors can be categorized into three levels: individual, technical, and social.

- At the individual level, trust is shaped by factors, such as drivers' reliance behavior, risk perception, prior system experience, specific driving conditions, knowledge, and demographic characteristics. Familiarization gained through exposure, training, and education programs can help drivers build trust and reduce perceived risks over time.
- At the technical level, trust depends on the HMI design, the presentation and timing of TORs, clarity of safety alerts, and perceived ease of use and usefulness, as well as vehicle capabilities, safety, and features. These elements play a key role in trust formation, acceptance, and the intention to use.
- At the social level, public expectations, brand reputation, and social media influence will inevitably contribute towards the trust and reliance of L3 technology. Concerns about L3 systems in safety-critical incidents can strongly impact consumer interest. Rising public awareness and establishing regulatory standards for risk communication can enhance consistency, transparency, and reliability across different autonomous systems (Naiseh et al., 2024).

The investigation of trust and acceptance factors aims to assist system designs that enhance transparency, reliability, and usability. However, few studies can provide a comprehensive integration of these factors within the context of evolving automated driving technologies. As Walker et al. (2023) observed, some studies focused solely on trust factors while overlooking the technological aspects of the system itself, thereby limiting the practical applicability of their findings. Therefore, individual or several contributing factors only offer partial insight into trust development. A balanced consideration of both drivers and technical elements is necessary to support sustained driver confidence and system performance in real-world scenarios. In real-world use, drivers continuously recalibrate their trust in a dynamic manner and adjust their behavior based on updated assessment of the system's capabilities across different situations. For example, a driver's initial trust in a Mercedes-Benz equipped with a Drive Pilot system may be high due to the brand's reputation and perceived quality. However, this trust can decline following accident reports, upon realizing that the system cannot be activated under all driving conditions, or when a monitoring request was issued but no manual intervention was needed (Heinrich et al., 2025).

To model trust as a dynamic balance in the context of traffic safety, Boström (2024) introduced a simplified equation, defining trust as a measure of confidence in the overall quality of a system:

$$\text{Trustworthiness} = (\text{credibility} + \text{reliability} + \text{intimacy}) / \text{self-orientation}.$$

This means L3 systems must be:

- Credible – evaluated under complex scenarios and authorized by regulatory frameworks;
- Reliable – proven to perform required functions under real-world conditions;
- Intimate – technologically advanced and responsive to user needs; and
- Transparent – featuring a clearly defined operational domain design that outlines both capabilities and limitations.

In the equation above, while the numerator variables of credibility, reliability, and intimacy build trust, the denominator variable self-orientation can erode it, especially if drivers perceive that the system prioritizes commercial interests over user safety and clear communication. The trust equation highlights the importance of transparency and clear driver-vehicle communication regarding system capabilities and limitations to avoid mode confusion and misuse (Boström, 2024; Schwindt-Drews et al., 2024). In addition, the L3 system should communicate its sensed surroundings and provide clear explanation of both what actions are being taken and why those actions are necessary without consuming user attention by multimodal interface (Gang et al., 2018; Avetisyan et al., 2022).

Drivers tend to trust their own judgement over the automated system in complex or less predictable safe driving situations (Tomasevic et al., 2022). This tendency highlights the persistent challenges of building trust, particularly in shaping drivers' attitudes to appropriate system use. These attitudes are expressed through drivers' subjective and emotional responses, potentially undermining the effectiveness of the trust-enhancing factors outlined above. As the deployment of L3 systems becomes more widespread, it remains important to consider the effects of long-term use and the frequency of transition demands on driver trust (Kinnear et al., 2020). While more considerations and factors support the building of trust and acceptance, trust can be simply understood as drivers' emotional response to perceived real value of systems and driver's ability to properly use the system within its designed limitations. A driver who trusts the system not only feels confident in its capabilities but also engages with it appropriately. Manufacturers need to monitor drivers' attitudes and use of the L3 system, allowing them to assess real-world use patterns and better understand trust and acceptance over time. Efforts should go beyond technical enhancement and include strategies such as leveraging social influence, incorporating trust-related factors into system design, and enhancing the ability to properly use the system (Nastjuk et al., 2020; Saravanos et al., 2024).

3.2. TRANSITION OF CONTROL

When an L3 system is activated within its ODD and performs the entire driving task, it indicates that the driver trusts the system and can engage in NDRTs. If the vehicle reaches the limits of its automation capabilities or leaves the ODD, the system will issue a TOR to prompt the driver to resume control (Merat et al., 2014; el Jouhri et al., 2022; Alms & Wagner, 2024; Heinrich et al., 2025). The takeover process involves a series of cognitive and motor stages, including perceiving the warning signal alerts (visual, auditory, or tactile), the cognitive processing of the critical traffic/vehicle situation, decision-making, resuming motor readiness, and executing the take-over (Huang et al., 2024). This process is inherently complex and introduced a significant issue known as the out-of-the-loop performance problem due to the loss of skills and driver's situation awareness in the event of system failure (Heinrich et al., 2025). Consequently, immediately responding to a TOR can be highly demanding and challenging, especially when the driver is deeply engaged in NDRTs (Yun & Yang, 2020).

In this report, we conducted an extensive literature review to examine the key factors that influence takeover performance. These factors include situational awareness variables (e.g. traffic complexity, warning modality, HMI design, types of NDRTs), individual factors (e.g. age, situation awareness, takeover capacity, driving experience and skill; Kinnear et al., 2020; Huang et al., 2024), and behavioral failures during takeover (e.g., delayed braking response and time to hands-on-wheel; McKerral et al., 2023). Over the past decades, research has increasingly focused on transition in critical situations, particularly automation failure (Tomasevic et al., 2022), transition strategies to bring the driver back into the loop (Heinrich et al., 2025), and appropriate takeover times in urgent situations specifying criteria for HMI design (Merat et al., 2014; Kuehn et al., 2017; Alms & Wagner, 2024).

Studies have shown that both takeover time and available time budget significantly affected takeover performance (Lin et al., 2020): shorter time budgets result in quicker but less effective takeover. Takeover time is commonly defined as the duration between the issue of a TOR and the moment the driver fully takes over. The takeover time budget refers to the available time window before the automated system reaches its operational limits if the driver did not respond or requires a change in automation mode due to environmental or system constraints (Tinga et al. 2022; Zhao et al., 2024). Research has assessed the takeover time across varying takeover time budgets (Tinga et al. 2022; Heinrich et al., 2025). In response to non-urgent situations, takeover time is around 5.6 seconds on average (Dillmann et al., 2023). Alms and Wagner (2024) further identified a 7-second takeover time as adequate even when the driver is engaged in NDRTs.

Findings of previous studies have indicated that a takeover time budget of around 7 seconds might be acceptable for safe intervention, while budgets exceeding 10 seconds tend to yield optimal takeover performance (Lin et al., 2020). According to the ALKS regulation, L3 automated driving systems must provide a time budget of 10 seconds for the transition of control (UNECE, 2021). While Heinrich et al. (2025) demonstrated that the 10-second takeover budget can be adequate in allowing drivers to respond safely to simple road blockages, Kuehn et al. (2017) argued that this time window may be insufficient to ensure a safe takeover if drivers are engaged in reading and conducting tasks on a tablet. To clarify the criteria for delivering timely and appropriate messages regarding transition of control, Merat et al. (2014) found in a driving simulation study that drivers typically experience a lag of 10 to 15 seconds between automation disengagement and resumption of control and may require up to 40 seconds to fully regain stable control. The comparatively longer takeover time observed in this study was not solely due to task complexity, but rather a combination of unpredictable system disengagement timing, resulting in delays in attention refocusing and visual engagement when control was required.

These varying findings suggest that appropriate takeover times depend on the specific assessment in different situation's urgency, time budget to collide with an obstacle, driving context/road environment, and types of NDRTs (Dillmann et al., 2023; Heinrich et al., 2025). In other words, there is no universally accepted takeover time (Kinnear et al., 2020). Research into takeover time for whether drivers can effectively and safely intervene will persist and remain challenging (Alms & Wagner, 2024).

3.3. SITUATION AWARENESS

Successful takeover scaffolds from effectively reconstructed situation awareness during limited takeover time (McKerral et al., 2023). Drivers' situation awareness is a critical factor for takeover performance, serving both as a metric and a causal explanation for a driver's failure to safely resume control (Liang et al., 2021; McKerral et al., 2023; Huang et al., 2024). In the driving context, situation awareness has been defined as the updated and meaningful understanding of events that occur in the surrounding environment (Liang et al., 2021; Kim et al., 2023), which is crucial for monitoring surrounding traffic and navigating the driving environment. As drivers are allowed to engage in NDRTs, they will drop "out of the loop" and have low levels of situation awareness (Merat et al., 2014; Gerber et al., 2023), resulting in detrimental driving performance (Dillman et al., 2021; Kim et al., 2023; Heinrich et al., 2025).

To address these problems, Dillman et al. (2021) recommended increasing visual exposure (e.g., more time spent monitoring the road) and manual control exposure (e.g., more chances of takeover situation) to help keep the driver in the loop and improve takeover reaction time and stability. Longer times spent monitoring the traffic situation and more dispersed visual attention allocation have been associated with improved overall situation awareness (Liang et al., 2021). Based on findings from a series of empirical takeover studies, an appropriate time budget of approximately 6 to 10 seconds is considered sufficient to establish adequate situation awareness and prepare for a takeover maneuver. Understanding the interplay between situation awareness and reaction times, as well as the influence of different warning signals, is essential for determining when and where specific signals are most effective, ensuring a safer transition during TORs.

NDRTs occupy different sensory modalities (e.g., audio-only, visual-tactile), and their impact on a driver's takeover ability depends on the degree of sensory overlap with the modality of the TOR. At the same time, engagement in NDRTs diverts attention away from the driving environment, thus impairing the driver's ability to reconstruct situation awareness during a takeover (Liang et al., 2021; Huang et al., 2024). Gerber et al. (2023) emphasized the need to restrict NDRTs under specified conditions, particularly in complex driving environments or when the reliability of automation is uncertain.

In contrast, McKerral et al. (2023) found that ongoing NDRT engagement may facilitate the construction and maintenance of better situation awareness over time, offering new insights into how NDRTs could be managed in the context of evolving automated driving technologies. Such findings conflict with planned regulations that restrict NDRT engagement due to safety concerns. To address the potential conflicts and mitigate the impact of NDRT engagement, driver monitor systems play a crucial role by facilitating task-switching, communicating automation uncertainty and intention, and reminding the user of their responsibilities. Further research is needed to examine how the cognitive load of NDRTs influences situation awareness during the NDRT's engagement and to identify effective strategies for improving situation awareness in L3 driving context (Zhu et al., 2024).

3.4. HUMAN-MACHINE INTERFACE

In vehicles, the HMI includes visual (e.g., instrument cluster, head-up display, center console), auditory (e.g., alerts, voice prompts, confirmation tone), and haptic (e.g., steering wheel and seat vibration, pedal resistance) modalities. The HMI determines how drivers interact with L3 systems by delivering essential information and managing both driving-related and NDRTs. For example, the center console typically supports the NDRT's engagement, while the instrument cluster provides vital driving information such as speed and warning messages (Wang et al., 2023). Drivers rely on the HMI to interpret the system's status, upcoming maneuvers, and operational capability. Therefore, the HMI must communicate clearly and intuitively to avoid misinterpretation that can lead to false expectation, over-reliance, and potential unsafe situations (Carsten & Martens, 2019). A well-designed HMI is fundamental for maintaining driver awareness, facilitating takeover performance, building trust, and minimizing uncertainty or stress (Carsten & Martens, 2019; Wang et al., 2024).

Several studies have outlined a set of recommendations for HMI design (Yun et al., 2020; Mehrotra et al., 2022; Wang et al., 2023; Wang et al., 2024; Zhu et al., 2024), focusing on modality and the timing of alert:

- **Modality:**
    - Should be designed to be multimodal (e.g. visual and auditory, visual and haptic)
    - Continuously display system status (e.g., on, off, activation, deactivation/disengagement, availability) and anticipatory information (e.g., future location/proximity to objects based on current trajectories)
    - Support situation awareness and required actions
    - Prioritize pictographic information and standardized symbology over text-based messages
    - Auditory and/or tactile displays should complement visual displays by reorienting driver's attention in critical situations and facilitate quicker and safer takeover transitions
    - Haptic displays (e.g. seat mounted, steering wheel) and acoustic guidance can enhance spatial awareness during takeover
- **Timing:**
    - Alerts should provide drivers with adequate time to regain control safely and effectively
    - Alert intensity should reflect the urgency of the situation without being a hindrance, distraction, or annoyance to driver
    - A warning cascade or multi-staged alert strategy (e.g., starting with visual, followed by auditory cues) is recommended to escalate urgency and address delayed responses
    - Longer alert duration can increase takeover time and facilitate a smoother transition of control; short and urgent requests may negatively impact takeover quality.

While much research has focused on takeover alerts, recent studies have expanded to examine other critical features of the HMI, such as amount of information and color (Huang et al., 2024).

To support drivers' situation awareness, HMI displays should provide situation information and real-time feedback, such as the current driving environment (other vehicles, traffic lanes), current velocity, future location/proximity to objects based on current trajectories, and system status (Bauerfeind et al., 2018; Mehrotra et al., 2022; Yun & Yang, 2022; Kim et al., 2023). It is also valuable to provide continuous information to support anticipation of upcoming changes, such as remaining time and distance until a TOR, upcoming mode, reasons for mode changing, hazard monitoring, and upcoming or current required driving tasks or allowed NDRT (White et al., 2019; Tinga et al., 2022; Kim et al., 2023). To support appropriate trust and reduce misunderstanding, the HMI can provide a complete and comprehensive information set. Ideally, it should adjust the amount and complexity of displayed information to match the driver's needs and the situational context (Tomasevic et al., 2022; Yun & Yang, 2022; Kim et al., 2023).

Several studies have examined the effectiveness of HMIs. A literature review by Wang et al. (2023) found that HMIs had no significant impact on measures, such as acceleration, lane position, on-road glance duration, trust, or usability. However, haptic displays were associated with faster responses, shorter lane-change durations, and increased frequency of rearview mirror checks during lane change. Similarly, el Jouhri et al. (2022) reported that color-themed HMIs, particularly those using red ambient lighting, conveyed a greater sense of urgency and were linked to shorter reaction times. Despite this, HMI color did not enhance perception or TOR performance. In fact, the use of red ambient lighting and colored interface may be distracting to drivers.

Although existing studies have offered valuable and practical design recommendations, effectively implementing HMI design remains a critical challenge for OEMs. To date, most research has primarily focused on alert modalities for takeover scenarios, leaving potential gaps between experimental HMIs and those used in OEM production vehicles (Wang et al., 2024). For example, the BMW Personal Pilot L3 system presents status messages in the instrument cluster, complemented by embedded multimodal alerts, aiming to keep drivers informed through both visual and sensory cues. Mercede-Benz introduced turquoise lighting elements on the steering wheel to signal the activation of its Drive Pilot feature. However, as these L3 systems in the market have not yet been widely adopted, comprehensive evaluations of their usability, use experience, and effectiveness are still lacking. It remains uncertain whether their alerts and light colors are effective in regaining drivers' attention during a transition of control.

3.5. REASONABLY FORESEEABLE MISUSE

L3 systems are designed with the assumption that drivers understand how to use the L3 system, remain alert, and prepare to take over control when needed. However, real-world driving behavior frequently undermines this assumption. It is reasonable to expect high likelihood of system misuse (Patel et al., 2023). To ensure safety, it is therefore crucial to understand and address the potential for reasonably foreseeable misuse. ISO 21448, referred to as the standard for Safety of the Intended Functionality (SOTIF), aims to prevent insufficiencies of the intended functionality or reasonably foreseeable misuse.

According to SOTIF, such misuse in the context of L3 refers to the potential for a driver to use the system in ways not intended by manufacturers, but which are still predictable based on human behavior. Examples include failing to respond to TORs, misusing the system's capabilities, or disengaging from the driving task altogether. Several studies have highlighted concerning patterns of misuse. Worle and Metz (2023) identified behaviors such as sleeping, leaving the driver's seat, or driving under the influence as clear deviations from intended use. Shi and Frey (2021) found a 3.38% rate of sleeping during L3 automated driving. Similarly, Schwindt-Drews et al. (2024) observed two participants changed their seating position while using an L3 system.

The misuse of an L3 system may stem from several causes: a lack of situation awareness and improper trust calibration (Gerber et al., 2023); over trust and complacency (Worle & Metz, 2023); overestimation of system capabilities or mode confusion (Schwindt-Drews et al., 2024); and cognitive issues such as false recognition, misjudgment, and being out-of-loop (Patel et al., 2023). In summary, anticipated system misuse resulted from misunderstandings related to the system's capability and design, as well as driver behavior (Patel et al., 2023), which can lead drivers to mistakenly believe that sleeping or leaving the seat is acceptable (Worle & Metz, 2023). Patel et al. (2023) also emphasized the driver's perception error of the environment and decision error for the given situation, applying them to a SOTIF-related misuse scenario. For future research, it is recommended to identify and understand the underlying causes of misuse and to investigate the effectiveness of the mitigation measures to prevent misuse in SOTIF-related contexts.

In the healthcare domain, ISO 14971 is the international standard for risk management in medical devices. Misuse classifications include use errors, intentional misuse, and off-label use, providing a useful framework that could be adopted by the ADS safety assurance domain. The requirement for identification of reasonably foreseeable misuse is to consider hazards that may be present when a device is used in a manner other than as intended by the manufacturer (Table 2; Agarwal, 2023). ISO 14971 emphasizes risk mitigation through design, labeling, training, and documentation. SOTIF extends traditional risk frameworks like ISO 14971 into intelligent systems by accounting for safety concerns beyond hardware or software failure. Both SOTIF and ISO 14971 are valuable to evaluate design strategies and mitigate misuse-related safety risks in automated systems in general and could guide the development of L3 systems in particular (See Table 2).

Table 2. Categorization of reasonably foreseeable misuse.

Categories of reasonably foreseeable misuse from risk management of medical devices (ISO 14971)	**Adapted reasonably foreseeable misuse categories for L3 development proposed in this report**
Use-error: slip, lapse or mistake; refers to unintentional errors that can occur due to poorly designed user interface or inaccurate, incomplete or ambiguous instructions for use	**Use-error**: interface presents insufficient, inappropriate or incorrect information to the driver
Intentional acts of misuse: When users knowingly deviate from the intended use.	**Intentional driver behavior**: loss of concentration, overreliance
Off-label use: Intentional use of the device for other applications than intended by the manufacturer	**Outside ODD**: incorrect assumption of user interaction from the system design or lack of understanding of the system by the users

Few studies have specifically addressed the issue of reasonably foreseeable misuse in L3 systems. As L3 systems become more widely used, driver engagement and road monitoring tend to decrease, increasing the risk of such misuse. Although technical solutions, such as driving monitoring systems or cooperative driving systems, are optimized to detect sleep onset and to mitigate automation complacency, these solutions alone may not be sufficient. There is a pressing need for systematic research to identify potential misuse scenarios, understand their root causes, and evaluate the effectiveness of various mitigation strategies. Proactively addressing these concerns is essential to ensure safety and support the introduction of L3 systems into widespread public use (Worle & Metz, 2023).

CHAPTER 4. DISCUSSION

For the deployment and development of L3 systems, previous studies have investigated a range of critical human factors regarding the acceptability of automation technology, sustainability, driver trust, intentions of use, HMI design, transition of control, and perceived benefits and disadvantages of automated vehicles (Tomasevic et al., 2022). This report comprehensively reviewed societal, market, regulatory, and academic perspectives on L3 systems, emphasizing the interrelationships among trust, situation awareness, transition of control, and HMI. Among these factors, trust serves as a starting point for the widespread deployment and adoption of L3 systems. When drivers trust the system, they are more likely to use it and engage in NDRTs (Kinnear et al., 2020), which in turn can deteriorate situation awareness, takeover performance, and overall driving safety. Therefore, a key research objective is to clearly define the role of driver trust, underscore the importance of human-centered design that keeps the driver in the loop, and support drivers in understanding the driving situation (Heinrich et al., 2025).

Researchers and developers of L3 systems have made substantial progress in providing evidence concerning the safety benefits of automation, with the goal of building public trust and promoting widespread adoption. Nevertheless, regardless of how technically reliable these systems become, the human-system interaction remains a critical challenge for ensuring safe and effective performance. Major concerns include HMI design, the extent of driver engagement in NDRTs, takeover time and quality, and driver training and education. These insights contribute to a comprehensive understanding of L3 systems.

4.1. HMI DESIGN

Well-designed HMIs are essential for facilitating effective interaction between the driver and the ADS. The previous section discussed that multimodal alerts or warnings can support trust, situation awareness, and smooth transition of control (Huang et al., 2024; Zhu et al., 2024). However, designing an HMI that can meet all those requirements remains challenging (Nair et al., 2020). Furthermore, empirical evaluations of these HMIs remain limited, and existing studies have not demonstrated consistent improvements in takeover times or glance behaviors (Mehrotra et al., 2022).

HMIs in vehicles encompass not only visual and auditory modalities but also lighting-based interfaces, such as ambient lighting and external signal lights. These lighting elements serve functional purposes, enabling the driver to monitor, understand, and interact with vehicle automation functions. Both interior and exterior lighting is being integrated into vehicle designs to enhance communication between vehicles, drivers, and surrounding road users. Interior lighting design may foster a sense of intimacy with the system, which, as Bostrom (2024) suggested, could in turn positively affect trust in the system.

A notable advancement in automotive lighting can be attributed to Mercedes-Benz, which was the first manufacturer to receive permits for special exterior marker lights for automated driving in the states of California and Nevada (Mecedes-Benz, 2023). The use of turquoise marker lights improves transparency and communication between automated vehicles and their surroundings, facilitates law enforcement, and enhances other road user predictability. However, these indicators may also bring potential unintended consequences. Other drivers may not understand the intended meaning of turquoise lights, potentially resulting in unpredictable behavior, such as unnecessary yielding or even risky behavior. In some cases, road users may intentionally try to disrupt the driving behavior, affecting the vehicle's lane positioning or triggering unnecessary ADS disengagements.

Designed in accordance with SAE Recommended Practice J3134, the turquoise-colored marker lights are integrated into the vehicle's front and rear lights, as well as the two outside mirrors. The visibility of turquoise lights allows reliable and fast detection for other road users, offers differentiation from existing vehicle lighting and traffic signals, and reduces the possibility of confusion with existing lighting colors. Turquoise has already been included in international standards and draft regulations (e.g., SAE J3134, UNECE, and China Compulsory Certification).

Other manufacturers have adopted similar colors for their interior designs. The BMW 7-series, equipped with the Personal Pilot L3 system, uses turquoise lighting on the steering wheel (Figure 4) and exterior marker lights to indicate that the automation is active. Likewise, the Honda Legend, featuring the Traffic Jam Pilot, employs blue lighting on the steering wheel to signal active automation (Figure 2). These innovations reflect a growing effort toward the standardization of visual signals for automated driving. A globally harmonized regulation for turquoise marker lights is currently under development to unify how automation status is communicated, improve road safety, and support broader deployment of autonomous technologies.

4.2. NDRTs

The new E-Class of Mercedes-Benz features an integrated infotainment system that includes a built-in TikTok app, over 30 different streaming services for movies and TV shows, games, web browsers, and a Zoom app (Golson, 2023). This design enables drivers to engage in a wide range of NDRTs during automated driving, such as watching videos, playing games, browsing websites, reading journals or magazines, talking with other passengers, sitting back to relax, and viewing the scenery and other vehicles. Shi and Frey (2021) explored the types of NDRTs that users are likely to engage in while using L3 systems. Their study found that all participants engaged in at least two NDRTs. High frequency activities included smartphone usage, reading, texting, talking with passengers, eating and driving, sleeping, watching movies/TV, working, and relaxing. The findings imply that NDRT engagement is both inevitable and varied, with many tasks commonly involving high cognitive loads.

However, many of these NDRTs are visually and cognitively demanding, and engagement in them has been consistently shown to degrade takeover performance and decrease situation awareness (Lin et al., 2020; Zhu et al., 2024). Despite this, some NDRTs have the potential to keep the driver attentive, offset fatigue, and even enhance takeover quality (Shi & Frey, 2021). Understanding the impact of NDRTs is essential for the development of L3 systems, as it helps determine the minimum time required for drivers to get "back in the loop" (Kinnear et al., 2020; Zhao et al., 2024). One key concern persists regarding whether all NDRTs can be considered safe and acceptable for all drivers to engage in, especially inexperienced drivers. Therefore, it may be necessary to implement restrictions on NDRT engagement in the emerging era of conditional automated driving, since the negative impact on takeover performance can be mitigated to some extent but cannot be eliminated (Xu et al., 2024).

The impact of cognitive demand associated with various NDRTs on transition of control and situation awareness remains a topic of discussion. Zhu et al. (2024) have explored the impact of different levels of cognitive load on situation awareness during takeovers. Results showed that the situation awareness level while listening to novels is much higher than watching TikTok or playing games, corresponding to the higher cognitive load of playing games than watching TikTok and listening to novels. Playing games imposed the highest cognitive load, followed by watching TikTok, and then listening to novels. These findings suggest that higher cognitive load results in low levels of situation awareness. That is, cognitively demanding NDRTs draw cognitive and attentional resources away from the driving task, thereby impairing the driver's ability to remain alert and respond promptly. A critical question arises: To what extent does the engagement in high-cognitive-load NDRTs affect takeover time and performance? For instance, if a driver plays games during automated driving, how long will it take them to respond to the intervention request? Further research is needed to identify which types of NDRTs are most difficult for drivers to disengage from, fall within a safe range for use during conditional automation, and lead to the longest takeover time.

4.3. TAKEOVER TIME

Previous research has shown that takeover time is influenced by HMI design, types of NDRTs, and driver experience. Most studies to date have primarily reported that NDRT engagement increases cognitive load and reduces situation awareness, requiring more takeover time for regain control in unscheduled emergency situations (Borojeni et al., 2018; Zhu et al., 2024). Switching from NDRTs back to driving not only slows reaction time but also compromises driving stability for up to 5 minutes (Xu et al., 2024). The more a driver engages in NDRTs, the less capable the driver will be to safely resume control.

The question of whether the 10-second takeover time is sufficient depends heavily on both the driving situation and the driver's cognitive state at the time of the TOR. In non-critical or low-complexity situations, such as light traffic, low speeds, and minimal obstacles, drivers tend to need less time to resume control. Alms and Wagner (2024) and Dillmann et al. (2023) suggested that 5 to 7 seconds is sufficient under these conditions. If the driver is engaged in low-cognitive-load NDRTs, a 10-second time budget typically provides a comfortable margin for resuming control with minimal risks. However, in critical situations or high-complexity situations, such as encountering a sudden obstacle, navigating urban traffic, or when drivers are engaged in high-cognitive-load or deeply distracting NDRTs, a 10-second takeover time may not be adequate for drivers to fully reorient themselves, assess the environment, and execute the maneuvers (Merat et al., 2014; Kuehn et al., 2017; Pipkorn et al., 2024). In more demanding scenarios, a takeover time between 12 and 15 seconds or even more may be necessary to allow drivers to regain stable control.

Given the variability in takeover readiness, takeover time criteria are adaptive, considering the nature of the driving environment, the driver's cognitive state, the design of the takeover request, and the complexity of NDRTs. It should be assumed that drivers may not be ready to respond immediately after a TOR (Pipkorn et al., 2024). Ideally, a flexible and adaptive takeover system that adjusts the time budget based on real-time driver engagement and environmental complexity would offer the best balance between driver convenience and safety. It is necessary to educate drivers about the impact of NDRTs on the takeover time and performance. Clear communication and driver training are essential components for ensuring that users understand the risks associated with delayed response and impaired situation awareness during automation-to-human transitions.

4.4. DRIVER TRAINING AND EXPOSURE

Using an L3 system effectively requires drivers to have a clear understanding of the system's functionality, particularly its limitations. According to Worle and Metz (2023), providing instruction or detailed system descriptions, along with more opportunities for system usage, can help drivers develop a correct understanding and perform better in critical events when the system reaches its limitations. To improve takeover performance and driving stability, Kim et al. (2023) summarized various techniques from previous studies, such as monitoring driving readiness, supplying situation awareness cues before a TOR, and delivering multimodal signals. These findings converge on the conclusion that training drivers to use L3 automation is crucial for safe deployment. Further research supports that targeted training combined with effective multimodal HMI design can significantly enhance situation awareness and re-engagement performance during TORs (Tomasevic et al., 2022; Huang et al., 2024). Additionally, extensive experience with L3 systems and ongoing learning can help drivers manage cognitive load associated with NDRTs, reduce reaction time, and better allocate attention between NDRTs and the driving task itself (Kim et al., 2023).

One effective training approach is to expose drivers to frequent and controlled TOR scenarios under safe conditions. Such repeated exposure helps drivers to develop anticipatory responses or even automatic behaviors during transitions, improving their ability to quickly get back in the loop (Dillmann et al., 2021; Kim et al., 2023; Xu et al., 2024). In addition, increased exposure can also mitigate the negative impact of NDRT engagement and improve driver's strategies for attention allocation (Zhu et al., 2024). Preparation time prior to TORs is also critical. Providing sufficient lead time can enable drivers to reallocate their attention, reduce task switching costs, and improve takeover stability. Thus, L3 systems should be designed to offer adequate preparation windows before the takeover (Xu et al., 2024).

While extensive manual driving experience can reduce the cognitive demands of basic driving tasks, infrequent manual control during automated driving can erode automaticity over time (Xu et al., 2024). Drivers who rarely resume manual control may become less skilled or slower to react during unexpected takeovers. It is essential that drivers periodically engage in manual driving and receive training that reinforces their awareness of task-switching cognitive challenges and post-takeover risks (Xu et al., 2024). In summary, the safe operation of L3 systems relies not only on advanced automation but also on well-informed, well-prepared, and well-trained drivers. Investing in systematic training, repeated exposure to takeover scenarios, and manual driving practice is essential to ensure effective human-automation collaboration.

CHAPTER 5. RECOMMENDATIONS

As L3 systems become increasingly prevalent, it is essential to address the multiple human factors that influence takeover performance. As highlighted throughout this report, driver readiness, cognitive demands from NDRTs, HMI effectiveness, repeated exposure to takeover events, and targeted training all play critical roles in effective transitions of control between automation and drivers. A proactive approach that integrates these factors can better prepare drivers to respond effectively when automation reaches its operational limits. Moving forward, system development and safety evaluation should focus on supporting drivers before, during, and after takeover events, enabling them to remain attentive, informed, and ready to safely resume control. Key recommendations are summarized in the following table (see Table 3).

Table 3. List of recommendations.

Category	Recommendation
Regulations and standards	Adopt safety case and safety management systems approaches
	Define a set of industry standards that will be adopted
Trust and acceptance	Enhance transparency and communication
	Build credibility through legal and technical validation
	Ensure system reliability in real-world conditions
	Support familiarization (intimacy) and user training
	Monitor and support trust recalibration
HMI design	Use multimodal takeover alerts (e.g., combination of visual and haptic)
	Clearly communicate system limitations and transitions
	Offer real-time environment and system feedback
	Implement gradual alert strategies
	Adopt color coding strategy for internal and external communication cues
Takeover performance	Provide at least 10 seconds for takeover time
	Issue early lead-time warning before TORs
	Encourage periodic manual driving to maintain skills
Situation awareness	Limit high-cognitive load NDRTs in complex traffic conditions
	Integrate advanced DMSs to track driver state
	Continuously provide road and traffic updates
	Provide education about cognitive task-switching risks
	Provide training on system use, limitations, and safe takeover
Exposure	Offer repeated takeover exposure in safe or simulated environments
	Train drivers on attention management strategies during NDRT engagement

Integrating the insights from previous studies can support the broader adoption of automated vehicle technology (Saravanos et al., 2024). This study synthesizes findings from market trends, regulatory, and academic research to provide practical recommendations for the development of automated driving. However, the evolving complexity of L3 systems introduces new challenges that are not yet fully addressed in current research and practice. For example, human behavioral benchmarks are currently lacking for high-speed, lateral maneuver scenarios now permitted under the updated UNECE Regulation No. 157. There is a shortage of empirical studies focused on driver gaze behavior during complex lateral transitions, such as lane changes (Guo et al., 2022), and a corresponding need for robust models that reflect human behavior under these conditions. Additionally, domain-specific human performance data aligned with L3 ODDs, such as benchmark crash avoidance metrics, behavior prediction models, and safety envelope parameters, are needed to support system validation. Future research should also explore effective HMI elements such as color coding and external communication cues, particularly those tailored to L3 interactions.

At the same time, open questions persist regarding how diverse populations interact with L3 systems. As Xu et al. (2024) pointed out, there are still several critical questions remaining for researchers, manufacturers, regulators, and road users: What types of human-vehicle interaction designs are most effective at mitigating the risks of cognitive task switching? Are novice drivers or other vulnerable groups capable of effectively switching their attention back to driving? What types of NDRTs can be considered safe for engagement within the ODD? Research into cognitive activity differences across NDRTs and their influence on transition readiness is also critical to future development. In a word, manufacturers, regulators, and researchers need to shape the future of mobility in a way that prioritizes human-centered design, consumers' trust, situation awareness, NDRT engagement, and regulatory clarity. Continued interdisciplinary research is essential to bridge existing gaps and ensure that human factors of automation are not an afterthought, but a foundational pillar in the evolution of intelligent transportation.

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