Overview of Operational Safety Concepts for Level 4 Automated Driving System Fleets

Best Practices

This document reviews current best practices applied in different industries involved with automated system operations and management. The review focuses on safety-critical sectors and applications where teleoperation, incident reporting, and fleet management aspects are key to their operation.

Introduction

The operation of Level 4 (L4) Automated Driving Systems (ADS) for Mobility as a Service (MaaS) is expected to share similar characteristics with other transportation, manufacturing, and energy industries that rely on managing remote operations at various levels of autonomy (LoA).

This report presents an overview of the current best practices in other industries to provide insight into L4 ADS as MaaS safe operation. Several sectors and publication types, e.g., peer-reviewed papers, industry standards, and government guidelines, were reviewed to identify best practices that could apply to L4 ADS for MaaS fleet operations. The review focused on fleet operators' responsibilities regarding inspection and maintenance procedures, incident reporting, training and certification, and control room environment.

Methodology

The review involved identifying industries with similar features to ADS MasS fleets to inform best practices. The automotive, trucking, and train industries were identified as close applications of vehicle technology. The selection also included sectors deploying autonomous systems (e.g., autonomous vessels) and with experience with remote monitoring and control (e.g., nuclear power plants).

The applicable best practices are organized by operational aspect and assessed through two qualitative scales: "Applicability" and 'Acceptance". "Applicability" refers to how these measures can be adapted for L4 ADS MaaS based on their technological and operational similarities as defined in Table 1.

Table 1: Applicability of best practices scale description.

Applicability Level	Description
High	Best practices directly apply to L4 ADS operation as MaaS and require little to no significant modifications.
Medium	Best practices apply to L4 ADS operation as MaaS but require modifications to reflect different levels of automation or operational scenarios.

Applicability Level	Description
Low	Best practices are not significantly related to the reference fleet operator's expected functions. System/procedure design principles can be adapted but require extensive modifications.

"Acceptance" categorizes the sources by the level of maturity or acceptance within the industry: industry standard, industry guidelines, government required, and research stage (peer-reviewed publications).

The best practice classification according to this scale is qualitative and based on the authors' expertise and the reference fleet defined in the project. This review does not intend to deliver a comprehensive review of all applicable practices to the L4 ADS MaaS operation; however, it focuses on operational aspects highlighted by the hazard identification results provided in the previous chapter. The practices with lower applicability are complemented with suggestions for modifications for L4 ADS fleet operations. For example, the best practice in the drone industry of requiring pilots to obtain a license would have low applicability, as ADS fleet operators may not necessarily require a license. A possible modification to this best practice would be to require operators to obtain certification by completing specific training.

Current Best Practices in Industry

Table 2 summarizes the most relevant best practices identified, grouped by operational aspect. This table covers practices related to inspection and maintenance procedures, incident management and reporting, training and certification, as well as Human-Systems Interface (HSI) and control room environment design. The industries with practices most relevant to the operation of L4 ADS vehicles in MaaS include civil and commercial aviation, non-automated passenger and commercial vehicles, autonomous marine vessels, railway systems, nuclear power plants, and civil drone operations.

The remaining sections of this chapter provide additional details to complement the complete best practices table provided in the appendix.

Table 2: Summary of identified industry best practices

Operational Aspect	Industry Best Practices	Applicability	Acceptance	Industry
Inspection and maintenance procedures	Establish on-route inspection procedures in coordination with externally trained personnel.	Low	Industry Standard	Automated Commercial Vehicles
	Maintain a record of maintenance activities history and develop safety checklists.	High	Industry Standard	Civil and Commercial Aviation
	Perform periodic system component inspections. E.g., brakes, lights, steering, structural rust, and tires.	High	Government Required	Passenger and Commercial Vehicles

Operational Aspect	Industry Best Practices	Applicability	Acceptance	Industry
Incident management and reporting	Automate data collection systems to aid incident investigation.	High	Industry Standard	Automated Commercial Vehicles
	Develop on-route incident management procedures (e.g., vehicle disengagement and emergency response teams) and incident investigation programs.	Medium	Industry Guideline	Automated Commercial Vehicles
	Enforce ODD restrictions and inform the operation of adverse weather.	High	Industry Guideline	Automated Commercial Vehicles
	"Stop Work Authority" concept: interrupting operation to avoid injuries/harm.	High	Industry Standard	Autonomous Marine Vessel
	Develop scenario-based emergency response plans.	High	Industry Standard	Autonomous Marine Vessel
	Apply incident review procedures within specified time window after an incident occurrence.	Medium	Government Required	Civil and Commercial Aviation
	Employ a safety team tasked to aid passengers through an emergency line.	Medium	Industry Standard	Passenger and Commercial Vehicles
	Develop adequate reporting forms depending on accident type.	Medium	Government Required	Railroad Systems
Training and certification	Provide personnel with scenario-based training.	Medium	Research Proposed	Civil and Commercial Aviation
	Provide operational procedures and requirements for pilots.	Medium	Government Required	Civilian Drone Operation
	Require registration and license to operate drones .	Low	Government Required	Civilian Drone Operation
	Periodically train personnel in operator-system interaction tasks.	High	Government Required	Nuclear Power Plants

Operational Aspect	Industry Best Practices	Applicability	Acceptance	Industry
HSI design and control room environments	Use multiple alarm systems (e.g., adverse weather, malfunctions, collision path detection).	High	Research Proposed	Autonomous Marine Vessel
	HSI presents ambient displays and multimodal information.	High	Research Proposed	Autonomous Marine Vessel
	HSI provides alarms and multimodal information based on specified hierarchy.	Medium	Government Required	Nuclear Power Plants
	HSI provides mechanisms for operators to interact and intervene in automated system.	Medium	Government Required	Nuclear Power Plants
	Ensure HSI does not produce alarm oversaturation.	Medium	Research Proposed	Offshore oil and gas
	Follow guidelines on control room design and layout to improve operator performance.	High	Government Required	Traffic control
	HSI emphasizes the intervention causes.	High	Research Proposed	Automated Commercial Vehicles
	Depth perception cues and contextual road information are incorporated in the HSI.	High	Research Proposed	Automated Commercial Vehicles

Pre-shift Inspection and Maintenance Procedures

Safety checks before operations are widespread in many industries, such as passenger and commercial vehicle operations, to ensure the safety of the passengers and external parties. Often, these safety checklists include reviewing vehicle elements crucial to successful operations.

Automated Commercial Vehicles

Automated commercial vehicles rely also on inspection and maintenance procedures developed for non-automated vehicles. This includes inspection procedures performed at the point of origin before dispatch and on-route inspections at dictated intervals of the trip. Additional procedures have been developed for ADS-equipped commercial vehicles that require communicating to the corresponding law enforcement units both the system status and/or whether the inspection process cleared it for operation (Commercial Vehicle Safety Alliance (CVSA), 2022).

- Applicability: Medium. Inspections during vehicle operation are not considered for passenger transport nor require informing law enforcement of operations.
- Potential modifications: Regarding inspections when the vehicles are not in operation, it is important to establish if external inspections will be conducted by the ADS developer and/or a transportation agency.

Civil and Commercial Aviation

The aviation industry, both civil and commercial, has developed exhaustive pre-flight inspection lists. These best practices ensure that any mistakes and technical failures resulting in latent failures can be traced and corrected (i.e., failure events that do not lead to immediate consequences yet may increase the likelihood of future high-risk consequences). Best practices unique to aviation inspection lists include collecting necessary documentation on plane maintenance, data and time of overhauls, new parts installed, and an additional items checklist (U.S. Department of Transportation Federal Aviation Administration, 2012).

- Applicability: High. The concept of safety checklists may be adopted in L4 ADS fleet operation with minimal modification.
- Potential modifications: The frequency and content of the pre-shift safety checklist be adapted to reflect that no onboard safety driver is considered in the ADS reference fleet. Vehicle pre-shift inspections may include ADS-specific functional tests in addition to physical inspection (sensor status, passenger-vehicle communication channels, etc.).

Passenger and Commercial Vehicles – Commercial Transportation

The industrial powered truck industry has developed extensive guidelines on vehicle inspection similar to the automotive checklists. In general, the best practices in the trucking industry focus on implementing physical safety checks prior to and at different intervals during operation. Example checklist items include ensuring the quality of the mast assembly, the battery, load handling attachments, and gripper jaws (Occupational Safety and Health Administration, United States Department of Labor, 2022).

- Applicability: Medium. Inspections during vehicle operation are not considered for passenger transport.
- Possible modifications: Vehicle pre-shift inspections may include ADS-specific functional tests in addition to physical inspection (sensor status, passenger-vehicle communication channels, etc.).

Passenger and Commercial Vehicles – Passenger transportation

A common best practice in passenger transportation services includes the use of vehicle safety checklists before operation. Common safety checklists include verifying the vehicle's state, registration, and passenger safety, if applicable. In this case, these safety checks are expected to be carried out by the driver, who is also expected to adhere to working hours regulations. Pre-shift vehicle inspections generally include a list of components and vehicle functionalities to be reviewed, such as vehicle integrity (brakes, tires, fluid levels), vehicle registration, and vehicle cleanliness (State of California Department of Motor Vehicles, 2022; International Road Transport Union (IRU) Academy, 2022; Department of Transport, Government of Western Australia, 2022).

- Applicability: High. The concept of safety checklists may be adopted in L4 ADS fleet operation with minimal modification. Pre-shift inspections are expected to be performed by the MOC crew prior to a vehicle’s operational shift.

- Potential modifications: Vehicle pre-shift inspections may include ADS-specific functional tests in addition to physical inspection (sensor status, passenger-vehicle communication channels, etc.).

Incident Management and Reporting

Incident reporting is expected to be managed by the fleet operator, potentially in coordination with the ADS developer, based on the guidelines or requirements specified by the corresponding regulatory entities. In general, a federal or state-level agency manages incident reporting in safety-critical industries.

Automated Commercial Vehicles

The autonomous trucking industry details a checklist of post-incident procedures and data collection methods to support incident investigation. The checklist of post-incident procedures includes measures for onboard or adjacent safety drivers such as: stopping the vehicle and turning off the engine, turning on hazard signals, moving to the side of the road if possible, contacting supervisors, calling 911 if applicable, and completing a standard accident report form (Aurora, 2022; Locomation, 2022). Data-collection methods include autonomous system data recorders for collecting sensor data, electronic logging devices for capturing driver and truck status, and driver vehicle inspection reporting to be completed by the driver.

- Applicability: Medium. Multiple elements of the post-incident procedure checklists are expected to be performed by onboard safety drivers, which are not inclided in the reference fleet.
- Possible modifications: ODD-infringement response and incident management principles can be adapted to include MaaS aspects and no-safety driver situations in remote fleet operator procedures. Information hierarchy is required to design data collection capacities and requirements for maintenance procedures and incident investigation. Procedure design principles can be adapted to the higher level of automation in ADS systems.

Autonomous Marine Vessels

Autonomous marine vessel research has developed best practices for incident management to increase safe vessel operation. These procedures expand upon incident prevention and management procedures developed for non-automated maritime vessels. These include activating a stop work authority procedure, implementing safety checks of communication channels before vessel departure, and developing emergency procedures for adverse weather and specific emergency scenarios (Stockton University Marine Field Station, 2022).

- Applicability: Medium. L4 ADS vehicle operation guidelines may rely on similar mechanisms to ensure operators can communicate with the vehicle before operation and enforce effective ODD restrictions depending on road and environmental conditions.
- Possible modifications: Procedure and intervention mechanism design principles can be adapted to the higher level of automation in ADS systems. Adverse weather operation is dependent upon the specified ODD.

Civil and Commercial Aviation

The Federal Aviation Administration (FAA) has formally developed incident reporting guidelines and databases. For instance, the Aviation Safety Reporting Program (ASRP) is a voluntary program described in the Aeronautical Information Publication (AIP) (Federal Aviation Administration, 2022). Reports can be developed by pilots, controllers, flight attendants, maintenance personnel and other users of the airspace system, or any other person, to file written reports of actual or potential discrepancies and deficiencies involving the safety of aviation operations. The operations covered by the program include departure, on route, approach, and landing operations and procedures, air traffic control procedures and equipment, crew and air traffic control communications, aircraft cabin operations, aircraft movement at the airport, near midair collisions, aircraft maintenance and record keeping, and airport conditions or services.

A separate procedure refers to the Near Midair Collision (NMAC) Reporting Program, aimed to develop programs, policies, and procedures to reduce these incidents. Flight Standards Facilities investigate these reports in coordination with Air Traffic Facilities. Data from these investigations are transmitted to FAA Headquarters in Washington, D.C., where they are compiled and analyzed, and where safety programs and recommendations are developed. These NMAC reports include key flight information, such as the incident's date, time, location, and altitude, as well as evasion actions and injuries, if any. The investigation may also examine existing radar, communication, and weather data. When possible, all cockpit crew members and air traffic controllers are interviewed regarding factors involving the NMAC incident.

Additionally, data analytic processes must review incidents' performance promptly to ensure no crucial flaw is present in other aircraft. Finally, collaboration between managers and employees on self-reporting incidents performance is crucial.

- Applicability: Medium. Incident investigation and safety policies in this industry are mainly driven by federal-level agencies.
- Potential modifications: Incident reporting principles can be adapted to MaaS and ADS specific contexts. Fleet operators of L4 ADS vehicles may be expected to record incidents and develop comprehensive databases for internal and regulatory use. The widespread adoption of common reporting guidelines may depend on regulatory entities.

Passenger and Commercial Vehicles – Passenger Transportation

Passenger transport ride-hailing services (such as Lyft, Uber) limit their incident management to general safety guidelines for drivers and passengers. Incident management, in general, relies on community reports to contact emergency services or the companies' dedicated emergency response lines to offer support (Lyft, 2021). Additionally, dedicated safety teams may be available to assist passengers in an emergency through a dedicated emergency phone number.

- Applicability: Medium. Passengers may not be expected to initiate post-incident procedures as a significant portion of ADS vehicle operation may not include passengers on board.
- Possible modifications: Safety team roles and functions principles can be adapted for MaaS context.

Railroad Systems

Railroad incident reporting requirements are developed at the federal level by the Federal Railroad Administration (FRA) (U.S. Department of Transport Federal Railroad Administration, 2022). Types of incidents are defined and require specific forms and details to be reported. The primary groups of accidents and incidents to be reported monthly by railroads are highway-rail grade crossing accidents, rail equipment incidents, and casualties to persons. In addition to monthly railroad-reported accidents and incidents, railroads are required to provide FRA with immediate notification of diverse types of accidents.

- Applicability: Medium. Incident investigation in this industry is mainly driven by federal-level agencies.
- Possible modifications: Incident reporting principles can be adapted to MaaS and ADS specific contexts. Fleet operators of L4 ADS vehicles may be expected to record incidents and develop comprehensive databases for internal and regulatory use. The widespread adoption of common reporting guidelines may depend on regulatory entities.

Training and Certification

Across multiple industries, the training and certification of operators and pilots may depend on external private or local-, state-, and/or federal-level agencies.

Civil and Commercial Aviation

Extensive documentation for the training, testing, and certification of pilots and air traffic controllers has been developed at the federal level. Pilots' three most important skills are scenario-based training, learner-centered grading, and single pilot resource management (Robertson, 2010). In addition, aviation training emphasizes that pilots should be comfortable with automation. To this end, training emphasizes information management and determining which mode of automation to use in specific scenarios (Robertson, 2010).

- Applicability: Medium. Operators are expected to interact remotely with the ADS-equipped vehicles and passengers.
- Possible modifications: Scenario-based training needs to be developed in control room scenarios, where single pilot resource management may not be applicable.

Civilian Drone Operation

As the drone industry has become more commercialized, standard operational and pilot training guidelines have been developed. Generally, these best practices are focused on the separate roles drone operators and pilots are required to perform. Drone operators must register the drone, develop operational procedures, operate within areas with no radio interference, train pilots for operator-specific operational procedures, and ensure drone maps are geo-aware and up to date. Drone pilots may be required to acquire a drone pilot license (EASA, n.d.).

- Applicability: Low. This industry considers drone pilots and operators as different entities, in which the drone pilots may receive external training and certification.

- Possible modifications: Registering and certifying fleet operators may require regulatory entity inputs. Procedure design principles can be adapted to the higher level of automation present in ADS systems.

Nuclear Power Plants

Extensive documentation of operator training and operation guidelines for monitoring and supervising nuclear systems have been developed. These guidelines and government-level requirements are based on thorough risk analysis and the system addresses multiple aspects of training, certification, and operation of nuclear power plants. Training policies at a high level focus on crew members' role as supervisors and their interaction with systems of varying levels of automation. Periodic scenario-based training in simulated control rooms focusing on specific incident scenarios is key to these systems' operation. (EPRI, 2005).

- Applicability: Medium. Operators function as a crew with specified roles and responsibilities. Operators interact with a lower-level autonomous system and may directly intervene in the system's operation.
- Possible modifications: Procedure design and training principles can be adapted to the higher level of automation present in ADS systems.

HSI Design and Control Room Environment Operation

The design of HSI functions and presentation have a key role in improving the safety of system operation, independent of the level of automation. In combination with the design of control room environments, these design choices and requirements directly affect the roles and responsibilities of operators.

Automated Commercial Vehicles

Research in autonomous commercial vehicle operation has provided insights into HSI design to improve the safety of their operations. As onboard and/or remote operators are expected to interact with the ADS-equipped vehicles, research has focused on identifying design aspects that may be introduced or improved to increase situational awareness. In particular, six challenges have been identified as relevant to the teleoperation of fleets: lack of physical sensing, human perception, video and communication quality, interaction with humans, impaired visibility, and lack of sounds (Tener & Lanir, 2022). To address these challenges, HSI design suggestions include adding cues to bridge the physical disconnect and depth perception, adding contextual road information, and emphasizing the cause for intervention requests (Tener & Lanir, 2022).

- Applicability: High. Main findings from human factors research addressing human-system interaction may provide relevant guidance to HSI design.
- Possible modifications: HSI design principles can be adapted to the higher level of automation in ADS systems and include MaaS aspects into the ADS system monitoring when no safety driver is in the vehicle. Information hierarchy is required to design data collection capacities and requirements for real-time monitoring and intervention functions.

Autonomous Marine Vessels

Regarding HSI and control room design, autonomous marine vessel research has focused on identifying key modifications required to adapt existing non-automated system operation guidelines and standards. Research has focused on identifying design aspects that may be introduced or improved to increase situational awareness, such as the use of alarm systems, and developing context-based emergency procedures is highly recommended (Man et al., 2015). Additionally, ambient displays, remotely movable cameras, and multimodal presentation of information are also suggested (Wahlström et al., 2015).

- Applicability: Medium. The difference between operations of ADS and vessels' number ef elements to monitor and the timiming of events may lead to different requirements in HIS design.
- Possible modifications: HSI design principles can be adapted to ADS operations.

Nuclear Power Plants

Extensive documentation of system design and operator training guidelines for monitoring and supervising nuclear systems have been developed. In these systems, the established goal of control room environments is to provide enhanced ability to personnel to monitor and supervise automation and greater cooperation between human and autonomous agents (EPRI & U.S. Department of Energy, 2004).

The operation of nuclear power plants and control room environments are heavily regulated, and formal design guidelines for HSI design, operator training, and emergency response have been created. In these systems, personnel interacts with the plant supported by an automation system with varying levels of autonomy. This system accurately represents the power plant, providing input and guidance for decision-making, and may be interrupted or complemented by personnel actions. Note that personnel interaction with automation should be supported with operational and emergency procedures. Some relevant guidelines regarding the functions of the HSI are:

- HSI should provide a means for personnel to modify the goal of automation and provide controls that simplify achieving the desired level of automation. Adjustments to the level of automation should be initiated or approved by personnel.
- Personnel should be able to delegate some tasks to automation. HSI should indicate the current mode of automation and identify the agents performing specific actions and the status of actions.
- There should be adequate task transfer when switching between automation modes, supporting situation awareness and crew task performance. Additionally, HSI should provide controls to suspend or terminate automation mode.
- HSI control entry fields used by personnel should be presented close to information that must be monitored and provide alerts for manual inputs, if necessary.
- HSI should provide a means to query automation tasks to determine the underlying decision-making process. Additionally, the system should provide feedback about the personnel's actions.
- HSI should indicate appropriate cautions and warnings and alert operators when a condition may prevent automation from functioning. Similarly, HSI should provide

information indicating when automation is needed and indicate initial conditions required for the automation to function.
- HSI should indicate automation failures and errors. HSI should indicate reasons for automation failures. HSI should provide rapid access to backup actions.

General recommendations for HSI design also include utilizing navigation aids when employing multiple displays. Its design should minimize secondary tasks and distractions and contain features that reduce the effort required to interact with automation. For instance, warning messages and alarms are presented in a prioritized order and are always marked with timestamps. Remote control rooms for offshore oil and gas facilities and traffic control report following similar design guidelines to those discussed for nuclear power plants (in general, considering lower levels of autonomy) (Hurlen et al., 2022).

- Applicability: Medium. Operators interact with a lower-level autonomous system and may directly intervene in the system's operation. Note that ADS generally do not consider dynamic levels of automation.
- Possible modifications: Information and alarm hierarchy need to be determined for MaaS applications. Control room environment and HSI design principles can be adapted to the higher level of automation present in ADS systems.

Other Industries with Low Level of Autonomy (LoA) systems

Other industries with low levels of automated systems with applicable best practices include using automated heavy mining vehicles to perform pre-defined and standardized tasks. The vehicles follow designated paths between fixed destinations, and onsite operators monitor the vehicles and road conditions in real-time. In general, in commercial mining vehicles with low-levels of automation, the HSI function and design include anomaly-based alarm systems, visualization of the vehicles' current position and projected paths, connectivity status, and industry-specific performance metrics.

- Applicability: Medium.
- Potential modifications: HSI design principles can be adapted to the higher level of automation and operational conditions present in ADS systems.

Main Findings

This report reviews various industries that share operational similarities to the deployment of L4 ADS fleets for MaaS. The key areas reviewed concern inspection and maintenance procedures, incident management and reporting, training and certification of operators, and design guidelines of HSI and control room environments. These best practices identified with medium and high applicability are used to inform the development of the L4 ADS fleet operators' safety responsibility (Task 4). The most relevant best practices include:

- Implementing detailed inspection checklists for vehicles before operation. These vehicle pre-shift inspections may include ADS-specific functional tests and physical inspection (sensor status, passenger-vehicle communication channels, etc.).

- Developing detailed incident reporting and investigation procedures. Fleet operators of L4 ADS vehicles may be expected to record incidents and develop comprehensive databases for internal and regulatory use. However, the widespread adoption of common reporting guidelines may depend on regulatory entities. It may benefit fleet operators to introduce these reporting and transparency practices before being formally required by regulatory authorities.
- Developing data collection policies to support incident investigations. The information collected during operation and after an incident should be adapted to reflect MaaS aspects and no driver situations in remote fleet operator procedures (such as the roles of remote safety teams). For instance, filing different forms depending on the type of incident, investigating potential root causes, and determining corrective actions. A formal information hierarchy is also required to design data collection capacities and requirements for maintenance procedures and incident investigation.
- Training personnel in different aspects of system operation. Scenario-based training and HSI use may be highly relevant to the fleet management system, remote operators, and maintenance crew. Additionally, developing and training personnel to follow and implement comprehensive operational procedures and scenario-specific emergency procedures. Further discussion is recommended regarding single-operator and crew scenario-based training in control room scenarios for L4 ADS operation. Registering and certifying fleet operators may require regulatory entity inputs.
- Adapting HSI and control room environment design principles to the higher level of automation in ADS systems, including MaaS aspects into the ADS system monitoring when no safety driver is in the vehicle, and support situational awareness of remote operators. Further discussion is recommended regarding the information hierarchy required to design data collection capacities and requirements for real-time monitoring and intervention functions.

Appendix

[Full Applicability Table]

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