Advances in Reliability, Safety and Security, Part 1 – Kołowrocki, Dąbrowska (eds.)
© 2024 Polish Safety and Reliability Association, Gdynia, ISBN 978-83-68136-13-5 (printed), ISBN 978-83-68136-00-5 (electronic)

Advances in Reliability, Safety and Security
ESREL 2024
Monograph Book Series

Task Allocation And Control Transitions In Autonomous Driving System Operations

Camila Correa-Jullian[a], Marilia Ramos[b], Ali Mosleh[b], Jiaqi Ma[c]

[a]Department of Mechanical and Aerospace Engineering, University of California Los Angeles, Los Angeles, USA
[b]B. John Garrick Institute for the Risk Sciences, University of California Los Angeles, Los Angeles, USA
[c]Department of Civil and Environmental Engineering, University of California Los Angeles, Los Angeles, USA

Abstract

Automated Driving Systems (ADS) are expected to play a significant role in the transportation environment in the coming decades, either deployed for passenger transport or as features in privately-owned vehicles. In both cases, humans will continue interacting with these systems as drivers, operators, and/or fellow road users. An element defining the current levels of driving automation is the task division and allocation between the human and the autonomous agent while operating under specific conditions. In this context, takeover and handover events, i.e., control transitions that can be triggered by exceeding the specified operational conditions, have become a focus of interest in multiple safety, reliability, and human factors research. This work discusses the high-level tasks human and autonomous agents perform in ADS operations. Three cases of interest are defined based on their relation to the ADS-equipped vehicle: a remote operator, a safety driver, and a consumer-level driver. This definition is based on which agent is responsible for high-level tasks, such as monitoring, planning, and executing the Dynamic Driving Tasks. A new taxonomy for control transitions and interventions is proposed for the three use cases. This taxonomy considers who initiated the control transition, who is in control after the transitions, the context that triggers the event, and whether it is a success or failure. Including successful or failed states in the taxonomy is relevant to address potential hazard scenarios and develop appropriate safety mechanisms to prevent or mitigate their risk.

Keywords: automated driving systems, control transitions, takeover and handover, task allocation

---

1. Introduction

The participation of Automated Driving Systems (ADS) vehicle technology in the transportation landscape is expected to increase in the near future. Currently, the Society of Automotive Engineers (SAE) defines six levels of vehicle automation (SAE International, 2021). These levels are broadly divided into driver support features (Levels 0-2) and automated driving features (Levels 3-5). This division is based on the task allocation between the human and the automated driving technology. From Level 3 (L3) onwards, the Dynamic Driving Tasks (DDTs) are progressively transferred from the human driver to the ADS. However, at L3, the human driver is still expected to act as a ***fallback-ready user***, intervening in the vehicle's actions upon the request of the ADS. These control transitions between the driver and the autonomy occur when approaching the exit of the Operational Design Domain (ODD) or in unexpected situations (Favarò, Eurich and Nader, 2018; Boggs, Arvin and Khattak, 2020). Currently, Mercedes-Benz owns the only system certified as L3 in the U.S (Mercedes-Benz, 2023). Vehicles equipped with L4 ADS with no safety drivers became the focus of passenger transport for Mobility as a Service (MaaS). In the U.S., Waymo, Cruise, and Zoox are at varying levels of development, deployment, and commercialization of passenger transport services (California DMV, 2024). Recent incident reports imply that a more focused approach on operational safety are required, for instance, to avoid traffic disruptions, or to determine appropriate incident management procedures (National Highway Traffic Safety Administration, 2022). At L4, the ADS are expected to perform fallback and achieve a Minimal Risk Condition (MRC) autonomously; hence, the user is not expected to monitor or intervene in the vehicle's actions *while* the vehicle remains within the ODD. Yet, it is likely that for the foreseeable future, remote human assistance will be required to support vehicle operations (Kettwich et al., 2021). Level 5 (L5) represents a theoretical fully self-driving vehicle, unrestricted in its operational range.

Control transitions between the human and the automated driving system are designed to account for limitations of the ADS capabilities at certain levels of autonomy. This mechanism allows the human to take control of the vehicle and operate it outside of its ODD, considering for instance, geographical, road type, or weather restrictions, vehicle perception failures, or as a safety measure when encountering traffic conditions out the ODD's scope. In this shared-autonomy regime, it becomes necessary to outline the possible driving states and conditions under which the human or autonomous agent (the automated driving system) performs the DDTs. The division and allocation of these tasks have played an important role in the Society of Automotive Engineer (SAE) levels of automation definition and other regulatory bodies. Multiple studies have explored task allocation, situational awareness, task complexity and task load, as well as the collaboration between the human driver or remote operator with the autonomous driving agent (Mutzenich et al., 2021; Xing et al., 2021; Chu et al., 2023). Similarly, many taxonomies for driving states and control transitions have been proposed to represent the different driving situations possible in a shared-autonomy setting (Maggi et al., 2022). These taxonomies mainly focus on scenarios where the driver on-board interacts with L2/L3 ADS-equipped vehicles. In (Lu et al., 2016), authors discussed the division of primary driving tasks into (1) Lateral control (steering, lane changing, curve driving), (2) Longitudinal control (starting, accelerating, stopping), and (3) Monitoring. They define five static driving states based on whether the longitudinal and lateral control either switches to one of the two agents or is a combination of both. The combination of the driving states and the underlying reason for the control transition generates six control transitions (Fig. 1). This classification depends on (a) who initiates the control transition, (b) who is in control of the vehicle after the transition, and (c) the situation under which the control transition occurred. The latter is used to indicate whether the transition is voluntary or optional, or triggered by an external situation such that it becomes mandatory.

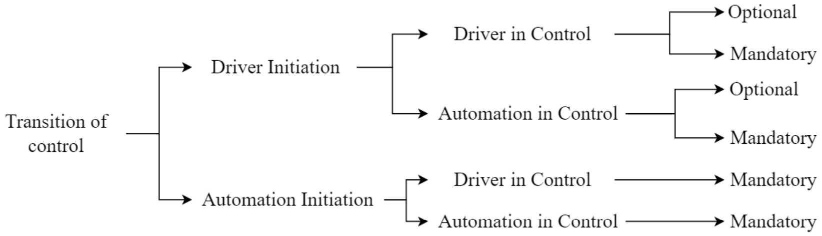

Fig. 1. Classification tree of transitions of control. Adapted from Lu et al., 2016.

Alternatively, (McCall et al., 2019) categorize vehicle control on three levels: operational (low-level interactions, i.e., accelerating), tactical (e.g., obstacle avoidance), and strategic (e.g., navigational planning). They propose a control transition taxonomy that covers scheduled, emergency, and non-emergency handovers (in this case, from the autonomous agent to manual control) and differentiates between system- and driver-initiated control transitions. The combination of these factors leads to the control transitions: a) scheduled handover, b) non-scheduled handover – driver initiated, c) non-scheduled handover – system initiated, d) non-scheduled handover – driver-initiated emergency, e) non-scheduled handover – system-initiated emergency. Other studies, such as (Walch et al., 2015) distinguish how the control transition mechanisms differentiate the type of transition. Walch et al. include immediate handover (e.g., when drivers grasp the steering wheel), a stepwise handover control (e.g., first longitudinal control followed by lateral control, or vice versa), driver monitored handover (e.g., by grasping the steering wheel and after a countdown, the control is handed over), and system monitored handover (e.g., the system monitors the inputs of the driver after the handover). In (Wintersberger, Green and Riener, 2017), the sequence of events occurring in both handovers (driver to the autonomous agent) and hand-backs (autonomous agent to driver) is also discussed, differentiating between urgent or imminent control transitions, and scheduled or voluntary transitions.

The discussed taxonomies do not include the event's outcome or mention failed or refused transitions. Providing a taxonomy that includes outcomes and consequences may be a starting point to discussions of dynamic levels of autonomy and their impact in safety measure design (Yang et al., 2020). Further, these taxonomies do not apply to the case of a remote operator monitoring the vehicle's operation, which has become a highly discussed topic based on recent incident reports (National Highway Traffic Safety Administration, 2022). For driverless applications (L4), it is plausible that monitoring and supervision tasks fall to remote operators to some extent. The challenges these operators face differ substantially from on-board drivers, principally given the physical disconnection to the vehicle. Thus, remote operators must rely entirely on the human-system interface provided, the information transmitted by the vehicle, and are subject to external network latency issues (Zhang, 2020; Kuru, 2021; Tener and Lanir, 2022). The inclusion of failed/successful end-states and extending the control transition discussions to remote operators are two elements that are key to performing safety assessments of conditional and highly automated vehicle operations currently envisioned as L3/L4. This work presents a first step to analyze the tasks that will be performed by the human and autonomous agents in these operations. For this, different agent profiles are defined based on their main functions and tasks. Following this, a control transition taxonomy is presented for the three use cases: a remote operator, a safety driver, and a consumer-level driver. Finally, we discuss the implications for future work on interaction, collaboration, and teams of human and autonomous agents.

2. Definition of agents and high-level tasks

The analysis considers a passenger vehicle equipped with ADS capabilities to operate within a specified ODD. The ODD includes urban and suburban areas with adequate connectivity conditions for localization and communication purposes, and the vehicle operates under fair weather conditions during daytime and nighttime, including clear, cloudy, and only moderate fog, rain, and snow conditions. The ADS-equipped vehicle has three main functions:

1. Perform Autonomous Driving tasks: vehicle perception, planning and control. It includes the entirety of the object and event detection and reaction (OEDR) functionality under nominal conditions, ensuring operation is within the intended ODD, determining and implementing DDT fallback strategies, and entering an MRC if required to ensure safety.
2. Maintain the vehicle integrity: maintenance of the required levels of integrity of the vehicle's safety-critical physical and cyber systems. It includes using a self-diagnostic module that continuously monitors the vehicle's ADS functionality, as well as regular vehicle health indicators, generating alerts or triggering adequate DDT fallback in the event of system failures.
3. Provide interaction and communication mechanisms: human-system interaction and communication mechanisms appropriate for the use case. It includes on-board interactive displays, alert and warning messaging systems, wireless and local communication channels, and control transition, driver monitoring and/or emergency mechanisms. To perform its communication tasks, the ADS must rely on either wireless connection over 5G cellular networks or on-board alerts.

The analysis considers three possible use cases of ADS-equipped vehicles. These profiles are loosely based on the current definitions of L3/L4 levels of driving automation but consider dynamic changes based on the driving situation and the state of the vehicle (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Case I: Remote safety operator supervising a high-level ADS-equipped vehicle for MaaS.
- Case II: On-board safety driver supervising a high-level ADS-equipped vehicle for MaaS.
- Case III: Consumer-lever driver in a privately-owned ADS-equipped vehicle.

The definition of these cases is based on *which* and *when* an agent is primarily responsible for performing high-level tasks. Four levels of engagement are used to describe the participation of the agents and categorize these in Case I-III depending on the following high-level tasks:

- Monitor DDTs: Perform Object and Event Detection tasks.
- Plan DDTs: Perform the planning stage of the Object and Event Reaction tasks.
- Execute DDTs: Perform the execution stage of the Object and Event Reaction. In the case of the remote operator, this refers to selecting and transmitting fallback commands to the vehicle.
- Control Vehicle: Physically control the vehicle.
- Supervise Vehicle: Monitor the state of the vehicle.
- Monitor Driver/Operator: Monitor the state of the driver/operator.
- Initiate Control Transitions: Initiate the control transfer request or commands. In the case of the remote operator, this refers to transmitting fallback commands to the vehicle.
- Request Support: Request support from other agents to perform shared tasks.
- Perform MaaS Functions: Performs tasks related to passenger transport, including passenger pick-up/drop-off, passenger support, etc.

The four levels of engagement are: (1) Always: This task is continuously performed or available during the system's operation; (2) Partial: This task is performed temporarily (when the ADS is engaged) or up to a partial degree (the remote operator is engaged with multiple vehicles); (3) Backup: This is a safety-backup task only performed if another agent has failed to perform a main or temporary task; and (4) Never: The agent does not perform this task during operation.

Table 1. Driving profile summary.

Case	Agent	Monitor DDTs	Plan DDTs	Execute DDTs	Control Vehicle	Supervise Vehicle	Monitor Driver/ Operator	Initiate Control Transition	Request Support	Perform MaaS Functions
I	ADS	Always	Always	Always	Always	Always	Never	Never	Always	Always
	Safety Operator	Partial	Backup	Backup	Never	Partial	Partial	Always	Never	Backup
	ADS Advisory	Always	Always	Never	Never	Always	Always	Never	Partial	Never
II	ADS	Always	Partial	Partial	Partial	Always	Always	Always	Partial	Partial
	Safety Driver	Partial	Partial	Partial	Partial	Partial	Partial	Always	Never	Partial
III	ADS	Always	Partial	Partial	Partial	Always	Always	Always	Partial	Never
	Driver	Partial	Partial	Partial	Partial	Partial	Partial	Always	Never	Never

In Case I, the operation is supported by a Fleet Operations Center (FOC) and a Maintenance Operations Center (MOC) (see (Correa-Jullian et al., 2022a, 2022b) for a full definition of the FOC and MOC). The remote operator is a crew member trained and/or certified to operate in MaaS contexts, supervising the fleet operations from a control room environment (FOC). The remote safety operator has three main functions: (1) Supervise the trip status of multiple vehicles and intervene in the vehicles' operation when requested; (2) dispatch the vehicle to various locations depending on vehicle status, location, and occupation status, e.g., to the MOC, battery charging station, etc.; and (3) report anomalous vehicle behavior or MRC events to the MOC. The safety operators can transmit commands to the vehicle to implement specific DDT fallback strategies, guide it through trajectory waypoints in challenging situations, and remotely trigger the vehicle to enter an MRC. In the event of an MRC, the operator initiates post-incident procedures and contacts law enforcement and first responders, if required. Alert messages include those referring to safety (e.g., an incident has occurred), vehicle health (e.g., a vehicle failure has been detected), and stop requests (from passengers or third parties). The ADS may notify the operator of actions implemented without needing approval (e.g., re-routing to avoid traffic) or transmit regular vehicle warnings or suggested actions based on internal health metrics (e.g., request dispatch to charging station given low battery). Additionally, some information is communicated passively, such as vehicle location, health metrics or indicators (e.g., battery levels, diagnostic logs, connectivity status), processed video and audio feed.

In Cases II-III, both the on-board driver and the ADS may perform the DDTs, as well as their respective perception and localization data collection tasks. Case II refers to a safety driver trained and certified to perform safety tasks (supervision, response to take-over requests, initiate disengagements) and interacts with the ADS agent, the on-board passenger, and remote fleet operators who provide limited service-related support. In contrast, Case III refers to a consumer-level driver in an ADS-equipped vehicle for personal use. This driver has a limited knowledge and understanding of the vehicle's operating conditions, functionalities, and alerts. When the ADS is actively engaged, the on-board driver may act as a fallback-ready user, independently of whether the ADS agent can nominally perform the DDT fallback. When the ADS agent is not engaged, the on-board driver performs the regular DDTs expected during manual driving and can request the ADS agent to engage when appropriate. The driver can initiate control transitions (e.g., manual input) or accept take-over requests (e.g., steering wheel control or braking). The on-board driver, while expected to perform monitoring tasks continuously, may fail to maintain situational awareness (reduced attention, engaging with NDRTs) regarding the state of the vehicle and driving environment. Thus, the ADS is equipped with non-invasive driver monitoring tools to keep the driver engaged with the DDTs. Alert messages include those referring to safety (e.g., multi-model audio, visual, and haptic alerts), driver monitoring (e.g., front-facing gaze or hand-on steering wheel), vehicle health (e.g., a vehicle failure has been detected), driver-initiated control transfer status (e.g., success or failure), and system-initiated control transfer (i.e., take-over requests). The ADS may transmit regular vehicle warnings or suggested actions based on internal health metrics (e.g., low battery or tire pressure). Additionally, some information is communicated passively, such as general health metrics, as well as infotainment and navigation applications.

3. Driving states and control transitions

To define control transitions, we must first differentiate the driving states for the on-board driver and the remote operator cases. When the automation is engaged, the ADS agent is responsible for both the longitudinal and lateral controls, plus the monitoring task. At planning level, the ADS controls the operational and tactical maneuvers the vehicle must perform, while the strategic goals are determined by another agent (remote operator, safety driver, or passenger). Six driving states can be defined for Cases I-III depending on whether the automation is engaged (Table 2).

In Case I, the autonomy agent is continuously engaged during operation performing all vehicle perception, planning, and control tasks. The vehicle only disengages the ADS agent after entering MRC in the event of an incident. The remote operator agent performs monitoring tasks and may transmit dispatch or fallback commands if required. Note that the remote operator may be expected to monitor multiple ADS agents simultaneously, which brings additional challenges from the perspective of task load and system design that need to be addressed by system designers. In Cases II-III, when the automation is engaged, the driver is still required to perform monitoring tasks to some degree and may request control transfer if desired. The extent of the monitoring tasks will depend on multiple factors, including system design and the role designated to the driver by the ADS developer, vehicle OEM, or fleet operator, respectively. However, when the automation is not engaged, the ADS agent is still performing monitoring tasks focused on the driving environment and the driver (through the DMS). Based on the collected information, the ADS is expected to provide warnings, alerts, or request control transitions if required.

Table 2. Driving states defined for Cases I-III.

Case/State	ADS Engaged			ADS Disengaged		
Case I	Longitudinal	Lateral	Monitoring	Longitudinal	Lateral	Monitoring
Safety Operator	No	No	Yes	N/A	N/A	Yes
ADS	Yes	Yes	Yes	N/A	N/A	Yes
Case II-III						
Driver	No	No	Yes	Yes	Yes	Yes
ADS	Yes	Yes	Yes	No	No	Yes

3.1. Case I: remote safety operator

In driverless ADS applications for MaaS, the vehicle control is exclusive to the ADS software. Hence, there is no physical control transition mechanism in place. While remote operators can transmit dispatch commands, trajectory waypoints and DDT fallback commands, the ADS-equipped vehicle is the agent responsible for incorporating these commands into its path and vehicle control planning modules. The remote operator is considered to initiate control transitions when transmitting dispatch or fallback commands, as they do perform the planning and implementation of vehicle control (except the execution). For this purpose, we will refer to these as control interventions rather than control transitions. For the remote operators, we establish the following rules of control interventions:

- The control interventions may be initiated by the remote operator, based on the information provided by the ADS vehicle or passenger support unit (service operators). These intervention requests may be highly time sensitive. For instance, in case the ADS has failed to implement a DDT fallback correctly to achieve MRC or has not detected the need to do so the remote operator transmits a DDT fallback command ("necessary interventions").
- Other interventions initiated by the operator can also be of low time sensitivity, such as in the case of rerouting vehicles to the MOC for preemptive charging or for scheduled maintenance events ("suggested interventions"). If the operator does not intervene at this stage and the system evolves towards a higher-consequence scenario, this may trigger the vehicle to alert the operator for a "necessary intervention" as described or a "recommended intervention" as detailed below.
- Control interventions may also be initiated by the automation requesting the intervention of the remote operator based on alerts and warnings. In general, these interventions are expected to be highly time-sensitive, such as the case of the vehicle encountering an edge-case and requesting support, or after the vehicle has achieved MRC in response to an ODD breach or critical failure. It is useful to distinguish between highly time-sensitive responses ("necessary interventions") and moderate time-sensitive responses ("recommended interventions"). In the latter case, remote operators would respond to vehicle alerts requesting confirmation or supporting in rerouting to maintenance centers for non-critical repairs, battery charging, etc. In the case the remote operator does not provide support to the vehicle within a

specified timeframe, it may trigger the ADS to implement an emergency stop and post-incident procedures being initiated.

- It is expected that the ADS receives the control intervention commands, incorporates them into its planning tasks, and implements the resulting vehicle control actions. While many factors may contribute to a failure in the implementation (communication failures, software, or vehicle control failures), it is considered that the vehicle must always comply with these requests, in the form of incorporating them into the built-in OEDR planning module.

Considering these high-level division of tasks, the following control transition taxonomy is presented (Fig. 2):

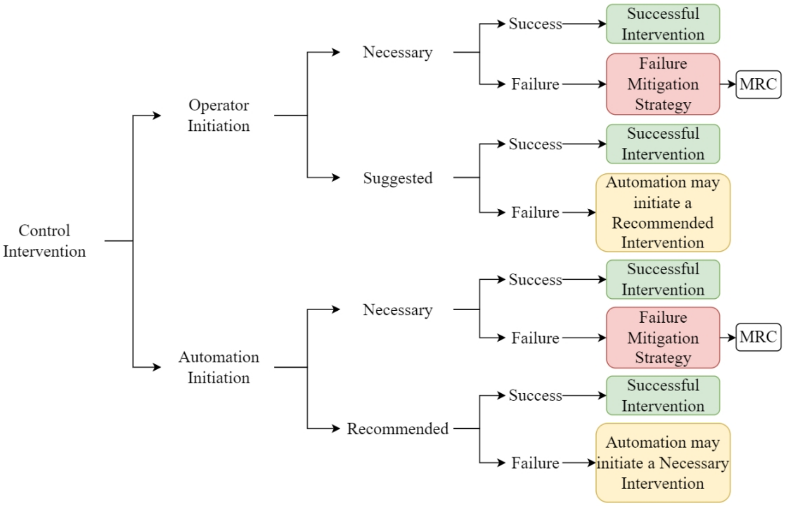

Fig. 2. Classification tree of control interventions, success, and failure end-states – Case I.

The remote operator may initiate control interventions resulting in:

1. Successful Necessary Operator-Initiated Intervention: The remote operator has detected the need for, planned, and transmitted the necessary commands prior to the vehicle requesting assistance.
2. Failed Necessary Operator-Initiated Intervention: The remote operator has failed to detect the need for, plan, or transmit the necessary commands prior to the vehicle requesting assistance. If the ADS does not implement a fallback autonomously, the vehicle is at risk of collision. A backup Failure Mitigation Strategy (FMS) may be available for the vehicle as defined by (SAE International, 2021).
3. Successful Suggested Operator-Initiated Intervention: The remote operator has detected the need for, planned, and transmitted preemptive commands to the vehicle.
4. Failed Suggested Operator-Initiated Intervention: The remote operator has not detected, planned, or transmitted preemptive commands to the vehicle. If the remote operator does not intervene, the situation may evolve to a Recommended Automation-Initiated Intervention (See 7-8).

The ADS may initiate control interventions resulting in:

5. Successful Necessary Automation-Initiated Intervention: The remote operator has detected the ADS request for a control intervention. The operator then plans and transmits the necessary commands to the vehicle to perform a DDT fallback.
6. Failed Necessary Automation-Initiated Intervention: The remote operator has not detected the ADS request, planned, or transmitted the necessary commands to the vehicle to perform a DDT fallback. If the ADS does not implement an FMS autonomously, the vehicle is at risk of collision.
7. Successful Recommended Automation-Initiated Intervention: The remote operator has detected the ADS alerts, planned, and transmitted the recommend commands to the vehicle.
8. Failed Recommended Automation-Initiated Intervention: The remote operator has not detected the ADS alerts, planned, or transmitted the recommend commands to the vehicle. If the remote operator does not intervene, the situation may evolve to a Necessary Automation-Initiated Intervention (See 5-6).

Note that this taxonomy does not consider the failure in the implementation of the intervention, i.e., the vehicle suffers a failure that interrupts the implementation. An example of how this interaction is represented by a sequence of events is presented in Fig. 3, showcasing interventions (1) and (2). In this case, the ADS-equipped vehicle has not detected that a DDT fallback is required. Hence, the remote operator acts as safety barrier, and based on the monitored information from the passengers and/or vehicle, can select and transmit the adequate fallback strategy. The reception and implementation of the DDT fallback command is the responsibility of the ADS agent. Another example is presented in Fig. 4, where a failed suggested intervention (3-4) may escalate to a necessary control intervention (5-6) if the remote operator does not react to the alerts transmitted by the ADS (7-8).

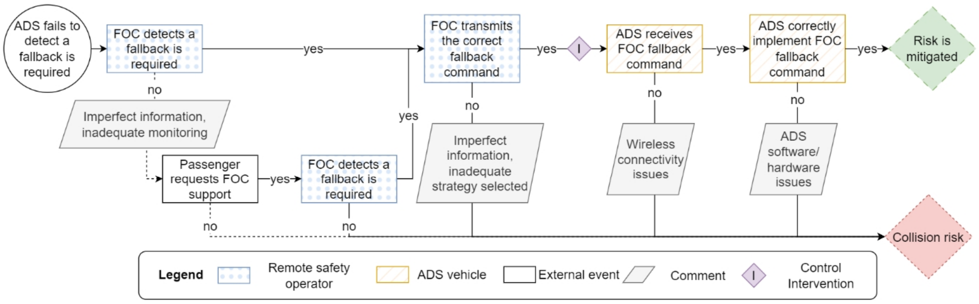

Fig. 3. Example of remote safety operator necessary control intervention to ADS-equipped vehicle.

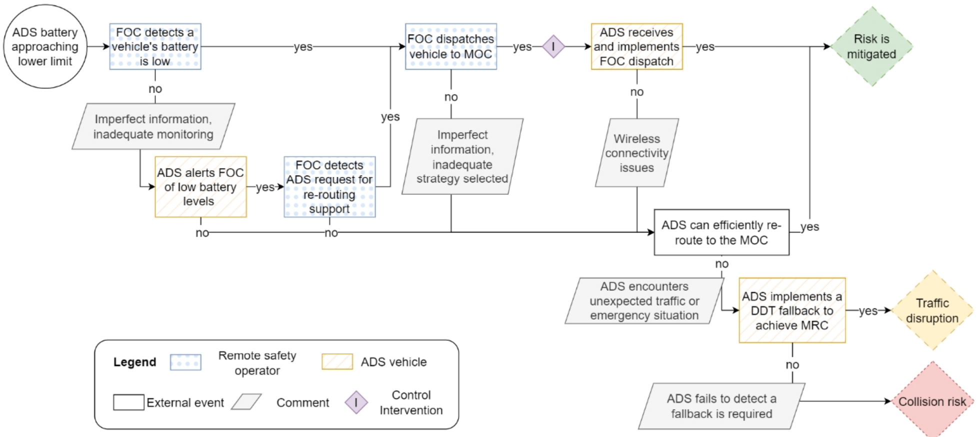

Fig. 4. Example of remote safety operator suggested to necessary control intervention escalation.

3.2. Case II-III: on-board driver

For use cases where there is a driver on board the vehicle, the ADS and the driver share control of the vehicle. As a convention for this work, when the control is transferred from the driver to the ADS it is referred to as ‘handover’ while when the control is transferred from the ADS to the driver it is referred to as ‘takeover’. The mechanisms available to the driver to initiate the control transitions are physical, either by directly engaging with the steering wheel, brakes, or throttle pedals when requested by the ADS or by requesting a handover through specific buttons installed in the steering wheel. For the drivers on-board, we establish the following rules of control transitions:

- When the driver initiates the handover, the ADS may approve or reject the request, given the driving context and the state of the vehicle. Frequently, the vehicle design may communicate the availability of handover transitions through the driver’s dashboard or main display. The driver may re-initiate the action after the required conditions have been satisfied, e.g., vehicle speed, weather conditions, distance to other vehicles.
- When the driver initiates the takeover, the ADS is expected to comply and transfer the vehicle control to the driver. However, it may be possible that waiting time may be requested by the system if it determines the conditions of the takeover are unsafe. As discussed in (Mercedes-Benz, 2023), this distinction depends on the intensity of the driver’s actions.

- The ADS agent may initiate a takeover, providing the driver with the necessary alarms, warnings, and assistance to regain situational awareness for a safe control transition. This request cannot be rejected, and if the driver does not react within a specified time limit, the vehicle is expected to fallback to an MRC, independent of the underlying reason for the takeover. If it is due to vehicle failure, the Failure Mitigation Strategy (FMS) function of the vehicle is expected to allow the vehicle to come to a safe stop.
- The ADS agent may request a handover, providing the driver with the necessary alarms and assistance to confirm the control transition. While the ADS agent may determine that the driver is unfit (through the DMS) or the driving conditions are unsafe to request the control transfer, the ADS agent cannot automatically initiate the handover. In the event the driver cannot or does not react within a specified time frame (approving or rejecting the control hand-over), the vehicle is expected to fallback to an MRC.
- Mandatory control transfers are related to vehicle failures and imminent ODD breaches, which may be detected by the vehicle and/or the driver.

Considering these high-level division of tasks, the following control transition taxonomy is proposed (Figure 5).

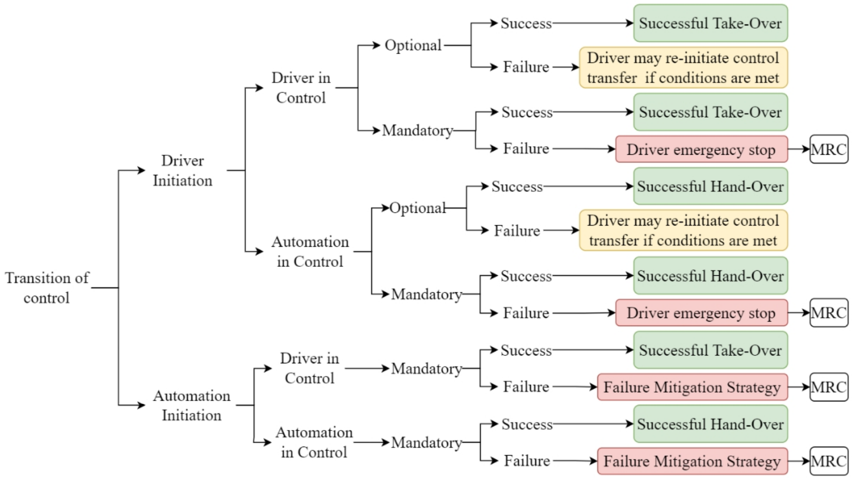

Fig. 5. Classification tree of control interventions, success, and failure end-states – Case II.

In this case, the distinction between optional and mandatory transitions are included. The driver may initiate control interventions resulting in:

1. Successful Driver Initiated, Driver in Control: Successful takeover, the driver has regained control of the vehicle from the ADS agent. This transition covers the Optional and Mandatory scenarios.
2. Failed Optional Driver Initiated, Driver in Control: Failed takeover, the driver may re-initiate control transfer if conditions are met.
3. Failed Mandatory Driver Initiated, Driver in Control: Failed takeover, the driver can request an emergency stop, overriding the ADS agent.
4. Successful Driver Initiated, Automation in Control: Successful handover, the driver has transferred control of the vehicle to the ADS agent. This transition covers the Optional and Mandatory scenarios.
5. Failed Optional Driver Initiated, Automation in Control: Failed handover, the driver may re-initiate control transfer if conditions are met.
6. Failed Mandatory Driver Initiated, Automation in Control: Failed takeover, the driver can request an emergency stop, overriding the ADS agent.

The ADS may initiate control interventions resulting in:

7. Successful Automation Initiated, Driver in Control: Successful takeover, the driver has regained control of the vehicle from the ADS agent.
8. Successful Automation Initiated, Driver in Control: Successful handover, the driver has transferred control of the vehicle to the ADS agent.
9. Failed Automation Initiated, Driver in Control: Failed takeover, if the driver does not engage, the ADS triggers a DDT fallback or Failure Mitigation Strategy (as required) to reach an MRC.

10. Failed Automation Initiated, Automation in Control: Failed handover, if the driver does not approve the hand-over, the ADS triggers a DDT fallback or Failure Mitigation Strategy (as required) to reach an MRC.

An example sequence of events showcasing transitions (1), (2), (4) and (5) is shown in Figure 6. In this case, the driver may request to handover the vehicle control to the ADS, but either the ADS is not available to engage, or complications arise that prompt the driver to takeover control from the ADS.

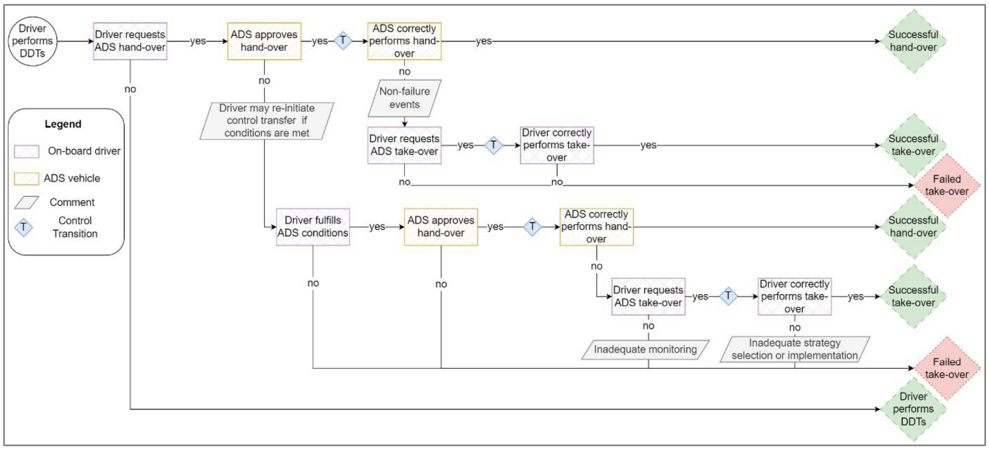

Fig. 6. Example of optional driver-initiated control transition sequence.

4. Discussion

As the ADS industry further develops and the technology matures, the taxonomies and definitions used to describe agents, mechanisms, scenarios, and failures in this context also need to evolve. An emerging theme in autonomous system design and safety, including vehicle automation studies, is to analyze human-system interaction from a collaborative perspective (Xing et al., 2021). In this context, the approach developed and applied in this work addresses three relevant issues. Firstly, it presents the ADS operations as a multi-agent system that is defined and analyzed at the same level of detail. By considering the human and the ADS as two agents performing a series of tasks for a common goal, i.e., acting as team members, we can leverage a substantial body of research on how human and organizational factors impact team performance. Pursuing this research direction may provide valuable insights into risk and safety assessments other than only from a functional safety standpoint. For instance, adequately defining what a failure event implies for human users and operators when interacting with an autonomous systems (Ramos et al., 2018). Secondly, it proposes a taxonomy that is applicable to two relevant use cases envisioned in the short- and medium-term of ADS operations: onboard drivers and remote operators. Lastly, it includes potential end-states of successful or unsuccessful control transitions. By including successful and failed outcomes in the taxonomy, we provide a path to expand the use of scenario-based tools to assess the effectiveness of the safety mechanisms and functions in a shared-autonomy setting.

5. Conclusions

As vehicles equipped with ADS capacities increase their share in the market and on the roads, either as personal vehicles or as passenger transport options, it is crucial to advance the state of understanding of human-ADS interactions and collaboration. This work presents a discussion on the task division and allocation between the human and the autonomous agents involved in the ADS operations. The three use cases focus on the interaction of remote operators, safety drivers, and consumer-level drivers with a highly automated vehicle based on the current definitions of L3/L4. Based on the task division and previous taxonomies, a control transition taxonomy is proposed for both the remote operator and the on-board driver. The taxonomy approach presented in this work is based on (1) which agent initiates the control transition, (2) which agent is in control of the vehicle after the transition, (3) the broad context that triggers the control transition, and (4) the success or failed end state of the control transition scenario. Examples are presented discussing the relevance of differentiating between suggested, recommended, and necessary control interventions in the case of the remote operator, as well as showcasing the communication mechanisms between the driver and the on-board driver. The proposed taxonomy serves as a starting point to define the failure events in the context of human-autonomy teams.

References

Boggs, A.M., Arvin, R., Khattak, A.J. 2020. Exploring the who, what, when, where, and why of automated vehicle disengagements, Accident Analysis & Prevention 136, 105406. Available at: https://doi.org/10.1016/j.aap.2019.105406.

California DMV 2024) Autonomous Vehicle Testing Permit Holders. Available at: https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-testing-permit-holders/ (Accessed: 16 January 2024).

Chu, M. et al. 2023. Work with AI and Work for AI: Autonomous Vehicle Safety Drivers' Lived Experiences, arXiv preprint arXiv …, 1(1). Available at: https://doi.org/10.1145/3544548.3581564.

Correa-Jullian, C. et al. 2022a. Modeling Fleet Operations of Autonomous Driving Systems in Mobility as a Service for Safety Risk Analysis., in M.C. Leva et al. (eds) 32nd European Safety and Reliability Conference (ESREL 2022). Singapore: Research Publishing Services. Available at: https://doi.org/10.3850/978-981-18-5183-4_J03-06-566-cd.

Correa-Jullian, C. et al. 2022b. Safety Hazard Identification for Autonomous Driving Systems Fleet Operations in Mobility as a Service, In Probabilistic Safety Assessment and Management, PSAM 2022.

Favarò, F., Eurich, S. and Nader, N. 2018. Autonomous vehicles' disengagements: Trends, triggers, and regulatory limitations', Accident Analysis & Prevention 110, 136–148. Available at: https://doi.org/10.1016/j.aap.2017.11.001.

Kettwich, C. et al. 2021. What if the Automation Fails? – A Classification of Scenarios in Teleoperated Driving', in 13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. New York, NY, USA: ACM, 92–96. Available at: https://doi.org/10.1145/3473682.3480271.

Kuru, K. 2021. Conceptualisation of Human-on-the-Loop Haptic Teleoperation With Fully Autonomous Self-Driving Vehicles in the Urban Environment', IEEE Open Journal of Intelligent Transportation Systems 2, 448–469. Available at: https://doi.org/10.1109/OJITS.2021.3132725.

Lu, Z. et al. 2016. Human factors of transitions in automated driving: A general framework and literature survey, Transportation Research Part F: Traffic Psychology and Behaviour 43, 183–198. Available at: https://doi.org/10.1016/j.trf.2016.10.007.

Maggi, D. et al. 2022. When terminology hinders research: the colloquialisms of transitions of control in automated driving, Cognition, Technology and Work 24(3), 509–520. Available at: https://doi.org/10.1007/s10111-022-00705-3.

McCall, R. et al. 2019. A taxonomy of autonomous vehicle handover situations, Transportation Research Part A: Policy and Practice 124, 507–522. Available at: https://doi.org/10.1016/j.tra.2018.05.005.

Mercedes-Benz. 2023. DRIVE PILOT. Available at: https://www.mbusa.com/en/owners/manuals/drive-pilot (Accessed: 24 October 2023).

Mutzenich, C. et al. 2021. Situation Awareness in Remote Operators of Autonomous Vehicles: Developing a Taxonomy of Situation Awareness in Video-Relays of Driving Scenes, Frontiers in Psychology, 12(November), 4943. Available at: https://doi.org/10.3389/fpsyg.2021.727500.

National Highway Traffic Safety Administration. 2022. Summary Report: Standing General Order on Crash Reporting for Automated Driving Systems, U.S. Department of Transportation Summary Report DOT HS 813 324, (June), 1–9. Available at: www.nhtsa.gov/sites/nhtsa.gov/files/2022-06/ADS-SGO-Report-June-2022.pdf (Accessed: 13 March 2023).

Ramos, M.A.A. et al. 2018. Accounting for human failure in autonomous ship operations, in S. Haugen et al. (eds) Safety and Reliability – Safe Societies in a Changing World. Proceedings of ESREL 2018, June 17-21, 2018, Trondheim, Norway. 1st Editio. London: CRC Press, 9. Available at: https://doi.org/10.1201/9781351174664.

SAE International. 2021. Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, SAE Standard J3016_202104.

Tener, F. and Lanir, J. 2022. Driving from a Distance: Challenges and Guidelines for Autonomous Vehicle Teleoperation Interfaces, in Conference on Human Factors in Computing Systems - Proceedings. New York, NY, USA: ACM, 1–13. Available at: https://doi.org/10.1145/3491102.3501827.

Walch, M. et al. 2015. Autonomous driving: investigating the feasibility of car-driver handover assistance, in Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. New York, NY, USA: ACM, 11–18. Available at: https://doi.org/10.1145/2799250.2799268.

Wintersberger, P., Green, P. and Riener, A. 2017. Am I Driving or Are You or Are We Both? A Taxonomy for Handover and Handback in Automated Driving, in Proceedings of the 9th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design: driving assessment 2017. Iowa City, Iowa: University of Iowa, 333–339. Available at: https://doi.org/10.17077/drivingassessment.1655.

Xing, Y. et al. 2021. Toward human-vehicle collaboration: Review and perspectives on human-centered collaborative automated driving, Transportation Research Part C: Emerging Technologies, 128, p. 103199. Available at: https://doi.org/10.1016/j.trc.2021.103199.

Yang, X. et al. 2020. A systems-theoretic approach to hazard identification of marine systems with dynamic autonomy, Ocean Engineering, 217, 107930. Available at: https://doi.org/10.1016/J.OCEANENG.2020.107930.

Zhang, T. 2020. Toward Automated Vehicle Teleoperation: Vision, Opportunities, and Challenges., IEEE Internet of Things Journal 7(12), 11347–11354. Available at: https://doi.org/10.1109/JIOT.2020.3028766.