

Automated Driving Impediments

Chris Mentzer, Ryan D. Lamm, and Jerry Towler
Southwest Research Institute

ABSTRACT

Since the turn of the millennium, automated vehicle technology has matured at an exponential rate, evolving from research largely funded and motivated by military and agricultural needs to a near-production market focused on everyday driving on public roads. Research and development has been conducted by a variety of entities ranging from universities to automotive manufacturers to technology firms demonstrating capabilities in both highway and urban environments. While this technology continues to show promise, corner cases, or situations outside the average driving environment, have emerged highlighting scenarios that impede the realization of full automation anywhere, anytime. This paper will review several of these corner cases and research deficiencies that need to be addressed for automated driving systems to be broadly deployed and trusted.

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INTRODUCTION

SAE has established a taxonomy for automated driving systems, defining six levels of automation from No Automation (Level 0) to Full Automation (Level 5). [Figure 1](#) completely defines the hierarchy, but in brief, the levels are as follows:

- Level 0 (No Automation): the human driver is responsible for all driving tasks.
- Level 1 (Driver Assistance): the vehicle performs *either* lateral (steering; *i.e.* lane keeping) or longitudinal (acceleration/deceleration; *i.e.*, cruise control) control, but not both, in some conditions.
- Level 2 (Partial Automation): the vehicle performs *both* lateral and longitudinal control in some conditions.
- Level 3 (Conditional Automation): the vehicle performs all driving tasks in some conditions, but can fall back to the human.
- Level 4 (High Automation): the vehicle performs all driving tasks in some conditions without relying on fallback to the human.
- Level 5 (Full Automation): Level 4, but in all conditions.

The top three levels (3-5) apply explicitly to Automated Driving Systems. These levels are differentiated by their fallback operation (human (Level 3) or machine (Levels 4-5)) and their driving modes (constrained (Levels 3-4) or unconstrained (Level 5)).

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System	System	Human driver	Some driving modes
4	High Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	System	System	System	Some driving modes
5	Full Automation	the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	System	System	All driving modes

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Figure 1. SAE's Levels of Automation. Levels 3-5 define gradations of automated driving systems. [1]

The corner cases this paper will explore highlight some of the difficulties impeding progression from Level 3 to Level 5 automation. These difficulties include accommodating inconsistent and unreliable infrastructure markings and signage, achieving unconstrained automation (including the "last mile" problem), operating robustly in adverse weather conditions, understanding intent of other actors, and developing complex scene recognition.

In 2014, the California Department of Motor Vehicles started granting Autonomous Vehicle Testing Permits. The associated reporting requirements for accidents and disengagements provide some insight into problem areas that still exist for automated driving. The number of reported accidents has continued to stay low and all human accident occurred during manual operation or was caused by a human

driver in another vehicle. While these early reports are very promising, they do not indicate incidents where a safety driver takeover was required to prevent a collision. The detail of disengagement reporting is inconsistent, but still provides some information on the amount and location of vehicle testing. It is important to note that, since testing was conducted at the discretion of the permit holder, it is unclear how different driving conditions or environments would affect these reports. Table 1 below shows a high level synopsis of self-reported disengagement data.

Table 1. Synopsis of California Department of Motor Vehicles’ Autonomous Vehicle Disengagement Reports [2][3][4][5][6][7][8]

Developer	# of Vehicles	Miles Driven	Dissengagements	Type of road
Bosch	2	935	625	Interstate, freeway
Delphi	2	16662	405	Interstate, freeway
Google	49	424331	341	Street, highway
Nissan	4	1485	106	Street, highway
MB	2	1739	1051	Street, highway
Telsa	?	?	0	?
VW	2	5531	85	Highway

The reports tabulated above summarize events between September 2014 and November 2015. Because they vary in detail, drawing direct conclusions from just these numbers is difficult. Furthermore, the situations in which the disengagements took place include planned disengagements as part of regular testing, disengagements prompted by the automated driving system, and disengagements initiated by the human driver. The reports that provide additional detail, however, point to the most common difficulties facing automated vehicle researchers. The most common cause for disengagement was failure to fully or accurately perceive the environment, including simple artifacts like lane markings and traffic lights as well as more-complex scenarios. These failures suggest a need for better perception systems than those currently available.

To help compensate for limited perception performance, many vehicle systems rely on high-precision maps and localization, which can work very well until the vehicle reaches an area that it has not previously mapped or changes have been made to the mapped area due to construction, new signage, etc. Some perception techniques show great effectiveness, but are specific to a certain problem. This specificity requires custom solutions for each detection task, which does not scale to objects or scenarios the system has not seen before. Novel machine learning techniques, on the other hand, can generalize to new perception tasks, but pose difficulties with respect to both understanding and determinism. Finally, regardless of algorithmic advances, adverse weather such as heavy rain, thick fog, and snow, challenge the sensors themselves, obscuring their view and preventing their use.

After perception, the next biggest area of difficulty is interacting with other vehicles, predicting their intent, and reacting appropriately. A similar challenge arises in the area of complex scene understanding. Each of these challenges will be addressed by example in the Illustrative Corner Cases section below.

Fallback to the Human (Moving from Level 3 to Level 4)

While the perception challenges above remain to be solved, one of the most challenging aspects of achieving increasing levels of automation involves safely handling system degradation. For systems below Level 3, the intelligence system can assume that, when it encounters an error, the human will take over the dynamic driving task. At Level 3, the system must identify failure and request human intervention (*i.e.*, it cannot fail silently); as a result, while it can rely on falling back to the human, the challenges discussed in this paper are relevant to continuing the driving task until such fallback occurs. As a system approaches Level 4, transitioning to the operator is no longer an option, so the system must not only minimize the chances of this occurring (for example, by using redundant components), but also be able to safely bring the system to a halt when its perception, localization, or control capabilities are hindered.

Most extant Level 3 systems require some level of human-machine interface between the operator and the vehicle to ensure the driver is able to take over in the event of a system failure, but even this interaction has difficult failure modes. Systems typically assess operator alertness via eye tracking or assess physical presence by detecting hand contact with the steering wheel. In the scenario depicted in Figure 2 below, however, both of these checks may succeed, but the operator clearly cannot decelerate the vehicle quickly in the event of a system-initiated fallback.



Figure 2. A difficult to detect situation where the driver is incapable of assuming fallback responsibility for the dynamic driving task.

Just as accurately assessing a human’s readiness to control the vehicle is difficult, assessing a computer’s readiness to do the same presents challenges. There are many failsafe approaches under consideration, including monitoring processes, separate watchdog hardware, and electromechanical solutions. However, robustly detecting system degradation remains an unsolved problem. Bounding the system’s expectation for reasonable action in the event of catastrophic failures remains a point of discussion within various industries.