AUTONOMOUS VEHICLES AND DRIVER CAPABILITY

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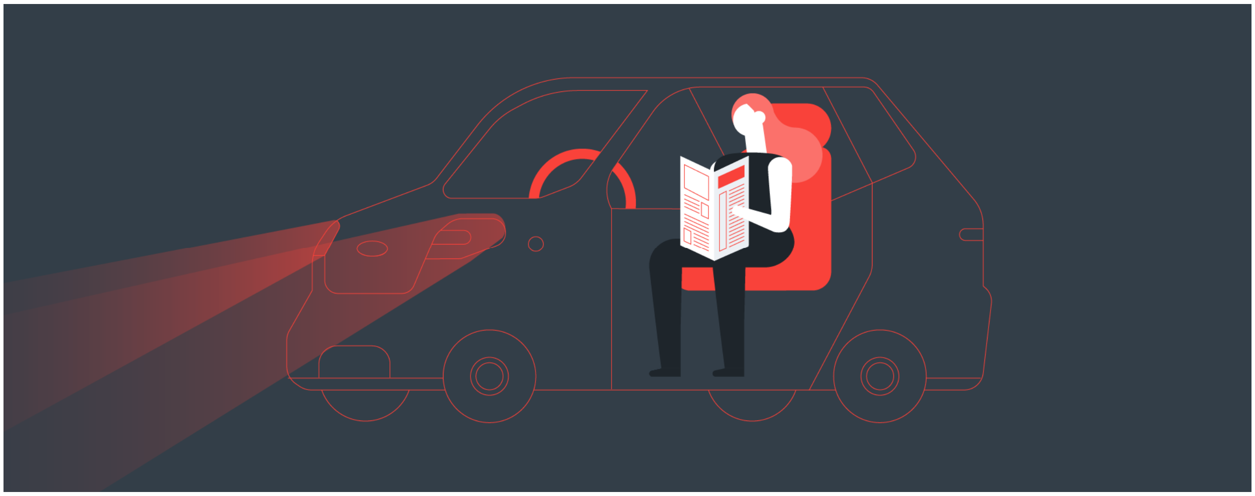
VEHICLE AUTOMATION MAY HAVE A NEGATIVE IMPACT ON DRIVER SKILL SINCE DRIVERS WILL SPEND LESS TIME ACTIVELY CONTROLLING THE VEHICLE AND WILL NOT BUILD (OR MAINTAIN) DRIVING SKILLS.

PARTIAL OR CONDITIONAL AUTOMATION REQUIRES ADDITIONAL DRIVER CAPABILITIES TO EFFECTIVELY MONITOR THE FUNCTION OF AUTONOMOUS SYSTEMS AND MAINTAIN THE AWARENESS NECESSARY TO RESUME CONTROL OF THE VEHICLE WHEN REQUIRED.

THESE ISSUES POSE CHALLENGES TO THE SAFE ADOPTION OF AUTONOMOUS SYSTEMS. THIS PAPER DISCUSSES THE TRANSITION TO FULL AUTONOMY, IDENTIFIES SIMILAR SITUATIONS IN OTHER FIELDS AND CONSIDERS MITIGATIONS THAT MIGHT BE EMPLOYED.



The Journey to Autonomous Vehicles

Autonomous vehicles have made rapid progress in recent years since the inaugural DARPA Grand Challenge in 2004, which required vehicles to travel 150 miles across the Mojave Desert, when none of the entrants completed the course. Today, driverless cars are being trialled in many cities across the world, partial automation features are available in many new vehicles, and conditional automation systems will be on the market in the very near future.

The capabilities of autonomous vehicles can be described using the SAE model[1], which includes six levels and is summarised in Table 1 below.

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**

Table 1: SAE automation levels

At levels 0, 1 and 2, the driver is actively engaged in controlling the vehicle, is wholly responsible at all times, and, if driver aids are used, must verify that the car is being driven safely by these systems. At level 3, the driver may pass responsibility for driving the vehicle to the systems in certain driving modes, (operational design domains) but must maintain a level of awareness such that they are able to take control within a short period. In supported driving modes, level 4 automation systems do not require the driver to maintain awareness and are able to safely stop the vehicle if the driver does not take control when prompted. (Autonomous buses, taxis or "pods" that operate within a geofenced area are also considered to be level 4 systems).

These systems will eliminate the requirement for the driver to maintain attention and be prepared to take control of the vehicle but will not remove the requirement for driving skills since they will only function in some situations and the driver will operate the vehicle at other times. In practice, modes where the driver will be required to take control of the vehicle may include more challenging situations, such as rural roads, poor weather conditions and roadworks, which require a greater level of skill. It will therefore be necessary for drivers to maintain a high level of competence, which allows them to deal safely with challenging driving conditions when required until the advent of level 5 automation. Vehicles operating at level 5 will be able to operate without intervention from the driver in all environment and circumstances and have the potential to eliminate the requirement for the operator of the vehicle to be a competent driver.

NEW SKILLS AND CAPABILITIES

The changing requirements for driver skills were assessed in a study by the Michigan Department of Transportation and found that autonomous systems required new driver skills[2]. All automation systems below level 5 require some level of monitoring. At its most basic, this might be as simple as monitoring vehicle instruments to determine whether traction control is active but more complex systems require more sophisticated monitoring. For example, a level 2 system, such as the Tesla Autopilot system requires the driver to monitor the system status via the instruments but also the correct function of the system by observation of its behaviour. The requirement for this skill peaks at levels 2 and 3 in the short to medium-term and declines at levels 4 and 5 as the vehicle is able to stop safely without driver intervention in supported driving modes.

Level 2 automation introduces a requirement for context switching, which describes the ability to resume control of the vehicle. It is suggested that the requirement for this skill is moderate at level 2 since the driver is expected to constantly supervise the operation of the autonomous systems. This will reduce the cognitive load associated with assuming control of the vehicle compared with level 3 where the driver is not required to monitor the vehicle systems to the same extent but may need to assume control at short notice, which is a potentially dramatic shift in context and represents the peak in the requirement for this skill. The need for context switching is much lower at level 4 since the driver will only be required to take control in certain circumstances and can be provided with more advanced warning of this shift.

This is shown in Figure 1 below, which shows how the requirement for different driver skills may change with increasing levels of automation. The availability and penetration of autonomous systems is increasing and, whilst the timescale for this are uncertain, levels 2 and 3 represent the short to medium term, and levels 4 and 5 represent the medium and long-term respectively. It is likely that level 5 systems will eventually become ubiquitous but systems operating at various levels will need to coexist during this transition.

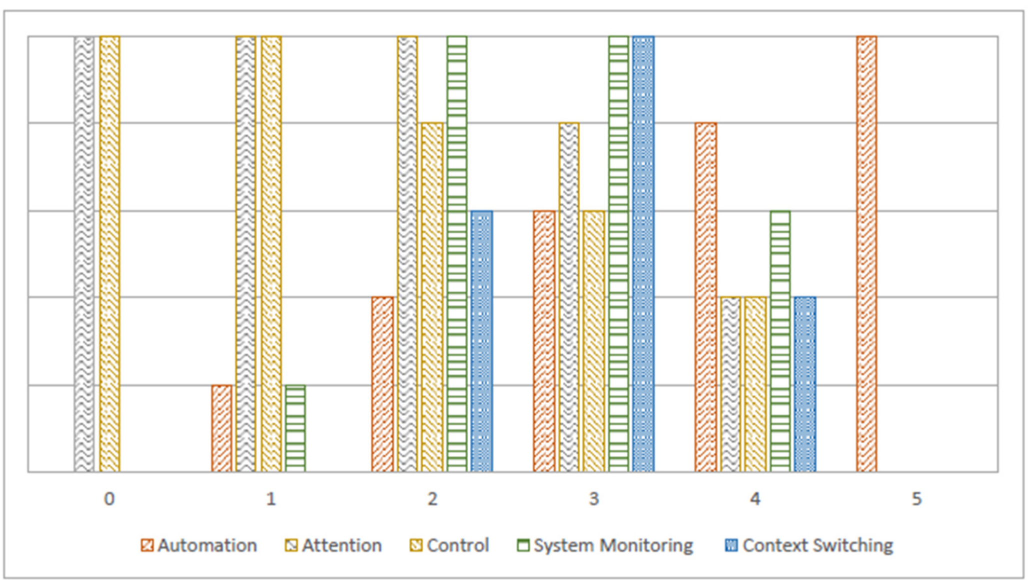


Figure 1: SAE Level vs. Driver Capabilities

The Challenges

VIGILANT ATTENTION AND DISTRACTION

Humans do not naturally find it easy to maintain concentration and we must all master the ability to focus on a task. It is much more difficult to do this when the task is cognitively simple or repetitive and requires low levels of attentiveness[3]. The skill to maintain concentration in this situation may be termed "vigilant attention" and is essential for such tasks as monitoring closed circuit television or security scanners in an airport. In this situation, we must apply significant effort to remain focussed on the task in hand, which can result in a feeling of tiredness and, over time, a reduction in performance. Where such work is necessary, staff are rotated frequently to ensure that attention and effective performance are maintained. Thus, Level 3 systems, which allow the driver to disengage from the task to a degree and be subject to myriad distractions but may require them to resume control at short notice present a particular challenge. This theory has been borne-out in trials by Google[4] and Ford[5], where trained test drivers were found to be unable to maintain attention and were recorded by in-car systems applying make-up, using personal electronic devices and sleeping. As a result, both companies deemed level 3 automation to be potentially dangerous and ceased trials until level 4 systems were available. This highlights the danger of allowing drivers to relinquish control to any extent since this engenders the perception that attention is not required and increases the chance that the driver will succumb to distraction. The safety of level 3 autonomous systems is dependent on the ability of the driver to resume control at short notice and the evidence suggests that this will not necessarily be achievable over an extended period. Restriction of the period for which level 3 autonomous systems could be used would mitigate this issue but would reduce their attractiveness considerably and might delay the take-up of autonomous systems.

ACQUISITION AND LOSS OF DRIVING SKILLS

The concept that significant practice is required to master a complex skill that requires, knowledge, experience and physical competence is well known and was highlighted by the popular phycologist Malcom Gladwell as the "10,000 hours rule", that being the amount of effort required to master such a skill. While this may be an over-simplification, the evidence suggests that experience is directly correlated with the number of collisions that were attributed to driver skills. A US committee tasked with reducing the number of crashes involving teenage drivers reported[6] that the rate of crashes declined rapidly over the first seven months following licensure and continued to fall until 24 months after licensure at a level approximately 60% below newly qualified drivers. The study Maintaining Driving Skills in Semi-Autonomous Vehicles (MADSAV) considered the decline of driving skills that might result from the introduction of driverless vehicles and found[7] that whilst a period spent without driving did reduce reported skill levels, the more firmly driver skill was established prior to the period of non-driving, the higher drivers rated their skill when they resume driving and that drivers who had gained less experience prior to stopping driving showed a greater decline in perceived competence.

ACQUISITION OF SKILLS IN MEDICAL TRAINING

There has been a progressive reduction in the working hours of doctors in the US and Europe, including doctors in postgraduate training posts. This has been driven by recommendations and legislation intended to improve patient safety and doctors' working conditions. Decreasing the working hours of trainee doctors has the potential to reduce the quality of the training and the competence of doctors since less time spent training could be expected to reduce the number of cases that the trainees would experience and their exposure to less common medical situations. US studies have shown that, when combined with appropriate training techniques, reducing working hours of trainee doctors below 80 hours a week has had limited impact on patient outcomes[8]. Insufficient data has been obtained to draw firm conclusions about the effect of reducing hours below 56 hours a week. These results suggest that the training provided under the US system was adequate to deliver the required level of competence and that further training did not add significant value. This implies that there is some adequate level of competence that would support safe, intermittent manual driving that could be identified and assessed via an updated driver education and testing programme.

RELIANCE ON AUTOMATION AND SYSTEMS COMPLEXITY IN AVIATION

In 2009, Air France flight 447 from Rio de Janeiro to Paris crashed into the Atlantic Ocean with the loss of all on board. The cause of this tragic accident was ultimately traced[9] to the inability of the flight crew to deal safely with the unexpected behaviour of automated systems following a failure of airspeed sensors due to ice formation with the result that the appropriate corrective action was not taken to lift the plane out of an aerodynamic stall. An aerodynamic stall occurs when the angle of attack is too steep, meaning that the nose is pointed too far above the horizontal and the wings cease to generate enough lift to keep the plane in the air. The correct action is to put the plane into a dive, which would restore lift. Identification and correction of this situation are considered to be basic flying skills and should be within the capabilities of all commercial pilots. The current state of autonomy in aviation is approximately aligned with level 3 and 4 autonomy as defined by SAE and at this level, the effort of the pilot is biased toward monitoring the automation systems rather than actively controlling the plane. The increased use of automated systems is believed to have reduced the proportion of time that pilots are actively flying the plane to the extent where basic flying skills are not retained and this was identified as a contributory factor in the Air France incident. This does not align with the principal finding of the MADSAV project[7]—that established driving skills tended to be retained. The difference may be explained by the additional complexity of the pilots' activities and supporting systems compared with the equivalent task and systems involved in driving a car.

The incorrect action of the pilots was found to have been precipitated by conflicting information provided by the various systems on the flight deck as the pilots could not determine which was correct. Pilots are extensively trained on a specific type of aircraft and can be expected to have a high level of knowledge of its systems, yet this was insufficient to allow the pilots in this incident to determine, in the heat of the moment, which systems were providing correct information. A similar situation may arise in motor vehicle as the complexity of automated systems increase and this could be compounded by greater variety of vehicles driven and the lower level of training received by drivers compared to pilots. Ensuring the autonomous systems can be understood and operated safely without specific training will be one of the most significant challenges faced by the automotive industry in implementing level 3 and 4 autonomous systems.

Conclusions and Mitigations

The introduction of autonomous vehicles poses a wide range of challenges but the ability of drivers to use these systems safely is paramount to the successful adoption of these technologies. The licenses and approvals needed to operate on the highway will not be granted and drivers will not accept these systems unless their safety in use can be demonstrated.

This paper identifies and discusses several challenges that will affect level 3 and 4 autonomous systems:

1. Humans are poor at maintaining focus for an extended period when engaged in a tedious task and cannot necessarily be relied upon to maintain awareness and resume control when required by a level 3 autonomous system;
2. Autonomous systems at level 3 and 4 require the driver to take control of the vehicle in some driving modes. There is evidence that established driving skills are retained after a period of non-use but the

reduced proportion of "active" driving that will be required using these systems will mean that new drivers will take longer to establish these skills and will present additional risk for an extended period;

3. Autonomous systems will initially operate in the least complex driving modes, such as day-time highway driving, and will return control to the driver in more challenging circumstances, such as through roadworks or on rural roads. New drivers who regularly use autonomous systems may lack the capability to safely deal with these situations as they will not have developed those skills due to the limited number of driving hours post-licensure; and

4. Autonomous systems will introduce additional complexity to the driving task, which increases the level of capability required to safely operate a vehicle equipped with this technology. This will exacerbate the concerns identified in items 2 and 3 and will increase the likelihood that the driver will be unable to identify and take appropriate corrective action should the autonomous systems fail.

The capabilities required to operate an autonomous vehicle will change during the transition from level 2 to level 5 autonomy and peak at level 3. The requirement for vigilant attention peaks at this point and may prove to be an insurmountable obstacle to widespread adoption of automation at this level. Both Google and Ford determined that these requirements were not achievable and progressed rapidly to level 4 automation. This may be an industry-wide trend, where level 3 autonomy has a relatively short life and is rapidly superseded by level 4 systems. This process will be affected by regulatory behaviour and the attitude of the insurance industry—insurance costs will increase if level 3 systems are statistically less safe and this will affect adoption rates. One option to accelerate the delivery of level 4 capabilities is to provide human support from a centralised location to cover situations where the autonomous systems are unable to function entirely without human guidance. This approach has been trialled by Waymo in the US and autonomous vehicles, operating within a geofenced area, are able to transfer control to a human operator when required.

Level 5 autonomous vehicles will resolve these issues since there is no requirement for the driver to control the vehicle in any circumstance. Data from the society of motor manufacturers states that the average age at which vehicles in the UK are scrapped in 13.9 years[10]. The life cycle of autonomous vehicles may vary greatly, particularly if individual ownership declines in favour of shared solutions, but as level 3 capabilities are just starting to become commercially[11] available, it seems reasonable to assume that the issues associated with lower levels of automation will exist for at least 20 years. In this period, a range of mitigations may be considered for the key challenges identified 1) maintaining focus and the ability to resume control when required, 2) developing and maintaining the competence to safely drive the vehicle when required, 3) developing and maintaining the more sophisticated skills necessary to drive in circumstances where the autonomous systems are not able to operate, and 4) operating increasingly complex vehicles equipped with autonomous systems.

The US Federal Aviation Administration has issued recommendations that manual flying activity be undertaken in appropriate phases of flight and exercises be conducted during flight and in simulators to exercise skills required to deal with normal flying conditions and more challenging situations. This approach could be adopted in autonomous vehicle and equipment similar to that which has been implemented in vehicles with level 2 systems to monitor driver attention could be used to enforce short periods of manual driving on a programmed basis or when the driver appears to be unable to fulfil the system monitoring role.

Driving qualifications will need to be modified to accommodate autonomous vehicles, both from the perspective of a human driver interacting with autonomous vehicles and as a user of autonomous systems. The skills required to effectively monitor autonomous systems and resume control when required should be taught and tested. This poses challenges due likely differences in the operation of systems produced by different manufacturer, which will need to be addressed through a combination of legislation and degree of industry-led standardisation. Education will also need to be provided and this might be associated with the purchase of vehicles with autonomous features. Newly qualified drivers who use a vehicle with autonomous features will take longer to amass the experience necessary to establish driving skills sufficiently to permit safe, infrequent use as might occur in a level 3 or 4 autonomous system. Several possibilities exist to address this issue, including: increases to the standard required to pass the driving test, which will extend the period spent as a learner driver and increase the experience of newly qualified drivers; or use of autonomous systems to enforce periods of manual driving to provider opportunity for new drivers to gain more experience of actively controlling the vehicle. Special consideration will need to be given to drivers who are less able to pick-up new skills or will face greater difficulty in using autonomous systems for reasons such as disability.

Transport infrastructure must be of a standard to allow operation of autonomous systems and reduce the likelihood that the driver will be required to resume control due to issues such as poor signage or road markings. Further work is required to understand the impact of infrastructure on autonomous systems and update standards to meet these needs. There will be a significant cost associated with implementing these requirements and this may cause pressure on transport budgets.

Alongside standardisation of infrastructure, it is likely that a high level of standardisation will be required in the control and operation of autonomous systems to enable drivers to operate a variety of vehicles safely. This will need to be addressed through a combination of legislation and degree of industry-led standardisation. Given the established norms of automotive control system, which have developed over many tens of years, and the continued existence of variation, it is unlikely that the rapid changes required to accommodate autonomous systems will coalesce on a common approach without regulatory intervention.

Regulators, driver testing bodies, infrastructure organisations and vehicle manufacturers all have a role to play in the successful introduction of autonomous vehicles. Potential mitigations exist for the challenges identified in this paper but they must be evaluated and applied rapidly to avoid being overtaken by the commercial introduction of autonomous systems, which if not properly supported, could result in an overall reduction in safety.

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