Situation Awareness in Future Autonomous Vehicles: Beware of the Unexpected

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Abstract. Vehicle autonomy is being heavily promoted as a means of improving transportation safety on the roadways. This goal, however, is highly dependent on the ability of human drivers to maintain situation awareness and intervene in circumstances that the automation cannot handle. While autonomy software is improving, it remains far less capable than human drivers. The automation conundrum shows that even as it improves, system autonomy is increasingly likely to reduce the ability of drivers to provide needed oversight. The Human-Automation System Oversight (HASO) model provides guidance on the design of vehicle autonomy to facilitate effective human-autonomy design for semi-autonomous vehicles.

Keywords: autonomous vehicles, situation awareness, driver safety.

1 Introduction

Self-driving vehicles are being widely promoted as innovations that will significantly improve driving safety by reducing human error. At least 17 companies are currently involved in developing and testing autonomous and semi-autonomous vehicles. The National Highway Transportation Safety Administration (NHTSA) in the United States has characterized 5 broad levels that depict the degree of autonomy of a vehicle (Figure 1).

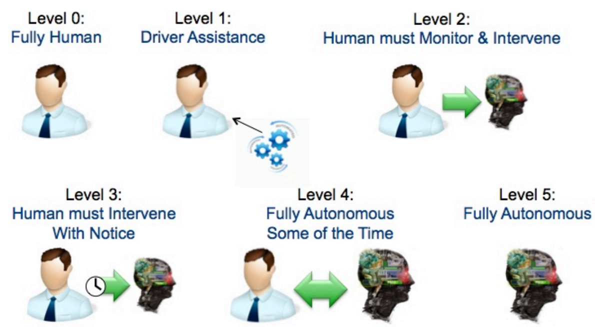

Fig. 1. Levels of vehicle autonomy [1]

Rationale for the addition of automation to automobiles includes the ability to support handicapped and elderly drivers, and the potential for reduction of traffic congestion in urban centers [2]. By far the most frequent justification for these vehicles is the claim that they will improve transportation safety by reducing accidents caused by human drivers [3]. This claim, however, is generally offered with little or no objective evidence of improved safety, and neglects the significant issues associated with the need for human drivers and pedestrians to interact with autonomous vehicles that may create new forms of accidents.

This paper will review the current state of autonomous vehicle technology and the challenges for effective integration of these vehicles with human drivers. A path forward is provided for the development of autonomous vehicles that addresses these challenges.

2 Driving Safety

While it is difficult to find clear data on how well current autonomous vehicles perform in real-world driving conditions, some information can be deduced from the disengagement reports that manufacturers testing vehicles in California are required to provide to that state. Disengagements include (1) manual takeovers by human drivers disengaging the automation, and (2) instances where the automation software detects a problem and disengages itself, thereby passing control back to the human driver. As shown in Table 1, the best performing technology is currently provided by Waymo (formerly Google).

Table 1. Reported average miles driven per disengagement

Manufacturer	2015	2016	2017
Google/Waymo	1,244	5,128	5,596
Nissan	14	146	208
Delphi	41	17.5	22.4
Mercedes-Benz	1.5	2	4.5

Waymo has been actively testing its vehicles on California roadways since 2009, which have accumulated over 5 million miles to date [4]. Table 1 shows that one of Waymo's vehicles can travel approximately 5,600 miles on average before a human driver has the need to intervene, or before the vehicle disengages on its own due to some detected problem.

In comparison, a human driver travels over 490,000 miles between accidents and over 95 million miles between fatal accidents based on 2015 data [5]. While not all disengagements would have necessarily resulted in an accident if a human driver had not been able to intervene, this comparison shows that vehicle automation efforts still have a long way to go to come even close to current levels of safety provided by human drivers. Common reasons for disengagements included: software failures

(81.6%), hardware issues (14%), weather conditions (4%) and road surface conditions (0.4%) [6].

It should be noted that while many autonomous vehicle developers are testing in California, this is not true for all, thus no similar data is present for some manufacturers, such as Tesla. (While Tesla claims that it's vehicles have a fatality rate of 1 per 320 million miles for vehicles equipped with autopilot hardware [7], this does not include a consideration of when the autopilot is actually in use, or the numbers of disengagements requiring driver interventions when in use.)

At least 3 recent fatal accidents in the United States indicate that the challenges for safety of semi-autonomous vehicles are quite real. In 2016, a Tesla being operated in "auto-pilot" mode (adaptive speed control plus automated lane following – considered a NHTSA level 2 capability) crashed into a truck crossing the highway, killing its driver. The National Transportation Safety Board (NTSB) found that the "cause of the crash was over-reliance on automation, lack of engagement by the driver, and inattention to the roadway" [8]. More recently another Tesla being operated in auto-pilot mode crashed into a highway barrier at a lane split, in which the driver did not intervene [7]. And an Uber automated vehicle fatally killed a pedestrian during testing in Arizona in an accident where the safety driver also failed to see the pedestrian and intervene [9].

All of these examples point to a critical problem for semi-automated vehicles: The loss of situation awareness (SA) that occurs when people oversee automation, limiting their ability to back-up the system and ultimately creating new types of failures. The difficulties associated with human oversight of automated systems are well documented in many domains (including aviation, manufacturing and power systems) and are not unexpected in driving [10-12]. If vehicle automation efforts are to be successful at improving safety, they must take into account the ways in which automation affects human performance and the ability of human drivers to be successful at intervening and interacting with the automation when needed. Particularly since, as Table 1 demonstrates, vehicle autonomy efforts will remain highly dependent on human drivers to maintain current levels of transportation safety for the foreseeable future.

3 Challenge for Situation Awareness

The ability for automation to incrementally add to existing safety levels assumes that people's performance will remain independent of the system autonomy, however, some 40 years of research on human interaction with automation shows this not to be the case [10, 12]. Specific to the driving task, researchers have found out-of-the-loop performance decrements due to automated steering systems for example [13].

Automation has a significant effect on lowering the situation awareness of the operator, creating out-of-the-loop performance deficits [14]. People have been shown to be both slow at detecting when the automation is in a situation that it is not programmed to handle, and slow at determining the cause of the problem for successful intervention. These issues occur because of:

(1) Poor vigilance when people become monitors, often coupled with increased trust or over-reliance on the automation,
(2) Limited information on the behavior of the automation and/or the relevant system and environment information due to either intentional or unintentional design decisions, and
(3) A reduced level of cognitive engagement that comes from becoming a passive processor rather than an active processor of information [14].

Even when people are trying to be vigilant, and the needed information is available, it has been found that effects of passive processing can still lead to poor SA. It is as if the automation transforms the driver into a passenger, with less understanding of what is happening. These problems are also worse when other tasks are present [15-18]. Thus, new forms of error affecting driver safety will be created as people tune out, lose vigilance, or take on secondary tasks such as talking or texting on mobile devices, eating, grooming and performing other extraneous tasks [19, 20]. While in some cases, automation may actually act to increase SA, by freeing the driver to look around more, this advantage has been found to decrease over time, as drivers become more trusting of vehicle automation [11], and as they increasingly engage in other tasks [21, 22].

While many engineers believe that a loss of driver SA will not be a problem in the future because of improved autonomy software, this has proven to be an unwarranted assumption. The *automation conundrum* shows that "the more automation is added to a system, and the more reliable and robust that automation is, the *less* likely that human operators overseeing the automation will be aware of critical information and able to take over manual control when needed" [10]. This finding is based on a multitude of studies showing that as automation becomes more capable, paradoxically people are even more likely to lose situation awareness and trust the automation. Further, as automation is added to more functions and the level of automation increases, their situation awareness is also more negatively affected, rendering them fairly poor at the job of manual oversight and intervention.

Unless the software is 100% reliable and able to handle all driving situations, even very good software will lead to new forms of error and accidents as the SA and well learned performance patterns of drivers are disrupted. By acting to reduce the engagement level of drivers, their ability to act as safeguards to imperfect autonomy is greatly reduced.

4 Dealing with the Unexpected

Driving software is generally created to deliver appropriate responses to a learned set of situations and conditions. Real world driving, however, is often messy. Unexpected events can happen that the software is not programed to handle. This is where experienced operators are invaluable as they can be creative and innovative in responding to novel situations. Further, people with high levels of SA are not just reacting to events; they are constantly projecting ahead. This allows them to be proactive rather than just reactive, able to avoid many dangerous and hazardous situations. For instance, they know to look for children who may chase after ball that has rolled into the street and slow accordingly. Until software for driving autonomy can demonstrate an ability to project and deal with the unexpected, the need for human drivers to stay engaged and able to act will remain [11].

Driving system autonomy is currently being developed based on artificial intelligence (AI) programs that learn over time [23], by observing statistical relationships in data, correlating observed features of the environment with set performance outcomes. As Pearl, a pioneer in the filed of AI, has recently pointed out, such systems are extremely limited because they cannot understand cause and effect [24]. They cannot project new adaptations for changing situations, instead learning only as a matter of trial and error. The ability to project future events will require much more capable software, built with models of the environment that can understand current and projected future situations upon which proactive decision making relies [23].

5 The Path Forward

As new forms of automation are developed for automobiles, the goals of improved driving safety will only be realized by carefully considering the capabilities of the human driver, and developing automation approaches that aid, rather than degrade, driver performance. Considerable research has been conducted in the field of human-automation interaction that provides guidance for creating more effective systems for advancing the goal of driving safety [10,11].

(1) *Support automation approaches that increase driver SA* – Considerable research shows that forms of automation that aid in supporting SA lead to performance improvements without falling prey to out-of-the-loop problems [10, 12, 25, 26]. This would include aids for indicating cars in the driver's blind spot, and collision warning systems, for example. It also includes integration of information to support comprehension and projection (e.g. range projections, display of future road hazards and traffic conditions, and displays that show what the automation's future actions will be).

(2) *Keep the driver in control and in the loop* – Higher levels of automation that attempt to apply automation to vehicle steering control will remain highly prone to SA loss and out-of-the loop performance difficulties [10] and should be avoided unless perfected to a level where human intervention is not needed (i.e. NHTSA LOA 5).

(3) *Provide automation transparency* – New research is being directed at the goal of creating "transparent" interfaces that support the understandability and predictability of the actions of the automated system [26]. These have been shown to increase SA when dealing with automation [27].

(4) *Minimize automation complexity* - To support the need for users to gain an accurate mental model of how the system works, minimizing complexity leads to improved ability to understand and project of system actions. This is

accomplished by ensuring logical consistency across features and modes, minimizing modes and logic branches, and providing a clear mapping between system functions and user goals.

In addition, improved attention to driver training with automated vehicles will be needed. Drivers will have a need to understand just how the system will behave under varying conditions, which may be effected by the automation modes and mode interactions that can occur with the system. Understanding the behaviors and limitations of automated systems will require far more systematic and detailed training than is currently provided with most automobile purchases. This will be a particular challenge with learning system technology that allows updates to system automation software to occur on a frequent basis [11].

Due to the inability to reliably respond to the unexpected, imperfect automation is doomed to creating new types of accidents as it degrades human performance. These new challenges must be met though increased attention to driver displays to improve automation transparency and through automation approaches that enhance driver SA.

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