Autonomous Vehicles: Human Factors Issues and Future Research

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Abstract

Automated vehicles are those in which at least some aspects of a safety-critical control function occur without direct driver input. It is predicted that automated vehicles, especially those capable of “driving themselves”, will improve road safety and provide a range of other transport and societal benefits. A fundamental issue, from a human factors perspective, is how to design automation so that drivers understand fully the capabilities and limitations of the vehicle, and maintain situational awareness of what the vehicle is doing and when manual intervention is needed – especially for first generation vehicles that require drivers to resume manual control of automated functions when the vehicle is incapable of controlling itself. The purpose of this paper is to document some of the human factors challenges associated with the transition from manually driven to self-driving vehicles, and to outline what we can be doing in Australia, through research and other means, to address them.

Introduction

Background

The National Highway Traffic Safety Administration (NHTSA, 2013) states that automated vehicles are those in which some aspects of a safety-critical control function (e.g. steering, throttle control) occur without direct driver input. The shift to highly automated driving (HAD) is predicted to have a number of economic and ecological benefits. For example, Levitan and Bloomfield (1998) propose that automated cars will be more efficient than manual cars, increase predictability of trip times, and reduce environmental pollution due to a decrease in fossil fuel consumption and emissions. Fitch, Bowman, and Llaneras (2014) contend that highly automated driving will greatly improve safety by reducing crashes that result from human error, predominantly that associated with driver distraction. Work to identify the impacts, requirements and enabling mechanisms for the implementation of this technology in Australia, and elsewhere, is potentially the most significant program of cooperative investigation and forecasting reviewed in the transport domain this century.

The NHTSA (2013) in the United States has distinguished between five different levels of vehicle automation:

0. No automation – driver is in complete control of primary controls;
1. Function-specific automation – driver can give limited authority to a primary control (e.g., maintenance of speed via cruise control);
2. Combined-function automation – automation of at least 2 primary control functions working together (e.g., Adaptive Cruise Control and Lane Keeping Assist);
3. Limited self-driving automation – the driver may cede full control of all safety-critical vehicle functions under certain conditions but is expected to be available for occasional control;
4. Self-driving automation – in which the vehicle performs all functions and monitors roadway conditions for the entire trip.

Examples of market-ready vehicle automation in the Level 1 category include Adaptive Cruise Control (ACC) and Lane Keeping Assist, which assist with longitudinal or lateral vehicle control, respectively (‘functional-specific automation’; NHTSA, 2013). The combination of such automated systems is considered Level 2 vehicle automation (NHTSA, 2013), and Level 2 vehicles are expected to be available on the Australian market later in 2015. Google’s “Driveless Car” is an example of a Level 3 vehicle; it requires a driver to take control of the vehicle when it reaches the limits of its technical competence. A number of projects have demonstrated higher levels of automation in test vehicles in various research projects (HAVEit; Flemisch & Schieben, 2010). However, some research groups predict that full vehicle automation (i.e., Level 4) will not be implemented on British roads until 2030 (e.g., Walker, Stanton, & Young, 2001).

A key issue with HAD at this stage of its development is that it is not yet 100% reliable and safe (Martens & van den Beukel, 2013). Therefore, in situations in which HAD fails or is limited (e.g., sensory degradation in poor weather conditions; inability of on-board computer algorithms to make a safe decision), the driver will be expected to take control of the vehicle and resume manual driving. For this transition of control to occur safely, it is imperative that the driver fully understands the capabilities and limitations of HAD and maintains full awareness of what the vehicle is doing and when intervention might be needed (Cummings & Ryan, 2014).

In this paper we document some of the human factors challenges associated with the transition from manually driven to self-driving vehicles. The paper has two aims. The first is to highlight a number of human factors issues that influence the safety and efficiency of human intervention in automated driving and possible repercussions of automated vehicle use on driver skill and safety. Secondly, the review will discuss and underscore important research questions aimed at addressing these human factors issues.

Human Factors issues

Driver inattention and distraction

Although automation is usually intended to lighten driver workload, this is not necessarily beneficial for driving and does not always lead to increased road safety. If the workload on the driver is too little during periods of automation, the driver may experience passive fatigue, which is argued to stem from situations in which cognitive load is low and there a lack of direct control over the task at hand (Desmon and Hancock, 2001). Moreover, research has shown that passive fatigue can degrade overall driver performance. For example, increased vehicle automation is associated with reduced driver vigilance indicated by increased braking and steering reaction times in response to a sudden critical event (Neubauer, Matthews, Langheim, & Saxby, 2012; Saxby, Matthews, Warm, Hitchcock, & Neubauer, 2013). In the realm of HAD, this reduced vigilance and inattention may pose problems for drivers required to manually intervene during critical automation failures as these critical events may impose such a sudden increase in demand on the driver that the s/he may have difficulty dealing with it, and possibly crash (Young & Stanton, 1997).

Conversely, boredom may also proliferate from low workload in periods of automated driving. As a result, drivers may seek to engage in other activities (e.g., a task that is more entertaining) as opposed to monitoring and supervising the autonomous driving. Two recent studies conducted in driving simulators support this premise, showing that drivers are more likely engage in secondary activities and spend more time looking away from the forward roadway at higher levels of driving automation (Merat, Jamson, Lai, & Carsten, 2012; Carsten, Lai, Barnard, Jamson, & Merat, 2012). In essence, these findings suggest that drivers may be more vulnerable to distractions during periods of driving automation, posing a safety issue by compromising the ability of the driver to suddenly regain control of the vehicle when required. Several studies have demonstrated the adverse effects of secondary task demands on take-over time and quality in automated driving (e.g., Merat et al., 2012).

Situational awareness

Situational awareness (SA) is defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995, p. 36). Colloquially, SA is an operator's dynamic understanding of what is happening around them (Salmon, Stanton, Walker, & Jenkins, 2009). When drivers divert attention away from the automated driving task (i.e., distraction) or attention is diminished in the absence of a competing activity (i.e., inattention; Regan, Lee and Young, 2009), their level of SA will likely diminish as attentional resources are not being devoted to maintaining awareness of the vehicle state and road situation (de Winter, Happee, Martens, & Stanton, 2014). This reduction in SA in periods of automation can be dangerous as automation actions and alerts will likely be unexpected and come as a surprise to the driver (creating an 'automation surprise'; Wiener, 1989; Hollnagel & Woods, 2005). For example, a driver that is occupied in some secondary task may fail to notice the autonomous vehicle navigating through foggy conditions (i.e., SA is low). In this instance, an alarm sounding to notify the driver that the automated systems are struggling in these conditions will come as a surprise to the driver. On the other hand, a driver that is paying attention to the road context (i.e. SA is high) will observe the onset of the foggy conditions and be ready for any automated failure alerts. Automation surprises can be detrimental to driver re-engagement time and quality as they may erratically increase driver workload, briefly rendering the driver unable to respond as a result (Vahidi & Eskandarian, 2003).

An insufficient level of driver SA can also lead to mode confusion. Mode confusion is a phenomenon that refers to a discrepancy between how the vehicle driver *believes* the vehicle to be operating and how the vehicle is *actually* operating (Cummings & Ryan, 2014). In lay terms, it is a sense of confusion concerning which aspects of vehicle performance is controlled by the driver and which is controlled by the automation at a particular instance (Martens & van den Beukel, 2013). If a driver is unaware of the state of the automated vehicle, he or she could make decisions based on the (incorrect) belief that the vehicle is in a certain state or in control of a certain aspect of driving when it currently is not (Bredereke & Lankenau, 2002). For example, a driver may reverse without looking with the (incorrect) assumption that operation of the vehicles' reverse collision sensors would warn of potential hazards.

Overreliance and trust

As automated systems take over control of many driving tasks, drivers may learn to overestimate and over-rely on automation performance. *Overreliance* occurs when a driver does not question the performance of automation and insufficiently counterchecks the automation status (Saffarian, de Winter, & Happee, 2012). The phenomenon is synonymous with a sense of over-trusting automated systems, in which an operator's trust in the automation exceeds its actual capabilities, resulting in the operator over-utilising it (Lee and See, 2004). However, too little trust may result in the technology being ignored and negating associated benefits with its use (Parasuraman & Riley, 1997). Therefore, trust in the system must be at an optimal (moderate) level.

The problem with overreliance and excessive trust in automated driving systems is that drivers may wrongly assume that the technology will warn them and intervene to prevent failure if and when necessary (Parasuraman & Riley, 1997). With this in mind, drivers may feel it is safe to engage in other activities, which will increase the propensity to become distracted (an issue for driver re-engagement) (Rudin-Brown & Parker, 2004), and adopt more hazardous driving behaviours (e.g., shorter headways; Hoedemaeker & Brookhuis, 1998) as the driver perceives the automation to be more capable than it actually is. These consequences of over-reliance in the automation are known as negative behavioural adaptation effects and can be detrimental to safe driving (Regan, 2004).

Skill degradation

Drivers that over-rely on highly automated driving systems may fail to use their manual driving skills over long periods of time (Parasuraman, Sheridan, & Wickens, 2000). The neglect of manual driving skills may, in turn, may degrade both the psychomotor dexterity and cognitive skills required to manually complete a task successfully and safely (e.g., Parasuraman et al., 2000). Ironically, this loss of skill may further encourage reliance on automation (Lee & Moray, 1994). The consequences of this skill degradation may be exacerbated in situations of automation failure as the driver may have difficulty resuming manual control of driving (Sarter, Woods, & Billings, 1997). In addition to the predicted long term effects (e.g., Rudin-Brown & Jamson, 2013), recent research has demonstrated that periods of automated driving may also impose more transient skill degradation. For example, a simulated driving study by Skottke, Debus, Wang, and Huestegge (2014) found that even brief periods of highly-automated driving were sufficient in impairing driving performance in a subsequent manual driving task, as evidenced by shorter headway times and increased variability of lateral position.

Motion sickness

A relatively unexplored, yet important, human factors issue in the realm of automated driving is that of an increased propensity for motion sickness of vehicle occupants. Motion sickness is a condition marked by symptoms of nausea, dizziness, and other physical discomfort (Golding, 1992) and can be associated with various modes of transportation (e.g., boats; Byrne & Parasuraman, 1996). The condition is most frequently caused by a conflict between visual and vestibular inputs (Benson, 1999), loss of control over one’s movements (Rolnick & Lubow, 1991) and reduced ability to anticipate the direction of movement (Golding & Gresty, 2005). Interestingly, Sivak and Schoettle (2015) purport that up to 10% of American adults are expected to experience motion sickness often in autonomous vehicles. The authors also contend that remedies for motion sickness in the form of the design of the automated vehicle are limited as the crux of the issue is that automation controls the drivers’ direction of motion, not the driver themselves, which may present issues of driver acceptance (see Regan, Horberry & Stevens, 2014).

Future research

The Transportation Research Board (TRB, 2013) has identified four priority areas for human factors research in the transition to highly autonomous vehicles. Here, we identify these issues, discuss previous research that has been aimed at addressing these issues, and forecast future research required to address them.

Re-engaging the driver

The process of how to efficiently and quickly re-engage the driver from automated driving in Level 2 and Level 3 autonomous vehicles is emerging as one of the key topics requiring research. Fundamental to this issue is the time frame required by drivers to successfully regain manual control of the vehicle. In reality, there is no optimal single or general take-over time; the time is likely to be influenced by a combination of variables such as traffic density, driver experience and driver engagement in secondary tasks at the time takeover is required (Zeeb, Buchner, & Schrauf, 2015). Despite this, preliminary research has shown that driver re-engagement may take between 5 and 7 seconds (Louw, Merat, & Jamson, 2015; Gold & Bengler, 2014). Merat, Jamson, Lai, Daly, and Carsten (2014) suggest that an additional 30-40 seconds may be required to stabilise driving behaviour once the transition takes place, especially in the event that the hand-over is unpredictable (which is especially relevant in the event of unexpected automation failure). However, the generalizability of these findings is limited due to the employment of simulated driving methodologies, which may not truly reflect critical situations in the real-world that one may assume would be more startling and stressful. Therefore, prospective studies need to (a) confirm the time budgets required for driver re-engagement using real-life driving methodologies and (b) corroborate how variables such as age and driving experience may moderate the quality and timing of this re-engagement. The mechanisms by which driver re-engagement is initiated will be discussed below.

The user interface and the communication of automation limitations

Optimal design of the human-machine interface (HMI) in autonomous vehicles is critical for safe driving, as the HMI is the point of communication between system and driver. During periods of automation, it is critical that the HMI keeps the driver involved in the driving task and aware of the vehicle status and road traffic situation (i.e., keeps the driver ‘in-the-loop’). Regan (2004) contends that the HMI must clearly communicate the automation status and limitations in an ergonomically-appropriate way that is both clearly visible and easy to monitor (at all times) to prevent automation surprises. It is paramount that the HMI maintains SA in the driver and that the driver does not fall ‘out-of-the-loop’, as this will impair re-engagement in conditions of automation failure (Louw et al., 2015).

Where automation failure is imminent, the HMI will need to signal a manual take-over request that carefully balances urgency and driver workload. Recent research has examined how the timing and modality of signals or alerts may influence driver behaviour in such safety critical situations. For example, HMI signals must be appropriately timed to ensure that they are (a) not too late as to give the driver sufficient time to successfully re-engage, and (b) not too early as that may be interpreted as a false alarm and be perceived as a nuisance for the driver (Lee & Lee, 2007). In addition, it is still unclear how multiple unfolding conflicts should be communicated to drivers as different alerts (signalling these multiple conflicts) that occur temporally close (or concurrently) may startle and confuse the driver, potentially augmenting driver reaction time in response to the situation (Fitch et al., 2014). In terms of the optimal modality of communicating a hand-over request, signals that are visual-auditory have been found to result in more efficient and safer re-engagement compared to those purely visual, which may not even be detected if the driver is distracted (Naujoks, Mai, & Naukum, 2014). Future research needs to continue to elaborate on the interplay between HMI design and take-over situations to ensure the automation state and limitations are communicated to the driver in the most optimal and holistic way possible to ensure safe driving.

Automation misuse and the need to monitor the driver

Drivers may misuse autonomous vehicles whenever attempts are made to operate it outside of design parameters. As discussed previously, drivers may have too much trust in the automation and feel it is safe to engage in other tasks (which will impair re-engagement if required) or place the vehicle in riskier driving manoeuvres (which the car is not capable of performing safely). Both of these issues of misuse may curtail safe driving (Regan, 2004).

Future research needs to be devoted to identifying how education, training and licensing may be used as a countermeasure for automation misuse in the future. For example, training programs should ensure the driver understands how to operate an autonomous vehicle safely, and understands its fundamental capabilities and limitations (Stanton & Young, 2005; Rudin-Brown & Parker, 2004), and becomes aware of the dangers of becoming too reliant on the technology (Regan, 2004). In addition, NHTSA (2013) argues that education needs to be devoted to ensuring drivers know how to resume control of the automation in the event that it cannot continue to operate automatically.

Where drivers do misuse automation and become distracted or inattentive, driver state assessment technology (DSA) might be used as a mitigation strategy. DSA monitors the driver’s alertness and attention level in real-time, reorienting the driver’s attention to the driving task he or she is judged as being “too distracted” from or inattentive to (e.g., when drowsy) according to some predetermined criteria (Rauch, Kaussner, Krüger, Boverie, & Flemisch, 2009). This can be deduced from (a) direct measures including degree of head rotation and direction of eye-gaze (i.e., away from forward roadway; Boverie and Giralt, 2008; Wierwielle, 1999; Hargutt, 2000) and (b) vehicular metrics such as lane keeping performance (i.e., poor lane keeping performance as a sign of driver inattention; Stephan, Hosking, Regan, Verdoorn, Young, & Haworth, 2006).

Preliminary research into the benefits of DSA technology and concurrent feedback to help drivers modulate distracting activities seem promising (Donmez, Boyle, & Lee, 2008). For example, recent trials of head rotation-monitoring systems have been shown to reduce distraction event frequency by almost 80% through distraction alerts and real-time feedback (Croke & Cerneaz, 2009; Heinzman & Zelinsky, 2010). In addition, a recent simulated driving study (Zeeb et al., 2015) showed that eye-gaze behaviour during automated driving can serve as a reliable predictor of the readiness to take over control of the vehicle. Despite initial success, future research will need to further scrutinise DSA technology. Studies need to focus on how the technology can address variability between drivers and different expressions of fatigue and drowsy states (Rauch et al., 2009), as well as privacy issues that may be elicited, which may affect the extent to which automation technology is accepted and utilised.

The personalisation of automation

Another prominent question in the domain of automated vehicles regards the level of standardisation among automated operations and interfaces (TRB, 2013). It is doubtful that different car companies will develop automated systems in similar ways, therefore giving the systems a high level of diversity. In a recent review, Saffarian et al. (2012) support this diversity suggesting that display and automation settings need to be configurable based on operator preference to ensure drivers can interact with it efficiently. However, a number of researchers note that this diversity and personalisation of automated systems will create issues for interoperability and that these systems should behave consistently so as not to violate driver and road user expectations (e.g., if a driver attempts to operate a different automated vehicle to their own) (Burns, 2014). This is an important area of research as the personalised dimensions of automated driving adjustments may be key for user acceptance.

Acceptance

Acceptance of autonomous vehicles is of paramount importance as it will determine whether the systems will actually be used. If automated driving is perceived as unacceptable (unreliable or not useful), drivers may refuse to use it and negate all associated benefits (Regan, Horberry, & Stevens, 2014). For example, ACC has been typically well received based on its perceived convenience and improved safety, however many are still sceptical and fail to utilise the technology in fear of system limitations and sensor degradation in particular (e.g., foggy conditions) (Larsson, 2012). In addition, platooning, which is the grouping of vehicles maintaining a constant short headway achieved by sensor technology, is a driving manoeuvre anticipated for future autonomous vehicles that may have issues with acceptance. A recent report (Larburu, Sanchez, & Rodriguez, 2010) suggests that men may be more tolerant of the short-headways envisaged for this style of driving compared to women, and that participants reported feeling uncomfortable at inter-vehicle distances of 16m and smaller. However, this is a distance greater than that considered to be energy efficient and safe in platooning (Larburu, Sanchez, & Rodriguez, 2010).

In regards to fully autonomous vehicles (Level 4 automation), a recent survey of public opinion provided insight into the types of issues that are most worried about (Schoettle & Sivak, 2014). For example, safety consequences of the system, the potential for the vehicles to become confused by unexpected events, legal liability for drivers and owners, or system security (e.g., hackers) are issues that are receiving considerable attention. On the other hand, issues such as how a driver would learn to use an autonomous vehicle or system performance in poor weather were less relevant issues, a finding which is surprising given the driver concerns noted by Larsson (2012). From this, it is apparent that there are still a range of issues and concerns that may act as a barrier to the acceptance of autonomous driving technology. These issues must be addressed to ensure that drivers utilise the technology and their associated safety benefits.

Conclusions

This brief review of the literature has highlighted a range of human factors challenges that will need to be addressed during the transition from fully manual to fully automated driving. Autonomous vehicle technology is not yet completely safe and reliable, therefore necessitating driver input when autonomous systems fail or are limited in their performance capabilities. The shifting role of the human driver from one in which they are in total control to one in which they are responsible primarily for monitoring and supervising the driving task may lead to problems of inattention, reduced situational awareness and manual skill degradation. In turn, these human factors may compromise the safety of manual control in cases where autonomous systems fail.

As automated technologies are being implemented in an increasing number of market-ready vehicles, there is an immediate and urgent need for future research to address these human factors issues. Studies need to be aimed at enhancing our understanding of how to safely and efficiently re-engage the driver and in designing the automated vehicle from a human-centred perspective. Investigations also need to identify potential misuses of automation and develop countermeasures to reduce behaviours such as overreliance. Finally, research should be devoted to further elaborating on the pros and cons of enabling the personalisation of automation systems and understanding, more generally, barriers to the acceptance of highly automated vehicles. Collectively, these avenues of research will play a vital role in ensuring that automated vehicles realise their potential benefits in increasing road safety.

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