Safety Science xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

The chatty co-driver: A linguistics approach applying lessons learnt from aviation incidents

Alexander Eriksson *, Neville A. Stanton

Transportation Research Group, Faculty of Engineering and Environment, University of Southampton, Boldrewood Campus, Southampton SO16 7QF, UK

ARTICLE INFO

Article history:
Received 21 April 2016
Received in revised form 4 January 2017
Accepted 18 May 2017
Available online xxxx

Keywords:
Automated driving
Communication
Common ground
Human automation collaboration
Transfer of control
Learning from incidents

ABSTRACT

Drivers of contemporary vehicles are now able to relinquish control of the driving task to the vehicle, essentially allowing the driver to be completely hands and feet free. However, changes to legislation taking effect in 2016 will require the driver to be able to override the automated driving systems or switch them off completely. Initially this functionality is likely to be limited to certain areas, such as motorways. This creates a situation where the driver is expected to take control of the vehicle after being removed from the driving control-loop for extended periods of time, which places high demand on coordination between driver and automation. Resuming control after being removed from the control-loop have proven difficult in domains where automation is prevalent, such as aviation. Therefore the authors propose the Gricean Maxims of Successful Conversation as a means to identify, and mitigate flaws in Human-Automation-Interaction. As automated driving systems have yet to penetrate the market to a sufficient level to apply the Maxims, the authors applied the Maxims to two accidents in aviation. By applying the Maxims to the case studies from a Human-Automation-Interaction perspective, the authors were able to identify lacking feedback in different components of the pilot interface. By applying this knowledge to the driving domain, the authors argue that the Maxims could be used as a means to bridge the gulf of evaluation, by allowing the automation to act like a chatty co-driver, thereby increasing system transparency and reducing the effects of being out-of-the-loop.

1. Introduction

Driving Automation (DA) involves the automation of one, or more, higher level cognitive driving tasks such as maintaining longitudinal and/or lateral vehicle position in relation to traffic and road environments (Young et al., 2007). DA distinguishes itself from vehicle automation by entailing forms of automation that involve the psychological part of driving, namely the tactical, operational and strategic levels of driving (Michon, 1985). The higher levels of control involving complex decisions and planning would qualify as DA (Young et al., 2007). By using DA in highly automated vehicles, all but the strategic level of driving could be transferred from the driver to the DA system. Only the highest level of control, i.e. goal setting on a strategical level, would remain with the driver for the main part of the journey. According to the National Highway Traffic Safety Administration (NHTSA) and the Bundesanstalt für Straßenwesen (BASt), DA functionality is likely to be limited to certain geographical areas, such as motorways (Gasser et al., 2009; NHTSA, 2013). Thus, there is a need for a human driver whose task is to resume control of the vehicle when the operational limits of DA are approached (Hollnagel and Woods, 2005; Stanton et al., 1997). This use of DA fundamentally alters the driving task (Hollnagel and Woods, 1983; Parasuraman et al., 2000; Woods, 1996), and will likely give rise to automation surprises (Sarter et al., 1997) and ironies (Bainbridge, 1983) such as unevenly distributed workload (Hollnagel and Woods, 1983, 2005; Kaber and Endsley, 1997; Kaber et al., 2001; Norman, 1990; Parasuraman, 2000; Sheridan, 1995; Woods, 1993; Young and Stanton, 1997, 2002, 2007b), loss of Situation Awareness (SA) and poor vigilance (Endsley, 1996; Endsley et al., 1997; Kaber and Endsley, 1997, 2004; Kaber et al., 2001; Sheridan, 1995; Woods, 1993), with the risk of ending up Out-Of-the-Loop (Endsley, 1996; Endsley et al., 1997; Kaber and Endsley, 1997, 2004; Kaber et al., 2001; Norman, 1990) as well as the possibility of mode errors (Andre and Degani, 1997; Degani et al., 1995; Leveson, 2004; Norman, 1983; Rushby et al., 1999; Sarter and Woods, 1995; Sheridan, 1995).

These problems manifest when the driver is required to return to the driving control loop, either due to mechanical malfunctions,

---

* Corresponding author at: Transportation Research Group, Room 4001, Building 176, Southampton Boldrewood Innovation Campus, University of Southampton, Burgess Road, Southampton SO16 7QF, UK.

E-mail address: alexander.eriksson@soton.ac.uk (A. Eriksson).

http://dx.doi.org/10.1016/j.ssci.2017.05.005
0925-7535/

sensor failure or when the vehicle approaches a context where automation is no longer supported, such as adverse weather conditions, adverse behaviour of other road users or unforeseen events in the road environment. An example of a contextual restriction in contemporary DA is Automated Cruise Control (ACC). Using ACC for prolonged periods of time may cause drivers to forget that ACC system is still engaged when it is time to leave the motorway, which, in busy traffic where vehicle speed is limited by other road users, could result in an increase of vehicle velocity when taking an off ramp as there are no vehicles in front of the car (Norman, 2009). It is therefore important to ensure that the driver receives the support and guidance necessary to safely get back in to the vehicle control loop (Cranor, 2008).

Failure-induced transfer of control has been extensively studied (see Desmond et al., 1998; Molloy and Parasuraman, 1996; Stanton et al., 1997; Strand et al., 2014; Young and Stanton, 2007a). It takes approximately <1 s to respond to sudden events in traffic (Summala, 2000; Swaroop and Rajagopal, 2001; Wolterink et al., 2011). A technical failure leading to an unplanned and immediate transfer of vehicle control back to the driver will likely give rise to an incident as the 0.7 s time headway (the time between the leading and host vehicle as a function of velocity and distance) is shorter than driver response time. Given that drivers are unlikely to be able to intervene in situations where a response time of less than one second is required, it is arguable that the likelihood of failure-induced transfer of control must be made negligible. The feasibility of DA rests on the systems' ability to cope with all but the most severe technical failures without loss of control on public roads.

Routine transfers of control under 'normal' circumstances has not been studied as extensively as failure-induced transfers, therefore many factors still need to be explored, such as: what method and time is used to transfer control, how will the Human Machine Interface (HMI) convey necessary information, and how will the transfer of control be managed by the driver (Beiker, 2012; Hoc et al., 2009; Merat et al., 2014). Christoffersen and Woods (2002) stated that in order to ensure coordination between human and machine, the system state must be transparent enough for the agents to understand problems and activities, as well as the plans of other agents and how they cope with external events such as traffic and sensor disturbances (Beller et al., 2013; Inagaki, 2003; Kaber et al., 2001; Klein et al., 2004; Rankin et al., 2013; Weick et al., 2005). This decreases the size of what Norman (2013) refers to as the gulf of evaluation, which is the effort required to interpret the state of the system and determine how well the behaviour corresponds to expectations. This puts a requirement on designers and engineers of automation to make the operational limits transparent (Seppelt and Lee, 2007).

A crucial part of ensuring system transparency is to ensure that Common Ground (CG) has been established. This is defined as the sum of two or more peoples (or agents) mutual beliefs, knowledge and suppositions (Clark, 1996; Heath et al., 2002; Hoc, 2001; Huber and Lewis, 2010; Keysar et al., 1998; Stalnaker, 2002; Vanderhaegen et al., 2006). CG may be achieved by ensuring that the driver receives feedback that either acknowledges that inputs have been registered, or that an error in the input transmission has occurred. According to Brennan (1998), feedback of this type is of utmost importance in achieving CG. Ensuring that CG is achieved is crucial in a highly automated vehicle as the driving task is distributed between driver and automation and to succeed both entities need to be aware of the other entities actions (Hollan et al., 2000; Hutchins, 1995a, 1995b; Wilson et al., 2007). An example of how this is applied in human-human communication is the use of acknowledging phrases such as "*roger*" when acknowledging statements in nuclear power plant control rooms and on the flight deck (Min et al., 2004).

Furthermore, if the system provides continuous, timely, task relevant feedback to the driver during for example highly automated driving, it is possible to reduce the cognitive effort of understanding the system state and whether user inputs are registered or not when it is time to resume manual control (Brennan, 1998; Clark and Wilkes-Gibbs, 1986; Sperber and Wilson, 1986). According to Patterson and Woods (2001) the purpose of the handover is to make sure that the incoming entity does not have an incorrect model of the process state, is aware of significant changes to the process, is prepared to deal with effects from previous events, is able to anticipate future events, and have the necessary knowledge to perform their duties. This is supported by research from Beller et al. (2013) who found that drivers who received automation reliability feedback were on average 1.1 s faster to respond to a failure, which, according to Summala (2000), is approximately the time it takes to respond to an unexpected event.

Evidently, appropriate feedback may reduce the time needed for a successful takeover as it could allow the driver to anticipate the need to intervene. Research by Kircher et al. (2014) has shown that drivers adapt their usage of automation by disengaging DA systems before operational limits are reached. These insights indicate that drivers are able to anticipate when to disengage automation in contemporary systems to ensure safe transfers of control. This does not necessarily mean that drivers will be able to adapt in such a way using systems in the future, as the majority of the driving task will be automated and the driver will be less involved in the driving task.

1.1. Principles of communication

In order to demonstrate the importance of communication and feedback Norman (1990) posited a thought experiment. In the first part of the experiment an airline pilot handed over control to the autopilot. In the second part of the experiment control was handed to a co-pilot instead of the autopilot. Norman argued that the task is "automated" from the captains point of view in both examples. If an event were to occur mid-flight to create an imbalance in the aircraft, both autopilot and co-pilot have the ability to successfully compensate for the imbalance. However, there is a large difference in the way the information about compensatory actions would be communicated to the captain. In the case of the autopilot the compensatory behaviour would only be communicated through the changes of controller settings in the cockpit and could easily be missed by the crew as they are out-of-the-loop. In the case of the co-pilot, compensatory actions would be executed by means of the physical movements of the co-pilot that is required to change controller settings and to move control yokes as well as verbal communication such as "the aircraft started to bank to the left so I have had to increase the right wing down setting of the control wheel". Thus, in the case of the co-pilot, the compensatory actions taken would be significantly more obvious to the captain. Examples of such situations are given in Section 2 of this paper.

In a DA context, a similar, but strictly theoretical scenario could be that the DA system compensates for an imbalance in the steering system caused, for example, by a partially deflated tire, by countersteering. If the vehicle utilised steer-by-wire technology, with which the physical connection between the wheels and the steering wheel is replaced by sensors, torque motors, and servos, it would be possible for the DA system to compensate for this imbalance by adjusting the position of the wheels to produce a countersteering effect without moving the steering wheel. If this was the case, and the driver was prompted to resume control it is very unlikely that the transient manoeuvre would be carried out in a safe manner as the vehicle would suddenly turn as the countersteering ceased at the moment of control transfer. If the DA system was to mimic the countersteering effect on the wheels

Please cite this article in press as: Eriksson, A., Stanton, N.A. The chatty co-driver: A linguistics approach applying lessons learnt from aviation incidents. Safety Sci. (2017), http://dx.doi.org/10.1016/j.ssci.2017.05.005