Automated vehicles as a co-pilot: improving communication during the transfer of control

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ABSTRACT

Increased automation capabilities create new challenges for automobile designers and manufacturers to address, such as out-of-the-loop performance, mode error, poorly calibrated trust, and breakdowns in communication between agents. A proposed approach to dealing with such issues is to view automation as a co-pilot rather through the implementation of cooperative concepts into automation design. The capabilities for agents to collaborate, coordinate and execute tasks in line with mutual goals and expectations is likely to have a great impact on a number of factors including safety, system efficiency, and trust. The Joint Activity framework proposed by Clark (1996), and applied to automation by Klein et al. (2005), provides a firm theoretical basis in which automation design can be built upon. This draws upon four stages of the handover task in automated vehicles and uses the method of 'action planning' to aid in the application of the joint activity framework to handover assistant design. Preliminary themes are discussed, alongside possible practical implications for automated vehicle handover design.

KEYWORDS

Handover, Communication, Automation, Interface Design, Automobile

Introduction

The future of driverless vehicle technology will require both driver and automation to collaborate with one another to ensure journey success. Level 3/4 automation share in common that automation will be in full control of lateral and longitudinal control of the vehicle, but may require/request the 'handover' of control (respectively) from the human driver due to an environmental event (SAE J3016, 2016). These 'events' can be categorised as being either a critical (e.g., sensor failure) or a non-critical (e.g., geographical/design boundary) event. In the case of a non-critical event, it is foreseen that the driver will typically have a comfortable amount of time to prepare for this transition (Clark, Stanton, & Revell, 2018).

Levels of automation that require human input can create novel issues for the system (Stanton, & Marsden, 1996). These issues include: a degradation in driver performance due to being 'out-of-the-loop' (OOTL) on account of a reduction in situation awareness (SA) and cognitive load (Stanton et al., 2006; Young, Stanton, & Harris, 2007), and errors related to modes and settings (Sarter, & Woods, 1995; Stanton, Dunoyer, & Leatherland, 2011; Stanton & Marsden, 1996).

1.1 Communication during handover

OOTL performance is not exclusive to human-automation interaction; such transitions commonly occur in safety critical human-teamwork domains such as healthcare, air traffic control and energy manufacturing, where effective communication during the handover process is safety-critical. Much of the human-human handover literature highlights inadequacies in task-oriented HHC as being a major problem for task-continuity (e.g., Abraham et al., 2016; Carroll, Williams, & Gallivan, 2012; Cohen, & Hilligoss, 2010; Flemming & Hubner, 2013). Incidents disproportionally occur directly following handover (e.g., Thomas, Schultz, Hannaford, & Runciman, 2013) indicating a vulnerability in a given system, largely attributed to a breakdown in communication. As noted by Eriksson and Stanton (2016), as cognitive activities increase, the requirement for greater communication increases proportionately.

Effective collaboration is that which prevents what is known as a ‘breakdown in communication’. This term is well cited across domains such as healthcare, including instances of breakdowns during shift-handover (e.g., Alvarado et al., 2006; Greenberg et al., 2007). Breakdowns in communication typically occur as a result of progressively differing mental representations of a situation, resulting in a lack of mutual understanding (Klein et al., 2004; 2005). Often, this only becomes apparent when it’s too late to repair the breakdown. This is known as a ‘coordination surprise’ (Klein et al., 2004; 2005). These surprises become apparent as a result of catching the problem early on and repairing the coordination, or as a result of an accident where communication repair is too late.

1.2 The Joint Activity Framework

Coordination within tasks is a central concept in human-human communication (Clark, 1996), computer-mediated communication (Monk et al., 2003) and human-agent interaction (Bradshaw et al., 2009). Klein, Woods, Bradshaw, Hoffman, & Feltovich (2004) discuss the steps required to make automation a ‘team-player’, which has led to further discussions surrounding coordinative concepts in human-agent interaction (e.g., Bradshaw et al., 2009; Klein, Feltovich, Bradshaw, & Woods, 2005). As noted by these authors, the coordinative concepts that make up ‘joint activity’ (JA) provides designers of automation with a clear understanding of how to alleviate breakdowns in communication. JA themes include: the joint action ladder, communicating intention, interdependency between agents, inter-predictability of actions between agents, building common ground, facilitating directability between agents, communication phase information, signalling status, coordination devices, and mitigating costs of coordination. This direct application of JA is yet to be applied to the field of level three road-vehicle automation.

1.5 Purpose of present article

The authors propose that the concepts of ‘joint activity’ can serve as a foundational basis in handover interactions within level 3/4 automated vehicles (AVs). The handover task provides agents with the opportunity to collaborate and work with one another to ensure that the journey is going to plan. As handover can occur for a variety of reasons, it is necessary that the handover is conducted carefully, and safely, to ensure that there is a mutual understanding of the current situation and expected behaviours. To develop discussion around how this can be achieved, this paper models the handover task and applies the concepts of joint activity to provide practical implications for handover design.

Method

2.1 Modelling the handover task

Inspired by the transition taxonomy proposed by McCall, McGee, Meschtscherjakov, Louveton, & Engel (2016) (the alert and the event), with two additional stages, the four stages that were considered in this analysis were: the “pre-plan” stage where information can be exchanged prior to the journey, the “alert” stage which indicates to the driver that they need to take control, a “knowledge sharing” stage that could be implemented to pre-planned handovers and represents a system that has more time for collaboration to occur - much like that of shift handover (e.g., Alvarado et al., 2006), and the “event” stage which encompasses the physical transfer of control. Information that could be transferred during handover was inspired by data collected from a human-human handover task in a driving simulator (see. Clark, Stanton, & Revell, 2018).

2.2 Applying the joint activity framework

To draw together the concepts of JA, and apply them to the handover task, the method of ‘action planning’ was used to map requirements onto the handover model. Action planning is a simple approach to generating actions (output) from a set of pre-researched requirements (Baskerville, 1999). Action Planning is iterative, and cyclical, which allows researchers to apply requirements drawn from theory or data to generate new concepts and ideas and induce a change in orientation (Baskerville, 1999). Its inception was largely due to a lack of connection between research and target domains. The first stage of action planning is diagnosing the problem and the elements that can be improved by applying previously learnt concepts within the relevant system. This process generates what are called ‘meta-requirements’ for the target outcome (Baskerville, 1999). In line with these, diagnoses can then be made in line with each requirement, which can then be planned for implementation by exploring avenues for solutions within the domain.

This study addresses these first two stages of action planning. By drawing upon lessons learnt from the JA concepts for automation outlined by Klein et al. (2004) (see section 1.2) to create meta-requirements, applied to the four defined handover stages. Following this, data collected from design workshops, and handover research can provide practical solutions to address each requirement. To inform how each implication could be implemented to a L3/4 AV, previous bodies of work guided potential information streams, and important considerations to make when considering handover assistant design (for a comprehensive review, see Mirnig et al., 2017). Most notably the following papers were used to inform implementation strategies: visual display of automation capabilities (Beller, Heesan, & Vollrath, 2013), presenting vocalised event information about event (Walch, Lange, Baumann, & Weber, 2015), presenting ambient visual information about event (Borojeni et al., 2016), presenting cooperative feedback (Eriksson, & Stanton, 2016), presenting detailed visual event information (Forster, Naujoks, & Neukum, 2016), multimodal/directional cues (Petermeijer, Bazilinskyy, Bengler, & de Winter, 2017), and communicating how/why the handover is taking place (Koo et al., 2015).

Results and Discussion

As findings are preliminary, this section solely outlines the salient themes that the authors deemed to be central in the application of JA to the handover task, as a result of the action planning process.

3.1 Bidirectional Communication

Implementing a design that takes into account the concepts of JA focuses on bi-directional communication involving a vast array of confirmations and alignments in goals/activities. This process allows both driver and automation to establish and maintain common ground by communicating how each perceives and understands the situation. This form of communication also ensures that each rung of the JA ladder has been addressed and mutually perceived by both parties (Clark, 1996).

Further, bidirectional communication allows for the JA concept of 'directability' to be addressed. This could include presenting the future actions of the automation, or involve directable interfaces that delivers information types where and when the driver feels it is necessary. Directability is important to both the driver and automation, as either one of them may need to coordinate the activity with the exclusive knowledge they have of the situation.

3.2 Goal Coordination and Capacity

Not only should there be the establishment of common ground during specific joint actions (e.g., both automation and driver agree to turn off at a particular junction), but goals must be mutually transmitted between each party to ensure that each party benefits from the coordinated activity in general (e.g., engage automation for increased safety). Therefore the authors define goals as falling into two categories: Global – The reasons for entering in collaboration with automation, for example, improve safety, drive more economically, improve accessibility, and the availability of secondary tasks (Fagnant & Kockelman, 2015); and Event-specific – The intentions of both parties for that current journey (e.g., safely arrive at specified destination). As Clark (1996) explains, both parties must align and acknowledge shared goals, and occasionally, make compromises with their own goals to achieve collaboration. As an example in level 3 automation, the automated system may prioritise safety above efficiency, and require the driver to confirm they have attended each information node presented to them. On the other hand, the driver may prioritise efficiency and attempt to take control. Either driver or automation must relax their goal in order to effectively collaborate on the handover task, and create shared goals. For level 3/4 AVs, goal coordination could be made prior to the journey, but also be adaptable during the journey. Signalling expectancies, such as when automation might require intervention (whether planned or unplanned) will create a mutual understanding towards the capacity the automation has to deal with certain situations.

3.3 Phase and State Coordination

In order to communicate what is expected of the driver at a particular time, presenting phase information (i.e., automation in control, alert, knowledge transfer, transition, driver in control) would allow for better communication between automation and driver. Not only would this address potential mode-errors (Sarter, & Woods, 1995; Stanton, Dunoyer, & Leatherland, 2011), but will also allow the driver to utilise cues, and access previously learnt protocol (e.g., the stages of transition) to better understand what is expected of them alleviating the likelihood of automation surprises and reducing the requirement for an increase in workload due to diagnosing system state (Young, Stanton, & Harris, 2007). Handover HMIs, such as the one found in Volvo's AV, use cues such as light-up steering wheel paddles to indicate to the driver that automation is active, and control inputs can be relinquished (Volvo, 2015). This kind of cue signals to the driver that the handover has been complete, and the vehicle has registered the driver's input. In turn, the driver knows that they can remove their feet and hands from the vehicle's inputs. More complex handover interactions, such as one that facilitates knowledge transfer, would inevitably need to present information about which phase it is in. Such signals are well documented in the joint activity framework.

3.4 Coordinating information transfer

For the purpose of raising system SA and cognitive load prior to handover (Merat & Jamson, 2009; Stanton et al., 2006; Stanton et al., 2017; Young, Stanton, & Harris, 2007) information is given to the driver as to what the current state of the situation is, and the potential points of interest. For each agent to create common ground during this process, we suggest that displays make use of real-time/augmented interfaces, and integrate feedback and acknowledgements between each agent. For automation, this is important because AV may need to ensure that the driver is aware of the situation so that they can safely take control of the vehicle. For the driver, it allows them to indicate when they are ready to move onto the next stage, and signal their understanding.

3.5 Preventing breakdowns in communication

This lack of certainty as to what the reason for handing control over, and the appropriate way to behave at this current time should be communicated by the initiating party to avoid any surprises. It seems necessary for take-over requests to be distinct from one another dependent on the event, as an emergency intervention may require different response to that of a pre-planned handover (see: Politis, Brewster, & Pollick, 2014 for an introduction to situational urgency). Outlining when, and in what situation a handover might occur prior to an event, may serve to prevent the driver from misinterpreting the urgency/motive of the handover, and subsequent increased vulnerability, either due to not taking over quickly enough or communicating insufficiently prior to taking control. Applications of this could include routine handovers providing sufficient notifications prior to the handover, and ensuring that alerts do not replicate that of their emergency counterparts.

A breakdown in communication may also occur if agents do not signal their capacity (Klein et al., 2004) where expectations of both agents do not align. For example, if the vehicle detects an upcoming capability boundary, communicating this information to the driver in advance will likely be beneficial. As the road-environment is dynamic and ever changing, upcoming handover situations (such as emergency road-works, or predicted weather changes) could be communicated to the driver during automation to help prepare them for the possibility of a handover taking place, and ensure a smoother transition.

3.7 Conclusion

Increased automation capabilities create new challenges for designers and manufactures to address such as out-of-the-loop performance, deskilling, uncalibrated trust, and breakdowns in communication between agents. A proposed approach to dealing with such issues is to view automation as a co-pilot rather than a tool, a move that a number of researchers support (e.g., Klein et al., 2005; Eriksson, & Stanton, 2016; Stanton, 2015). The capabilities for agents to collaborate, coordinate and execute tasks in line with mutual goals and expectations is likely to have a great impact on a number of factors including safety, efficiency, and trust. The Joint Activity framework proposed by Clark (1996) and applied to automation by Klein et al. (2005) serves as a firm theoretical basis in which automation design can be built upon. This study takes the handover problem in semi-automated vehicles that require transitions of control, and applies this framework to ensure that both driver and automation can achieve shared goals effectively. In doing so, we map onto the handover task implications from the framework and generate practical themes to help designers address the issue of communication when designing a handover assistant.

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