Developing an abstraction hierarchy for visual displays in semi-automated vehicles

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ABSTRACT

Understanding how to begin the process of designing a complex system can be challenging. Fortunately, human factors experts have a range of methods available for each step of the process from modelling domain constraints and affordances to more refined concept generation. For domains of high risk such as shared-control automated driving, understanding what, why and how to construct the environment around the human to optimise communication could be a major factor in preventing fatal collisions. In this presentation, we describe the process of developing an abstraction hierarchy – the process of mapping out physical objects, processes and values within the domain of semi-automated vehicles and present a section of this analysis exploring the implementation of visual displays for effective driver-automation communication.

KEYWORDS

Automation, cognitive work analysis, interface design, communication

Introduction

Level three and four automated driving requires the vehicle to transfer control between driver and automation at different stages of a journey (SAE, 2016). This is dependent on situational factors, and the capacity the agent has to perform the driving task effectively, in line with effective function allocation – the basis on which functions are allocated to agents in relation to their strengths (Fuld, 1997). A level three vehicle differs from a level 4 vehicle in that it requires human intervention for the system to perform safely, whereas level 4 automation can manage the situation safely. For both levels, either agent may request a transfer of control during the journey (SAE, 2016).

Both level 3 and 4 automated driving involve the driver becoming out-of-the-loop when engaging in secondary tasks to then re-entering the control loop when regaining control. These transfers of control, especially after longer times out-of-the-loop may lead to degraded situation awareness, mode confusion and control deficiencies (Bainbridge, 1983; Endsley and Kiris, 1995; Eriksson and Stanton, 2017). To alleviate these system vulnerabilities, it has been proposed that a handover assistant can aid in the communication of situational information such as hazards, guide the driver towards expected actions and relay information related to performance and capacity of the system (Walch et al., 2015). In turn, as outlined by previous research in human-automation coordination, communication could lead to a better understanding as to what modes are active, and whether the agent who is in control is able to handle the situation prior to, and during, the takeover of control (Klein, 2004).

It is important to understand what current technology is available to designers when developing novel designs. For AV interfaces that are developing at a consistent rate, an understanding of why traditional methods (such as a cluster display) may still be an appropriate method given technological developments is important. Conversely, new technology that may improve a system,

but has not yet been considered by the research community, could go unnoticed. Cognitive work analysis offers human factors practitioners to first define a domain value(s) and outline the relationships between objects and processes and how they address the domain value(s) (Jenkins et al., 2009; Vicente, 1999). From here, further analyses can be undertaken such as when processes should occur, which agents should be allocated these processes, how to inform training, and map out specific situations in detail. Here we present the process of developing an abstraction hierarchy (AH; part of a work-domain analysis) for effective communication in level three or four AVs with a particular focus on how visual displays address effective communication and the processes present.

Method

An AH is comprised of five tiers. The top tier outlines the overall functional purpose. Each tier becomes more specific following the tiers downwards by identifying values and priority measures, purpose related functions, object related processes and then the physical objects that make up the system. Nodes are then linked to the above and below tier using the logic of why the node exists (answered by connected nodes in a higher tier) and how to address a node (answered by connected nodes in a lower tier).

First, the functional purpose is defined – the overarching goal being addressed. The functional purpose in this analysis is 'Facilitate effective communication between driver and automation' due to the aforementioned links between communication and improving performance. Next, values and priority measures are developed representing measurable values that address the functional purpose. These were generated through an exploration of what research into distributed situation awareness (Stanton et al., 2006) and collaborative communication (Klein, 2005) aims to achieve. These are presented in Table 1.

Table 1: Values/priority measures derived from theory for application to AH

Value/Priority Measure	Contributory theory-base
Maximise distributed situation awareness	Distributed situation awareness
Optimise calibration of trust	Collaborative communication
Maximise coordinated activity	Collaborative communication
Maximise usability	Distributed situation awareness
Maximise efficiency	Distributed situation awareness
Maximise safety	Distributed situation awareness

Effective communication aims to improve situation awareness, optimise trust as to not allow for over-reliance or under-reliance, ensure that activity is coordinated (timings, states, expectancies), improve usability through intuitive presentation methods, maximise efficiency so that agents can transfer control clearly and in a timely manner, and overall, maximise safety through communicating collaboratively. It is recommended for an AH to be constructed by defining the top two tiers, then the bottom two tiers, to then link the analysis together with the third tier purpose related functions (Jenkins et al., 2009). The outcome generates new insights into how physical objects can be implemented to address the functional purpose through the tiers in between.

Physical objects for the shared-control AV domain were derived from level two and three AV manuals which included: the Tesla S-Class, the Audi A8 and the Volvo FH16. These objects were grouped together in the object related functions based on what they contribute to the system.

Finally, purpose related functions look for overarching functions of object processes that link to the measurable outcomes of the purpose. To ensure that the analysis was in line with the domain in its current form, the abstraction hierarchy was discussed and adapted with a subject matter expert – a human factors expert working on the development of level four AV technology for a major global automobile manufacturer.

Results

The abstraction hierarchy identified 35 physical objects, fifteen object related processes, six purpose related functions, six values and priority measures and one functional purpose. An insight into what visual displays can contribute to effective communication is shown in Figure 1. Figure 1 displays the AH output for visual displays. Physical objects are presented in the lowest tier, with a progression upwards into what these objects can afford to the system with regard to effective communication.
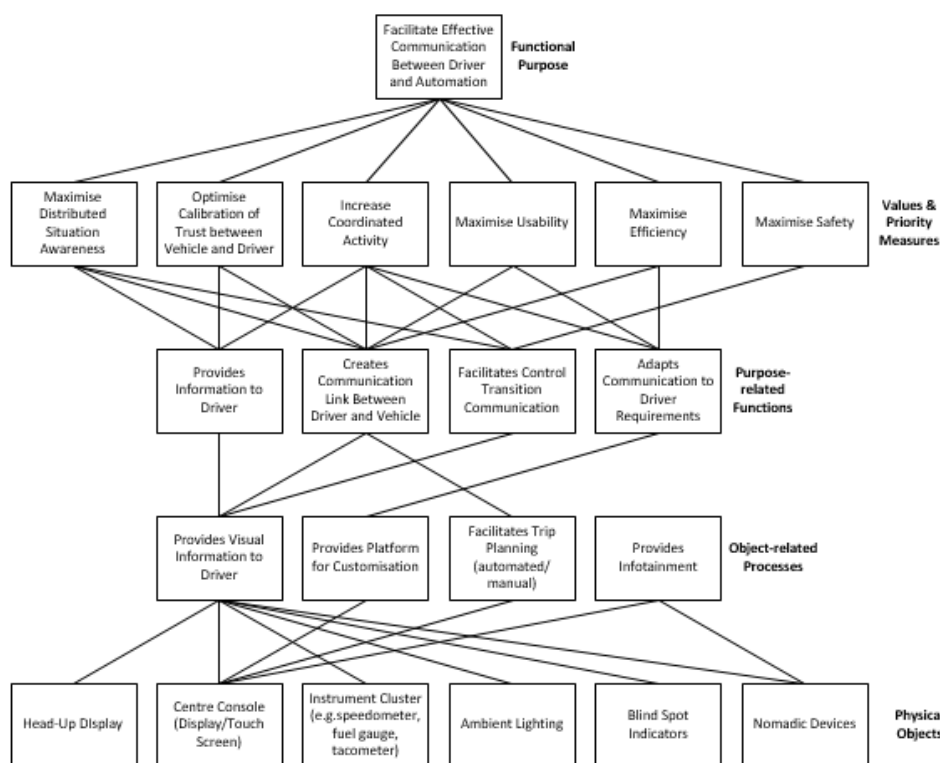

Figure 1: AH output showing connections and nodes for 6 visual display objects

The analysis found six physical objects that could be classed as a visual display including traditional methods (such as instrument cluster) to more novel approaches such as ambient lighting (cabin lighting) and nomadic devices – connected devices such as smart phones that can relay information to the driver. These were found to have roles in displaying visual information, allowing the driver to better customise functions, facilitate planning, and provide infotainment. The former three object-related processes were deemed to be relevant to the overall aim of effective communication. These processes achieved this through information relay, allowing agents to direct one another, facilitating control transitions, and adapting communication to better suit the situation and individual using the system. These nodes are then connected to the values and priority measures to give a better understanding as to how visual displays can be implemented to address measurable values.

Discussion and conclusion

Cognitive work analysis allows human factors experts to model a domain and better understand how to tackle complex issues that, if remained under-examined, could lead to errors and potentially fatal consequences (Jenkins et al., 2009; Vicente, 1999). The first stage in cognitive work analysis is work domain analysis, in which an abstraction hierarchy is created outlining how physical objects can perform to address the values of a desired outcome through the means of object related processes and value related purposes. Each node link between tiers allows researchers to visualise how domains can alter the design of the system to address the functional purpose.

For visual displays in level three or four AVs, it is evident that there is a range of modalities available to communicate with the driver. Each of these have their own way of addressing effective communication, and through well tested combinations of these objects could lead to a system that addresses values such as safety, situation awareness, coordination and usability. The AH is a starting point to further analysis in CWA, and the first step in designing prototypes for testing. Only through careful design iterations and testing can designs become more refined to tackle these issues more effectively, and so the AH should not be treated as a constraining factor in concept generation – rather, this process allows designers to begin their design journey with a better understanding of the elements of a domain and the working environment being analysed.

Acknowledgements

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