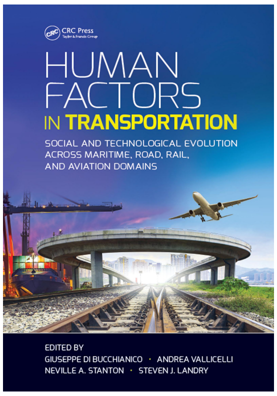

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Social and Technological Evolution Across Maritime, Road, Rail, and Aviation Domains

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17

Hands and Feet Free Driving: Ready or Not?

Victoria A. Banks and Neville A. Stanton

CONTENTS

17.1 Introduction

In 2013, the World Health Organization declared that approximately 1.24 million people per annum die as a result of road traffic accidents with half of these considered to be vulnerable road users: motorcyclists (23%), pedestrians (22%), and cyclists (5%). If the benefits of vehicle automation can outweigh potential costs, then it may prove to be beneficial in both economic, societal, and environmental terms (Stanton and Marsden, 1996; Young et al., 2011; Khan et al., 2012). Highly automated vehicles therefore have great potential in improving the safety of our roads. Even so, a recent study by Banks and Stanton (2015a) found that while the implementation of an autonomous emergency brake feature significantly reduced the number of accidents in a driving simulator study, it was detrimental to driver decision making with the weakening and disintegration of links between information processing nodes (e.g., Parasuraman et al., 2000). These studies indicate that despite improving road safety, there may be unintended behavioral changes on behalf of the driver as the level of automation increases in the driving task and more control delegation is handed to the vehicle.

One reason for this may be due to the changing nature of the driver's role within an already complex system of control-feedback loops as they move from being an active operator to a passive monitor of system operation (Byrne and Parasuraman, 1996). For example, an "almost driverless" system would see 100% of the physical driving task being completed by automated subsystems (Banks et al., 2013) but this does not mean that the role of the driver becomes redundant. Instead, they remain an important agent of control given that they will still continue to receive feedback from both the vehicle and wider environment that enables them to anticipate changes in the environment using feedforward information which may be far more superior to their automated counterparts due to learning and experience (see Figure 17.1). However, high levels of automation in the

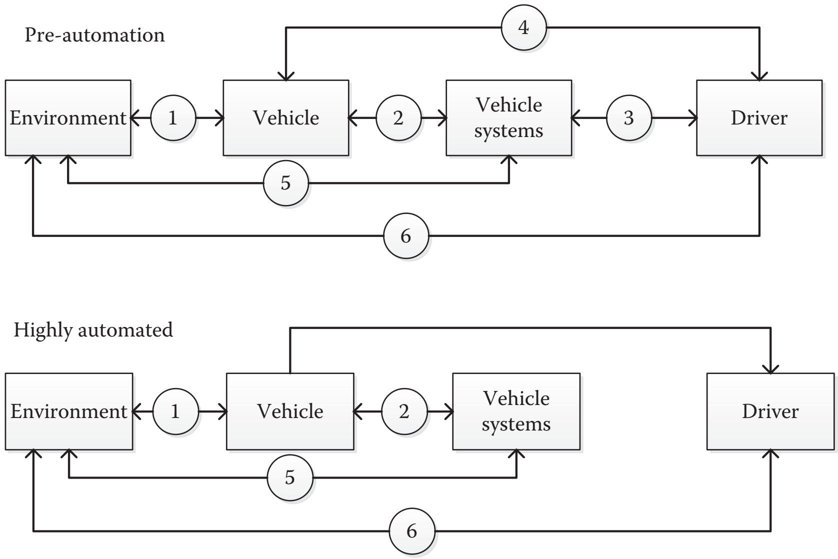

FIGURE 17.1
Control-feedback loops in driving.

driving task leave drivers vulnerable to disengagement (Cuevas et al., 2007; Bekier et al., 2012) from the primary task (driving) and more likely to engage in secondary tasks (i.e., in-vehicle entertainment) (Carsten et al., 2012; Jamson et al., 2013). With the likelihood of "eyes-off-road" time increasing as both the level of automation and the duration at which it is used increase, any failure on part of the automation may delay appropriate driver response (e.g., Young and Stanton, 2007). Failure of an automated longitudinal control system has been associated with inappropriate braking responses in both driving simulator (e.g., Young and Stanton, 2007) and test-track studies (e.g., Rudin-Brown and Parker, 2004). Furthermore, failure to an automated system of lateral control has previously been related to issues of driver complacency (e.g., Desmond et al., 1998). It is therefore becoming increasingly important to appreciate the driver's ability to undertake their *new* supervisory role as the average motorist becomes less actively involved in traditional vehicle handling especially when considering that a vast amount of research over the past 30 years has shown that drivers do not always respond in the way that engineers anticipate in the design of automated assistance (e.g., Hoedemaeker and Brookhuis, 1998; Rudin-Brown and Parker, 2004; Young and Stanton, 2007). This means that while fully automated cars are technologically feasible and have been for some time (Brookhuis and de Waard, 2006), during the intermediate phases of automation, the driver must remain active and in-the-loop (Hoeger et al., 2008) and work cooperatively with their automated counterparts (Soualmi et al., 2014).

Despite the allocation of function between the driver and automated subsystems being key in facilitating and developing driver-automation cooperation (Hoc, 2000), the industry has continued to be plagued by criticism for inadequately acknowledging the role of the driver and how it may change once these systems have been deployed (Banks et al., 2013). It would seem that we do not fully understand or appreciate the complexities of driver-automation cooperation in modern day cars (Weyer et al., 2015). This poses many challenges for systems designers to ensure that the interaction between humans and automated systems is designed appropriately (Strand et al., 2014) to ensure that the negative effects typically associated with being out-of-the-loop are minimized (Endsley and Kiris, 1995; Wickens and Hollands, 2000).

17.2 Adopting a Systems View Approach to Driving Automation

Systems engineering can be seen as an interdisciplinary approach to the field of engineering that integrates both technical and human-centered approaches to look more closely at work processes, optimization, and risk management. This holistic approach is concerned with how the functioning and performance of a joint cognitive system, such as driving (Salmon et al., 2008), can be best described and further understood. This viewpoint stems from the belief that every "agent" within a system plays a critical role in the successful completion of a task and more importantly, "agents" can be both human and nonhuman (Stanton et al., 2006; Salmon et al., 2009). Although early research into automation seemed to focus most heavily upon autonomy, current research now focuses upon satisfying the requirements of joint activity, including human–machine teamwork (Klein et al., 2004). An interdisciplinary approach such as this is extremely complex because the "behavior" or "interaction" that occurs between system components is not always well defined or understood. The aim of systems engineering therefore is to better define and characterize "system agents" and the interactions that occur between them. One way of doing this is through the application of distributed cognition (Hutchins, 1995a); an approach that aims to provide a clearer understanding of task partitioning between the driver and automated subsystems and recognizes that the cognitive processes normally completed by the driver can be shared across this system (Hollnagel, 2001).

From this perspective, situation awareness (SA; Endsley, 1995) is formulated through a myriad of individual components and cannot be predicted based solely upon one of these individual components or the mere combination of individual SA from different agents (Salas et al., 1995). This idea is particularly relevant to vehicle automation because the driver uses assistive aids to help build a "picture" of what is happening in the world (Walker et al., 2010). It is possible therefore to apply Endsley's (1995) three-stage model of SA to a system (e.g., Stanton et al., 2006) although there is a need therefore to move away from traditional notions of SA that currently dominate ergonomics to one that focuses upon entire systems (Gorman et al., 2006; Salmon et al., 2008; Sorensen et al., 2011; Walker et al., 2010). This is because there are very few complex tasks that can be performed on a completely individualistic basis (Perry, 2003; Walker et al., 2010). Distributed situation awareness (DSA; Stanton et al., 2006) offers a compatible approach that assumes SA is a system level phenomenon rather than individual-orientated (Salmon et al., 2008; Stanton et al., 2006). DSA outlines that SA can be held by human and nonhuman agents, that different agents view their environment differently and that at an individual level SA overlap will be dependent upon the goals of each agent. DSA also recognizes that communication can be nonverbal and that SA loosely holds systems together whereby one agent has the ability to compensate for degraded SA in another (Stanton et al., 2006).

Up until now, it is an approach that has been successfully applied to a number of domains including ship navigation (Hutchins, 1995b), airline cockpits (Hutchins and Klausen, 1996; Sorensen et al., 2011), engineering practice (Rogers, 1993), and air traffic control (Halverson, 1995). The application of distributed cognition to driving is a new and relatively unexplored medium yet there appears to be great benefit in doing so in terms of automation development and system safety.

17.2.1 Proposed Framework for the Application of Distributed Cognition to Driving Automation Research

The authors propose that in order to achieve a comprehensive understanding of distributed cognition in driving, the following steps can be taken to explore the design and allocation of system function for both preexisting automated technologies as well as in the development of future automated systems (see Figure 17.2). This approach combines traditional task analysis with qualitative research methods in a systems design framework.

17.2.1.1 Phase 1

17.2.1.1.1 Design Idea, Concept, or Prototype

The purpose of this stage is to identify the automated feature of interest and provide general information relating to its purpose and the subsystem components essential for its build and functionality.

EXAMPLE

The combination of Stop and Go Adaptive Cruise Control, an extension of Adaptive Cruise Control, and some form of Lane Keep Assist would see much of the driving task being completed autonomously enabling the driver in essence, to become "hands and feet free". Although a combined system of Automated Longitudinal and Lateral Control is not an entirely new concept (Young and Stanton, 2002), there has been a significant increase in manufacturers introducing their own versions that fit such a specification over recent years (e.g., General Motor's Super Cruise, Fleming, 2012; Mercedes Distronic Plus with Steering Assist, Daimler, 2013). Where Stop and Go Adaptive Cruise Control is capable of bringing the vehicle to a complete stop through the addition of radar that can operate at slower speeds and over shorter distances (Stanton et al., 2011), future Lane Keep Assist technologies may be able to automatically maintain lane position.

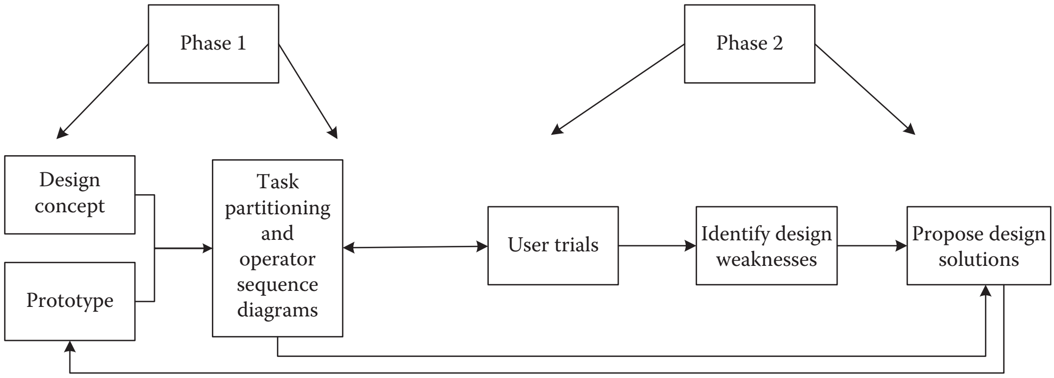

FIGURE 17.2
Systems design framework.

17.2.1.1.2 Task Partitioning and Operator Sequence Diagrams

This form of task analysis provides an insight into "who" owns "what" information, "who" performs "which" function, and so on. Once automated subsystems are activated by the driver, they assume that partial or full control has been assigned to the system. Task partitioning enables us to see how the workload begins to shift from the driver to the automated system (Banks et al., 2013). From a design point of view, and echoing the viewpoint of Endsley and Kaber (1997), it must be ensured that the driver knows exactly "who" is expected to do "what" during the driving task. Thus, in order to design a human-centered product, the designer should augment the task which the product is designed for. In this way, it is possible to establish "who" can do "what" at differing levels of automation. Much like Hutchins described two roles within a pilot's cockpit (pilot flying and pilot not flying), the driving system contains two primary actors capable of controlling the vehicle (driver and automation). A simple mapping exercise similar to the one outlined by Banks et al. (2014a) can achieve the desired output and show how the driver and automated subsystems can work in parallel or independently of one another to provide insight into how physical and cognitive work may be distributed between the driver and automation.

The first step of this process is to outline the functionality of the overall system.

EXAMPLE

Once the driver issues the command for longitudinal control to be automated, the longitudinal controller would begin to hold, represent, and modify information from the changing environment in order to reach the shared goal of the system network (in this case to maintain a desired speed and gap that is preset by the driver). Similarly, the shared goal of the system network that sees lateral control automated is to safely stay within the confines of a lane and avoid deviation. The lateral controller would begin scanning the road environment for lane markings, much like how the driver evaluates the pathway ahead. If no markings are found, the lateral controller would reach its system limits and alert the driver to regain control via human–machine interface (HMI) and possible auditory signals depending on individual manufacturers design parameters. If, however, lane markings are successfully identified, the vehicle could be controlled automatically by the lateral controller.

The second step of this process is to construct operator sequence diagrams (OSD). These offer one way of visualizing distributed cognition within the driving system by showing how work is distributed or "communicated" amongst different system agents in a much more overt manner than the description above (Brookhuis et al., 2008; Cuevas et al., 2007).

EXAMPLE

Figure 17.3 visually represents how workload is divided between system agents of a combined subsystem approach (i.e., automated longitudinal and lateral control systems). Based upon this representation, it would appear that automated subsystem components become central to the functionality of the driving system as the driver delegates increasing levels of control to them. Much of the additional information that is added into the driving task as a result of automation implementation remains firmly embedded within the automated subsystem architecture with only the most relevant information being shared with the driver via the HMI relating to system status.

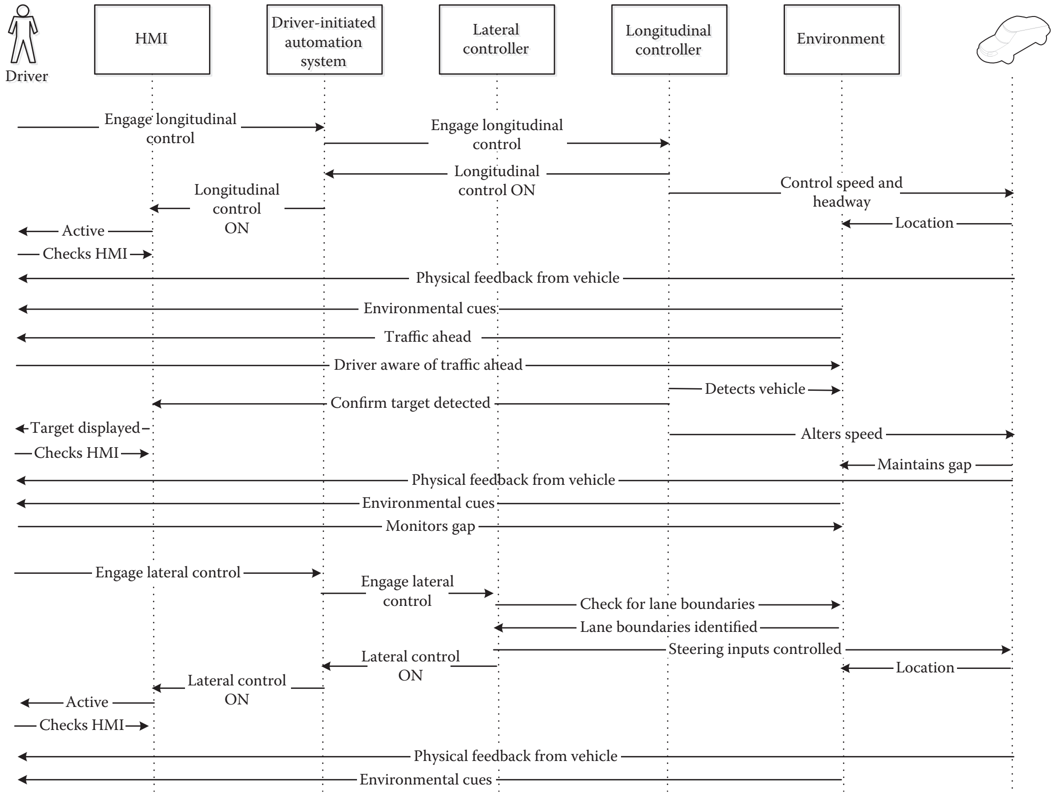

FIGURE 17.3
Basic schematic representation of distributed cognition in an automated system of longitudinal and lateral control.

> In order for the system to function effectively, all system agents will need to have an awareness of how each other (a) works and (b) have some intelligence regarding specific functional limitations. In essence, automated subsystems will monitor the behavior of each intelligent counterpart and adapt accordingly. All system agents will use and process information from the environment and from other system agents in order to respond accordingly (DSA; Stanton et al., 2006).

Although task analysis is a popular and widely used method to assist in the design and development of automated technologies (Putkonen and Hyrkkänen, 2007), it remains a challenge to capture both the cognitive and behavioral elements of a task and there is still some debate over whether it adequately represents cognition (Patrick, 1992). For example, the processes outlined within the OSD representation are likely to be continuous (i.e., continual monitoring and risk assessments will be performed to take into account the ever-changing environment) and also highly adaptable and not constrained to the processes outlined in representational methods. Constraining complex behavior in this way is of course limiting yet phase 1 of the systems design framework offers a reasonable approximation of distributed cognition in specific driving tasks. This means that they provide a good foundation for future investigation at the earliest stages of system development.

17.2.1.2 Phase 2

17.2.1.2.1 User Trials

In order to validate and extend the representation of OSDs, it is essential that these assumptions are experimentally tested through the conductance of user trials. Generating further insight into driver–vehicle–world interactions is thought to be possible through use of verbal protocol analysis (VPA; Ericsson and Simon, 1993) and has been as an extension methodology by Banks et al. (2014b), Banks and Stanton (2015a,b) in both driving simulation and on-road testing. In an extensive review of VPA methodology, Ericsson and Simon (1993) suggest that verbalizations give an insight into the contents of a subject's working memory. This means that verbal reports can generate a rich information source that would otherwise be inaccessible by any other form of data collection (Russo et al., 1989). It offers one way of recording human thought processing when completing a task in real-time meaning that information relating to human–machine interaction is present (Hughes and Parkes, 2003).

EXAMPLE

VPA was used by Banks and Stanton (2015a) to investigate the processes underlying driver decision making at different levels of automation. It revealed that human thought processing was directly affected by both the level and type of automation introduced into the driving task. Analysis revealed that while automation did not alter the decision-making pathway (e.g., the processes between initial hazard detection and response remained the same), it did appear to significantly weaken or sever the links between information processing nodes.

17.2.1.2.2 Identify Design Weaknesses

Based upon the findings of experimental user trials, it may be possible to identify system weaknesses that were not previously identified in the processes outlined in phase 1. For example, more specific issues relating to human–vehicle interaction in driving may be identified through driver protocols and subjective measures of workload (e.g., Hart and Staveland, 1988) and trust (e.g., Jian et al., 2000).

EXAMPLE

Driver verbalizations and subjective reports of mental workload and stress revealed evidence of driver–vehicle coordination problems within an early prototype system of automated longitudinal and lateral control with an automatic overtake function (Banks and Stanton, 2015b). This was an unexpected finding for system developers as they had overlooked the potential for miscommunication to occur between the driver and automated system.

17.2.1.2.3 Propose Design Solutions

Recommendations for alternative strategies should be raised following the appraisal of results if required. Any change to systems design should adopt task augmentation, modeling, and user trial strategies to ensure the success of later prototypes.

EXAMPLE

A recent study by Banks and Stanton (2015c) issued design recommendations for the HMI of a combined system of automated longitudinal and lateral control following a comprehensive thematic analysis of driver protocols that identified issues with ambiguity and inadequate warning mechanisms in the proposed HMI prototype.

17.3 Discussion

While phase 1 of the systems design framework holds great potential in describing system–level interaction in a relatively short space of time and can help define numerous hypotheses for future research direction, phase 2 seeks to empirically validate the assumptions made through the conductance of user trials. Although specific functionality issues cannot be easily addressed in these representations, as long as functionality issues are considered, OSDs may prove to be a useful HMI design and allocation of system functions in the development of future automated systems. What these methodologies do however demonstrate is that ironically, driver task loading does not appear to reduce with increased automation as commonly presumed. Quite possibly workload will actually increase as the driver is required to monitor and anticipate both the road environment, the behavior of other road users, and the automated aspects of vehicle control, synthesizing the wider literature on malleable attention (Young and Stanton, 2002).

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