Preface to the Special Section on Human Factors and Automation in Vehicles : Designing Highly Automated Vehicles With the Driver in Mind

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Preface to the Special Section on Human Factors and Automation in Vehicles: Designing Highly Automated Vehicles With the Driver in Mind

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Objective: This special section brings together diverse research regarding driver interaction with advanced automotive technology to guide design of increasingly automated vehicles.

Background: Rapidly evolving vehicle automation will likely change cars and trucks more in the next 5 years than the preceding 50, radically redefining what it means to drive.

Method: This special section includes 10 articles from European and North American researchers reporting simulator and naturalistic driving studies.

Results: Little research has considered the consequences of fully automated driving, with most focusing on lane-keeping and speed control systems individually. The studies reveal two underlying design philosophies: automate driving versus support driving. Results of several studies, consistent with previous research in other domains, suggest that the automate philosophy can delay driver responses to incidents in which the driver has to intervene and take control from the automation. Understanding how to orchestrate the transfer or sharing of control between the system and the driver, particularly in critical incidents, emerges as a central challenge.

Conclusion: Designers should not assume that automation can substitute seamlessly for a human driver, nor can they assume that the driver can safely accommodate the limitations of automation. Designers, policy makers, and researchers must give careful consideration to what role the person should have in highly automated vehicles and how to support the driver if the driver is to be responsible for vehicle control. As in other domains, driving safety increasingly depends on the combined performance of the human and automation, and successful designs will depend on recognizing and supporting the new roles of the driver.

Keywords: driver behavior, surface transportation systems, highway and vehicle design, surface transportation systems, system design features, aerospace systems

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INTRODUCTION

Cars have come a long way since the invention of the cruise control system by Ralph Teetor in 1945. The vehicle of today is able to assume more and more of the basic driving tasks, with many features of automated vehicles already available in many luxury and midpriced cars. Examples of such advanced driver assistance systems (ADAS) include automated parking, lane-keeping systems, adaptive cruise control, forward collision warning, speed regulation systems, curve speed warning, and blind spot monitoring. Incorporating all these systems in one vehicle could mean that the systems are more in control of the vehicle than the driver.

Results of the first large European project on field operational tests (euroFOT) were presented at a workshop in Brussels (June 26–27, 2012). Incorporating 28 partners, including major automotive manufacturers, this project collected field data spanning 4 years to provide insights on the interaction of drivers with ADAS. The project's main findings were that these systems are well accepted by European drivers and are generally beneficial to driving: They reduce the number of crashes, increase driver safety and comfort, and promote fuel efficiency (see http://www.eurofot-ip.eu/). These benefits of ADAS are encouraging manufacturers to include an increasing number of ADAS features in production vehicles.

In addition to the rising number of ADAS features incorporated in vehicles, the use of sensors and wireless communications for vehicles is also on the rise, allowing vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and perhaps even vehicle-to-other-road-users communication, for example, between vehicles and bicycles, motorcycles, or pedestrians. The rationale for introducing such systems in vehicles and the road infrastructure is that they will increase safety and comfort of the driver, reduce congestion, and promote a more efficient transport network. The implementation of the "Google car" and "cybercars" suggests that the near future may even include "driverless cars," a topic discussed at the Driverless Car Summit in Detroit, Michigan (June 2012; http://www.auvsi.org/AUVSI/EventDescription/?CalendarEventKey=f027d7f8-94f5-46b3-9054-5b124b161d46). Evidence of progress toward driverless cars can also be seen in Ford's hands-free perpendicular-parking feature (http://www.insideline.com/ford/ford-developing-hands-free-perpendicular-parking-feature-other-automated-technology.html), Volvo's City Safety imminent-collision avoidance braking system, and the Toyota Prius used in the Google autonomous driving project. Such technology will likely redefine the role of the driver.

Whereas North American research in this area from the 1990s has been concentrated mostly on dedicated automated highway systems (Horowitz & Varaiya, 2000; Levitan, Golembiewski, & Bloomfield, 1998), European research has moved away from this concept, developing vehicles for the existing road infrastructure (Parent, 2007). Examples of such research include the SARTRE project on platooning (http://www.sartre-project.eu/), HAVEit (http://www.haveit-eu.org), and CityMobil (http://www.citymobil-project.eu/). The majority of these projects have focused on the practicalities of implementing hardware and software, for example, ensuring that cameras and sensors function correctly and that the required infrastructure is in place. Sadly, there has been much less appreciation of how the *users* of such systems—that is, drivers of the vehicles and other road users, such as cyclists, passengers, and pedestrians—might interact with such vehicles.

Our understanding of people's interaction with such automated vehicles is largely based on what we know from research in aviation and process control (Roth, Bennett, & Woods, 1988; Sarter & Woods, 1995; Sheridan, 1992; Zuboff, 1988). Such research provides valuable lessons, but driving is substantially different and potentially more vulnerable to neglecting drivers in designing vehicle automation. However, it is encouraging to see a recent upsurge of such research concerning highly automated road vehicles. Examples include research on the impact of transitions between automation and manual driving, as conducted in the CityMobil and HAVEit projects (Flemisch et al., 2011; Schieben, Flemisch, Temme, & Köster, 2011; Toffetti et al., 2009) and the "intelligent copilot" work at MIT (Anderson, Karumanchi, & Iagnemma, 2012).

This special section of *Human Factors* brings together a range of studies conducted in the area of vehicle automation, with particular emphasis on understanding the human factors challenges faced in moving toward highly automated vehicles. Of the manuscripts submitted to the special issue, very few addressed the challenges of *highly automated driving*, with most papers concentrating on *assisted driving*, which involves systems such as adaptive cruise control (ACC) or forward collision warning (FCW) in isolation rather than in combination with steering assistance and navigation systems that might constitute a fully autonomous vehicle. This focus likely reflects the current state of automotive technology; however, the rapid pace of technology change and the prospect of highly autonomous vehicles in the coming years points to an urgent need for such research. As an introduction to this special section, we highlight contributions of the articles, relate them to the existing research based on human–automation interaction, and indicate general directions for future research.

FROM WARNING TO CONTROLLING

Collision warning systems represent a low level of vehicle automation that is becoming part of many production vehicles, yet its influence on driver behavior and driving safety is only partially understood. Two articles in this special section further our understanding of driver response to the lowest level of vehicle automation: warnings rather than vehicle control. Bao, LeBlanc, Sayer, and Flannagan (2012) describe how forward collision warnings help drivers accommodate the demands of controlling heavy trucks. They examined driver behavior in a naturalistic field study lasting 10 months and found that prolonged driving with the warning system increased truck drivers' time headway and therefore may reduce crash likelihood. In many situations, such warnings are not sufficient to avoid collisions, and the article by Muhrer, Reinprech, and Vollrath (in press) shows the benefit of driving with an adaptive FCW-and-automated-braking system (FCW+). During unexpected braking events, the FCW+ braked earlier and more effectively than drivers.

The FCW+ system described by Muhrer et al. (2012) highlights the promise of automation that is more competent than most drivers in extreme situations. Such systems have already reached the market in the form of Volvo's City Safe automated braking system and in stability control systems. The cost–benefit profile and general design philosophy associated with usurping driver control remain important research issues. An analytic framework has been developed to identify circumstances in which automation should assume full control (Inagaki, 2003; Moray, Inagaki, & Itoh, 2000), but how it applies to driving has not been fully defined.

DRIVER ADAPTATION AND ATTENTION

Bao et al. (2012) touch on the important issue of driver adaptation to automation, a theme that is further explored in articles by Koustanäi, Cavallo, Delhomme, and Mas (2012) and Xiong, Boyle, Moeckli, Dow, and Brown (2012). Koustanäi et al. describe the advantage of familiarization with FCW. They show that trust increases with greater familiarity, but acceptance does not. Xiong et al. examine how driving style and personality influence drivers' adaptation to ACC. They used a cluster analysis to identify three groups of drivers based on their propensity to risky behavior. These authors argue that personality, education, and experience with similar systems strongly influence adaptation to automation.

Three articles in this special section consider how drivers' adaptation to vehicle automation might interact with two prominent crash contributors: fatigue and distraction. Neubauer, Matthews, Langheim, and Saxby (2012) showed that providing drivers with control of the automation results in the same levels of stress and fatigue as enforced vehicle automation. Voluntary control of automation failed to alleviate fatigue, and drivers who were fatigued were more likely to engage the automation, which led to increased distress. They also found that managing automation could distract drivers and that fatigued drivers respond slowly to emergency events. In summary, their results suggest that automation does not necessarily mitigate but can exacerbate the effects of the fatigue.

Whereas Neubauer et al. (2012) suggest that the burden of managing vehicle automation may itself pose a distraction, Carsten, Lai, Barnard, Jamson, and Merat (2012) report an increase in secondary task engagement (e.g., watching an in-car DVD) with increased automation. Drivers' willingness to engage in distractions differs with lateral and longitudinal control, with drivers engaging more with the DVD when they had lateral support. Merat, Jamson, Lai, and Carsten (2012) pursued a similar theme and considered the consequences of secondary task engagement on drivers' response to critical incidents during manual and automatic control. When drivers who were engaged in a secondary task encountered a critical incident, their workload spiked, with demand for regaining control of the driving task exceeding their capacity, delaying their response to the critical incident. Both articles demonstrate the potential danger that high levels of automation combined with drivers' tendency for distraction will result in lower levels of situation awareness.

These five articles demonstrate that automation can affect driver performance in unforeseen ways, particularly when automation assumes a more central role in the vehicle control loop. A long history of research on automation has demonstrated the resumption costs associated with people who are out of the control loop but who need to retake control (Wickens & Kessel, 1979, 1981). In driving, this problem is particularly acute because critical events that require drivers to intervene are likely to be those situations where a rapid response is required. Automation may require drivers to intervene on a scale of milliseconds, but reentering the control loop may take seconds. Similar to other domains, an irony of vehicle automation is that it can accommodate the least demanding driving situations—encouraging drivers to disengage from driving—but then calls on the driver to address the most difficult situations (Bainbridge, 1983). Periods when drivers are most likely to fully rely on automation—highway driving—also require the most rapid reentry of drivers into the control loop. This irony points to how designers of automation with a high degree of control authority must take a corresponding degree of responsibility (Sarter & Woods, 1994).

BALANCING AUTHORITY AND RESPONSIBILITY

One approach to balancing authority and responsibility is to support rather than automate the driving task. Dijksterhuis, Stuiver, Mulder, Brookhuis, and de Waard (2012) describe how drivers respond to adaptive vehicle automation that strives to engage them. Such an approach might reduce the automation management demands noted by Neubauer et al. and the tendency for drivers to direct attention to nondriving tasks noted in the Carsten et al. and Merat et al. papers. Here, automation is designed to keep the driver in the loop as much as possible rather than to control the vehicle or warn the driver only in imminent crash situations. Dijksterhuis et al. used adaptive automation to guide drivers only when they exceed safety thresholds. Their support system improved lane keeping only when it was adaptive, compared with a nonadaptive version that was similar to a traditional lane-departure warning. Their results demonstrate that automation can be much more effective if it engages the driver in the control loop.

Keeping drivers in the loop is also the aim of Mulder, Abbink, and Boer (2012), who used haptic feedback to support shared control for curve negotiations. Rather than involving discrete warnings or automated steering, continuous haptic feedback guides drivers through the steering wheel. Their approach strives to minimize the problem of reengaging drivers when the automation fails by focusing on shared control. With shared control, the driver continues to have direct manual control but also receives continuous support from the automation. Mulder et al. describe a gradation of automation authority, concretely defined as the "stiffness around the optimal steer angle determined by the automation system" (p. 795). Such an approach ensures that drivers are engaged in the task and are not simply supervisors of the system, which necessarily leads to delayed responses when drivers must intervene in unexpected situations.

SOCIAL CONSIDERATIONS AND COLLECTIVE BEHAVIOR

Verberne, Ham, and Midden (2012) conclude this special section with an argument for the importance of shared goals between the driver and vehicle automation. They argue that people respond to technology in a social manner, similar to how people respond to other people (Lee & See, 2004; Nass & Moon, 2000). In this context, matching the goal of the automation with that of the driver is likely to be more trusted and accepted. In the context of ACC, their experiment confirmed their hypothesis when they found that ACC designed to share the drivers' goals was more trusted than ACC that did not. As vehicle technology becomes more sophisticated and anthropomorphic, particularly, the capacity for voice-based interaction (Nass & Brave, 2005), trust and other social responses may become critical.

Verberne et al.'s (2012) article focuses on the social response to the automation in the drivers' own vehicle, but another important issue concerns how drivers of conventional vehicles respond to highly automated vehicles that might violate social norms and expected behavior of "typical drivers." A related concern emerges from the interactions of conventional and autonomous vehicles and between groups of autonomous vehicles if they use different "social" conventions to guide behavior as they negotiate interactions in sharing the road and resolving potentially competing goals.

PROMISES AND PITFALLS OF HIGHLY AUTOMATED VEHICLES

This collection of articles shows that vehicle automation and support systems can both enhance and degrade driving safety. To some extent, the safety benefit might depend on whether the role of the driver assumed by the vehicle designers corresponds to the role drivers actually adopt. Even now, the role of the person behind the wheel is often not that of a driver but that of an office worker on a conference call, a mother caring for a child, or a teen connecting with friends (Hancock, in press). Technology that people view as taking on the role of the driver will likely exacerbate distraction and the tendency for other roles to displace the person as driver, leaving people vulnerable to situations the automation cannot handle.

At-risk drivers may have the most to gain from vehicle automation but may also be most vulnerable to its failing. Automation might be able to compensate for fatigue, alcohol impairment, lack of skills and judgment of novice drivers, and cognitive impairment in older drivers. Ironically, drivers who may benefit most might also be the most vulnerable to the challenges of relying on the automation appropriately and successfully and intervening when manual control is needed (Lee, 2007). It is essential to consider the most coherent ways to integrate vehicle automation, rather than a piecemeal approach that builds higher levels of automation from existing systems (e.g., combining ACC, lane-keeping assistance, lane departure warnings). Research from aircraft automation suggests that a piecemeal approach can lead to complicated interactions and confusion even among trained pilots (Degani & Heymann, 2002; Degani & Kirlik, 1995). Crafting automation architectures, algorithms, and interfaces that promote understanding and appropriate reliance represent important challenges.

In summary, the articles in this special issue reveal some human factors challenges of automation in vehicles. If a general theme emerges from these articles, it is that vehicle automation is likely to change the role of the driver, particularly as drivers adapt to automation over time. Automation does not simply substitute for the driver in performing discrete tasks. As in other domains, driving safety increasingly depends on the combined performance of the human and automation, and successful designs will depend on recognizing and supporting the new roles of people in controlling cars.

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