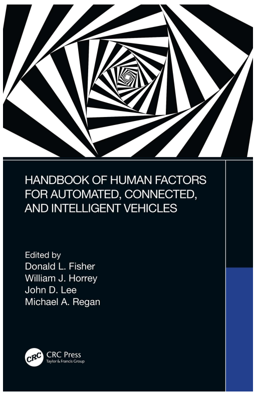

Handbook of Human Factors for Automated, Connected, and Intelligent Vehicles

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Future Research Needs and Conclusions

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24 Future Research Needs and Conclusions

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KEY POINTS

- The exact point at which a given vehicle technology will be present in the majority of the vehicle fleet is very difficult to predict, but no one expects Level 4 or 5 technologies to be a majority of the fleet in the next ten years.
- Given that the majority of the vehicle fleet for the next ten years will be Level 0–3 vehicles, along with vehicles which have active safety systems, the overwhelming majority of the chapters in the Handbook are relevant to today's human factors concerns and those concerns for at least the next decade.
- The best summaries of the future research needs are in the chapters themselves.
- This chapter focuses on the various research needs in each topical area which the editors believe are most critical, based on their broad reading of all of the chapters.

24.1 INTRODUCTION

Our collective experience professionally, as editors of this Handbook, and as avid readers of the chapters contained herein, provides us with a perspective on the issues surrounding the human factors concerns that are raised by the advance of automated, connected, and intelligent vehicles (ACIVs) that we would like to share with our readers. This experience may make us blind to the real concerns, but we hope not. And in so far as it does, you should turn, as we do, to the chapters themselves where the real expertise and wisdom lies.

So, what we want to do in closing is give readers the editors' reflections on the chapters and topics, which includes in addition to summaries of the chapters our best sense of the most critical human factors research, development, practice, planning, and/or policy needs as relevant to the chapter being discussed. We encourage you to disagree, to push the limits of what is possible, in whatever area is of most interest to you. We certainly do not have privileged access to what will unfold in the future. With that as background, we hope you find at least one or two nuggets in what follows.

24.2 THE STATE OF THE ART: ACIVS

The future of ACIVs has always been just around the corner, at least since the late 1930s (Chapter 2). But it has stalled several times since. The question facing us today is whether we are at another inflexion point. The author of Chapter 2 supplies example after example of the steady march forward of ACIVs. The progress truly is stunning and we encourage readers to go back to this chapter whenever they doubt the steady progress of technology. In fact, when we, the editors, started this Handbook we were not sure it would be relevant because industry leaders predicted that driverless cars would be on our streets by 2018 (Yadron, 2016). Yet a recent article in the *New York Times* in July of 2019 (Boudette, 2019) suggests that driverless cars are far into the future. And why?

The answer is telling: "the delay [is due] to something as obvious as it is stubborn: human behavior (Boudette, 2019)." This is much like blaming the victim. The human driver may be stubborn; but he or she is also very good at dealing with *ordinary* driving, which can involve complex negotiations between drivers in unexpected circumstances (as opposed to situations where, say, automatic emergency braking can be a real life saver). It is our advanced technologies that cannot yet do in many cases what the human driver does more or less faultlessly, human drivers having only 1.25 fatal crashes per 100 million miles. Yet we are now asking Level 1–3 automobiles to perform the functions that humans now perform so well: ordinary driving. But having Level 1–3 technologies substitute for what the human driver does can create unexpected problems.

The various chapter authors have argued throughout the Handbook why it is that Level 1–3 vehicles create human factors challenges. As has been pointed out so eloquently by the authors, drivers of current vehicles at these levels of automation can easily become disengaged, lose situation awareness (SA), and fail to take over control when necessary or do so too slowly to avoid a crash. A number of vehicle manufacturers are trying to change the image the public has of Level 1–3 vehicles by rebranding them. For example, at the 2019 Consumer Electronics Show, Toyota differentiated between its two new automated vehicle lines, Toyota Guardian (Levels 1–3) and Toyota Chauffeur (Levels 4–5). The CEO of the Toyota Research Center says of the Guardian mode: "With Guardian, the driver is in control of the car at all times except in those cases where Guardian anticipates a pending incident, alerts the driver and decides to employ a corrective response in coordination with driver input…. In this way, Guardian combines and coordinates the skills and strengths of the human and the machine (Global Toyota, Feature Innovation Automated Driving Technology Region U.S, 2019)." This concept (the car as Guardian rather than Chauffeur) was referred to as directed automation in Chapter 4 and its importance discussed there.

This appears to be a real shift from an emphasis on "driverless" cars to cars which serve as a backup for the human driver when that driver is no longer able to control the vehicle. The research question that really needs to be asked here is whether a vehicle that serves as a guardian can actually be developed, a vehicle in which the driver does have full control and, critically, does not disengage, until he or she is no longer capable of avoiding a crash. It simply is not known how much control the driver needs to maintain over the vehicle in order to keep engaged. Some vehicle manufacturers now allow drivers to keep their hands off the wheel as long as their eyes are on the road for some period of time in a given interval. Other vehicle manufacturers allow drivers to do almost anything as long as their hands are on the wheel for some period of time in a given interval. However, no one knows what exactly a driver must do to remain safely engaged at all points in time during a trip, knowing that the car he or she is driving will serve as a guardian if the situation warrants it. Research is needed into the most basic of questions.

24.3 ISSUES IN THE DEPLOYMENT OF ACIVS (PROBLEMS)

Before deploying ACIVs, it will be critical to understand issues centering on the driver—alone in the vehicle or embedded within a larger system, on the public's acceptance of such vehicles, and on the regulation of these vehicles. The key questions in our opinion that need to be addressed in each of the topics covered in the section on deployment (Chapters 3–14) are discussed briefly below.

24.3.1 Drivers' Mental Models of Vehicle Automation (Chapter 3)

Mental models might be one of the most critical considerations when dealing with the intersection between humans and automated systems. They inform almost every aspect of the driver's interaction with the system: when and how to use the system and what they do when the system is engaged, to name only a few. And, some of these interactions will have cascading effects on other aspects of behavior and performance (e.g., workload, situation awareness (SA), etc.). It is also easy to see connections between a driver's understanding of a system and their trust and acceptance of the system. In spite of their importance in this space, there is still much we do not know about driver's mental models of automated systems. We do know that drivers show significant deficits in their understanding of automated systems, including knowledge of their functional limitations (e.g., McDonald et al., 2018). We know less about how these gaps in understanding map directly onto driver decisions and behavioral and safety outcomes. More work is needed and, fortunately, many enterprising organizations are working to provide data points on this front. At the same time, we need to further develop our understanding of how mental models are formed in the first place and what types of information, branding, experiences, and so on might help to improve user's mental models. This can have important implications for automobile manufacturers as they consider the development of owner's manuals and related resources and for dealerships as well as marketing folks. Already, as part of this, we are seeing some initiatives to promote a common nomenclature for the systems comprising market-ready automation (e.g., AAA, 2019). This also will have an impact on our approaches to driver training and education. Ultimately, we would like to know the best way of tailoring a driver's mental model to the system that is present in their own vehicle. The list of specific research needs goes well beyond the space afforded in this chapter—suffice it to say that there is much work to do.

24.3.2 Driver Trust in ACIVs (Chapter 4)

Like mental models, trust has a pervasive influence on how people rely on and accept technology. Inadequate trust leads people to reject potentially useful technology and too much trust leads people to rely on technology when they shouldn't. Trust becomes an increasingly powerful influence as the complexity of automation makes it difficult to form a complete mental model. The advances in automotive technology confront drivers with a more diverse and complicated set of devices, and so trust is likely to play an increasingly important role in how drivers interact with vehicles.

Two general areas of research merit particular attention. The first concerns over-trust and the automation paradox. Efforts to improve the performance of automation makes it less likely that drivers will confront edge cases where they will need to take control. The less often a driver needs to take control the fewer opportunities drivers have to learn where the automation might fail, leaving the driver less able to build up enough exposure to systems to accurately calibrate their trust. How might feedback from the automation be accentuated to enhance exposure to systems? How might drivers be able to interact with automated systems and to generate feedback? Such design concepts require evaluation, which prompts the question: what techniques can be used in experimental settings to evaluate trust (often in absentia of long-term exposure)? The second general research area concerns the role of trust in driverless vehicles where the people take on the role of passengers. Such situations introduce a broad range of trust relationships that must be supported: between the passenger and the vehicle, between and among passengers in shared-ride situations, and between passengers and the companies operating the vehicles. People need to trust a vehicle to safely transport them to their destinations, but driverless vehicles will likely leave passengers with little opportunity to influence the vehicle, which might lead to feelings of dread risk that can undermine trust. What interaction architectures and interfaces can mitigate dread risk and promote trust? Because driverless vehicles are unlikely to be owned by individuals, an important research question is how to promote trust and trustworthy behavior in those who might share the vehicle. Likewise, companies operating vehicles will control people in new ways, raising the question of how to design transport services to operate in a trustworthy manner?

24.3.3 Public Opinion about ACIVs (Chapter 5)

As vehicles equipped with automated driving systems start entering the market, it is important to gauge public opinion about them—even if the public at large has had little or no direct exposure to them. This point was underscored by the authors in Chapter 5 and elsewhere (Cunningham, Regan, Horberry, & Dixit, 2019). As noted by these authors, an understanding of public opinion about automated driving systems can benefit different stakeholders in society in different ways: benefit governments, for example, in making future planning and investment decisions; benefit industry, for example, in helping technology developers design and refine their products in response to the perceived needs of end users; and benefit research organizations, in identifying new directions for research. Ultimately, as argued in Chapter 5, the predicted benefits of automated vehicles may never materialize unless there is societal acceptance of them. If not, people may refuse to purchase them, refuse to travel in them, or interact with them in ways unintended by designers.

The following are some research needs in this area, as distilled from Chapter 5 and elsewhere (Cunningham, Regan, Horberry, & Dixit, 2019). First, most studies of public opinion of automated vehicles have, to date, been cross-sectional in design, precluding formulation of any conclusions about causality between the constructs of interest. Future studies would benefit from the use of longitudinal designs to track changes in public opinion over time and discern the factors that underlie identified changes. Second, highly and fully automated passenger vehicles (SAE Levels 3–5) are not yet commercially available in large numbers. Consequently, measurement of public acceptability in most studies to date has been based on people having to imagine how such vehicles might operate in the future. An important area for future research is research on acceptance of such vehicles, after people have had direct exposure to them, and to compare the findings with those obtained prior to exposure—to determine to what extent measures of acceptability are predictive of measures of acceptance. Third, there is evidence that, while there is some commonality in opinion about automated vehicles across countries and cultures, there is also some divergence of opinion. Further research is needed to understand these differences across a wider range of countries and cultures, to inform local needs and to inform those who seek to market vehicles and systems in other countries and cultures. Finally, there are many population demographic and other variables (e.g., age, gender, willingness to pay) that can be used to predict societal acceptability and acceptance of highly automated driving systems. Further research is needed to understand which of these demographic and other variables, individually and collectively, account for most of the variance in public acceptability and acceptance of these technologies.

24.3.4 WORKLOAD, DISTRACTION, AND AUTOMATION (CHAPTER 6)

The introduction of automation into the vehicle will have an impact on the driver's roles and responsibilities. By extension, their experience of cognitive, visual, and manual workload will change, leading possibly to underload or to increased engagement in other tasks. These concerns play into other topics, such as SA (Chapter 7) and driver fitness to resume control (Chapter 9). Although research is now documenting the impact of vehicle automation on driver workload, arousal, and in-vehicle activities (e.g., potentially distracting tasks), there are many questions as of yet unanswered. Where the interface between driver workload and driver distraction is concerned, a number of issues warrant further research. For example, to what extent do prolonged periods of automated driving (low workload) encourage driver involvement in potentially distracting activities? To what extent does driver distraction lead to automation surprises, and associated spikes in workload, and how? To what extent do drivers self-regulate their workload (monitoring of the forward roadway) when distracted to prepare for takeover when required? In the context of a mixed fleet, will drivers of vehicles not capable of operating autonomously have workload spikes and be distracted by the behavior of other vehicles operating autonomously (in some or all operational design domains)—in much the same way that we are distracted now by drivers who drive erratically in traffic? In addition to the many specific research questions, there are also more general conceptual questions regarding workload, distraction, and automation. For example, will workload, distraction, and inattention, more generally, remain as issues in vehicles equipped with SAE Level 4 and 5 technologies that are operating autonomously (Cunningham & Regan, 2018)? For these levels, is it possible for such self-driving vehicles themselves to be distracted or overloaded (i.e., can the complexity of a situation exceed the processing power of the hardware and software to take the appropriate countermeasures)? We might call this "vehicle distraction" or "vehicle overload." Here, again, the frame of reference from which to conceptualize distraction and workload will change. But what competing activities, if any, could divert a vehicle's "attention" (or computational resources), more generally, away from activities critical for safe driving? In fact, what might it mean for a vehicle driving autonomously to be inattentive or be overloaded; and if it was, what might be the mechanisms of inattention and resource constraints?

24.3.5 Situation Awareness in Driving (Chapter 7)

Situation awareness (SA) characterizes the driver's understanding of the state of the vehicle and the environment that informs decision-making in the complex, dynamic traffic setting. SA involves perceiving and attending to information in the environment, integrating and making sense of this information, and projecting future status based on this information. It follows that SA implicates driver attention, information processing, and various cognitive constructs, such as working memory. As automation changes the driver's roles (Chapter 8), the manner in which drivers regulate their attention in support of SA will likewise change (e.g., Chapter 6, 9). The importance of complete and accurate SA is most salient when considering takeover situations where the driver needs to resume control of the vehicle. Many research questions beg answers (and these are highly intertwined with topics covered in other chapters). For example, what is the best way to keep the driver engaged (i.e., with good SA) in the driving task when the automation is operating? What factors degrade driver SA in advance of, during, and after takeover situations and by how much? While some of the solutions described below might offer possible benefits, there is a definite need for more data.

24.3.6 Allocation of Function to Humans and Automation and the Transfer of Control (Chapter 8)

The allocation of different driving functions, that is, the assignment of different responsibilities to either the driver or the automated system, has been the topic of much debate. Indeed, the decisions regarding this assignment have significant impacts on many of the topics discussed throughout this Handbook (e.g., workload, Chapter 6; SA, Chapter 7, driver impairments, Chapter 9, etc.). Functional allocation also factors into many of the discussions regarding design solutions (e.g., adaptive automation, Chapter 16). Discussions of allocation of function date back to the 1950s, where common guidance was based on who did a particular task better: humans or machines? If humans were superior at a task, then they should be responsible for that task (and vice versa). If one thing should be clear from the Handbook and Chapter 8 in particular, it is that the situation is not so straightforward. Humans are very good at driving and its subtasks; the crash rate per mile driven is very low (while acknowledging that every crash is a tragic event to be avoided). Automation is very good at performing many driving tasks as well. Therein lies one challenge: the degree of overlap in those tasks that both drivers and automation are good at. Who should be assigned what task? Another challenge relates to those tasks and subtasks at which drivers and automation are not very adept (e.g., driving in adverse conditions). As the authors note, this is especially critical when the human–automation system needs to negotiate control transfers. The appropriate allocation of functions and authority continues to be an important area for research, including questions of can a function be safely automated, should it be, and what happens when situational factors change? Unfortunately, or perhaps ironically, some of the decisions regarding the allocation of function are products of a design philosophy and occur far removed from the eventual moment by moment interactions between the driver, system, and the traffic environment. Automation does not simply replace the person in performing certain functions, but creates new functions associated with coordinating the automation, an important research question remains: How to anticipate and support that coordination?

24.3.7 DRIVER FITNESS IN THE RESUMPTION OF CONTROL (CHAPTER 9)

If the functions have been allocated appropriately to the human and automation, it is still the case that problems can arise in the transition of control from the vehicle back to the driver. As discussed by the authors in Chapter 9, the driver may not be fit to take back control for several different reasons, including distraction, fatigue, impairment, and simulator sickness. One question looms large. In particular, consider the general issue of impairment. The issue around impairment becomes more central every day as more and more states legalize marijuana, as the number of prescription and over-the-counter (OTC) drugs increases, especially among the elderly, and as the number of illegal drugs spread rapidly throughout the population. Recent estimates in the United States suggest that prescription, OTC, and illegal drugs are present in some 13% of the driving population (Kelley-Baker, Berning, Ramirez, Lacey, & Compton, 2017). But prevalence is not the only problem. Testing for the presence of marijuana or any of the myriad prescription, OTC and illegal drugs in blood or breath specimens drawn at the roadside can be very difficult for a wide variety of reasons. A number of countermeasures have been proposed (Smith, Turturici, & Camden, 2018). But none have been suggested that use real-time driver and vehicle monitoring algorithms to identify behavioral measures of impairment due to prescription, OTC, and illegal drugs [the Driver Alcohol Detection System for Safety is already being explored for alcohol before the driver actually starts driving (NHTSA, 2016)]. If a real-time behavioral test were used, it would not matter what substance was on-board, if any. This is largely a scientific question at this point. Actual application of such a behavioral evaluation of impairment based on real-time monitoring would require legal and other hurdles to be overcome. But, until one asks whether such a system has a high predictive validity and very few false alarms, one simply cannot take the next logical step towards implementation.

24.3.8 DRIVER CAPABILITIES IN THE RESUMPTION OF CONTROL (CHAPTER 10)

Drivers may not be ready to take back control at any given moment during a trip because of issues with their fitness to drive, issues which are transient. But, at a more fundamental level, they may not either currently be able to drive or are at an especially high risk when driving because of limitations in their basic capabilities. Drivers with such limitations include those who are medically at risk, those with visual impairments, and those with neurological and neurodegenerative impairments. For this class of drivers, the authors of Chapter 10 focus on the core clinical characteristics, the associated functional performance deficits, the effect of these deficits on driving behaviors, and the potential of automated vehicle technologies (SAE Level 0, 1, and 2) to mitigate the effects of the functional performance deficits and to enable the driver to resume driving. Although the empirical literature supports most of the sections in the chapter, the authors note that the last section (i.e., the potential of automated technologies to reduce performance deficits) represents an attempt on their part to map between the particular performance deficits and the advanced vehicle technologies that might address these deficits, an attempt which is grounded solely in the persuasiveness of the argument. Clearly, there is a pressing need to determine whether the advanced vehicle technologies can indeed mitigate the potential deficits of those drivers who are medically at risk, who have visual impairments, or who have neurological of neurodegenerative disorders. As just one example, consider older drivers. The authors point to intersection assistance as one technology that could decrease crashes among older drivers at intersections. If this were the case, it could have a large impact on the number of crashes of older drivers given that intersection crashes are among the riskiest and most prevalent for this group of drivers (Mayhew, Simpson, & Ferguson, 2006). Moreover, as pointed out in Chapter 10, a feature such as intersection assistant is also potentially useful for drivers with glaucoma, Parkinson's disease, and younger drivers with attention-deficit hyperactivity disorder. The question of real significance here is now largely a practical one: Will intersection assistant actually reduce the crash rates at intersections as intended?

24.3.9 DRIVER STATE MONITORING FOR DECREASED FITNESS TO DRIVE (CHAPTER 11)

Knowing that the driver is not fit to take back control or capable of more basic control is central to implementing the countermeasures that were described above. Driver state monitoring sensors and algorithms have taken a huge leap forward as discussed by the authors of Chapter 11. Remote sensing of the position of the eyes and the hands has now become standard. For example, the position of the eyes is now used to monitor both visual and cognitive distractions (Seppelt et al., 2017). However, much still remains to be done to sense and monitor drowsiness in real time, especially the occurrence of microsleeps. As noted in a previous chapter, in the United States sleepiness is estimated to be a factor in 100,000 police-reported crashes each year, including over 71,000 injuries and 1,550 fatalities (National Safety Council, 2019). Recent algorithms have been developed which can predict the second microsleep, but not the first (Watson & Zhou, 2016). Improving the algorithms so that they could detect the first microsleep is critical. Moreover, these algorithms still rely on electrocardiogram sensors which must be worn as a vest. Less cumbersome sensors need to be developed to further advance the application of the microsleep prediction algorithms.

24.3.10 BEHAVIORAL ADAPTATION AND ACIVs (CHAPTER 12)

We have spoken above as if drivers' behavior vis-à-vis the different features of an automated vehicle is static for the most part. However, as is made clear by the authors in Chapter 12, the issue of behavioral adaptation to automated vehicles and their various features is a complex one and absolutely critical to understanding the safety benefits of said vehicles (Sagberg, Fosser, & Saetermo, 1997). Ideally, it would be possible to predict with some assurance whether a given feature was going to lead to adaptation, either positive or negative. This issue of behavioral adaptation is made still more complex by the fact that the features of an automated vehicle are constantly changing as new upgrades are made to the software. Behavioral adaptation as it has been traditionally used refers to changes in behavior which occur over time as a function of exposure to a given feature. With automated vehicles this definition still holds. But now, the definition is broadened to include whatever behavioral changes the driver might incorporate into his or her behavior when changing from a manual vehicle to an automated vehicle in order to adapt his or her behavior to the assumed feature or features of the automated vehicle. Regardless of which definition is chosen, it seems that researchers will always be playing catch up unless a model can be developed which will predict with some confidence how drivers will adapt to a given feature, either over time, when changing from a manual to an automated vehicle, or when going from one version of the software to an updated version. Perhaps the development and evaluation of such a general model is too much of a stretch, but it stands as paramount to preventing unexpected effects of automation.

24.3.11 DISTRIBUTED SITUATION AWARENESS (CHAPTER 13)

SA is, as noted previously, an important consideration in the design of automated vehicles and the road systems in which they will operate. The authors of Chapter 13 suggested that distributed situation awareness (DSA) is the most useful construct when considering the design and analysis of automated vehicle systems, primarily because it considers the SA needs of both human and non-human agents as well as the required interactions between them. To demonstrate this approach, they presented an overview of a DSA model and an analysis of the recent Uber–Volvo fatal collision in Tempe, Arizona. In going forward, the authors of Chapter 13 present a framework to support DSA-based design in road transport, which provides an overview of the kinds of analyses required to ensure that DSA can be understood and catered to during autonomous vehicle design life cycles. The framework includes the use of on-road naturalistic studies to examine DSA and road user behavior in existing road environments, the use of systems analysis methods such as Cognitive Work Analysis to identify key design requirements, the use of sociotechnical systems theory (STS) and an STS-Design Toolkit to generate new design concepts, and, finally, the use of various evaluation approaches to evaluate design concepts. This framework may be usefully applied in future to the design, testing, and implementation of automated vehicles.

24.3.12 Human Factors Issues in the Regulation of Deployment (Chapter 14)

In Chapter 14, the author sets out to answer the question "What Human Factors issues need to be considered in preparing policy and regulation for the deployment of automated vehicles?" The focus of the chapter was on how much policy makers need to be involved in attempting to influence: (1) how companies design systems for human users and (2) how humans interact with those systems. As noted by the author, this is difficult in areas of new and evolving technology, where the risks may not yet be clear, let alone optimal solutions to address those risks. Consequently, the author argued that policy makers may need to consider moving towards less prescriptive and more outcomes-, or principles-based, approaches to policy and regulation to ensure that risks are managed and companies and individuals can be held responsible, while allowing for system innovation and evolution, but with less standardization, which can create its own risks. The author underscored in Chapter 14 the need for governments to continually update policy as human behavior changes and the understanding of human risks surrounding automated vehicles evolves, and identified two main areas for future research. First, there is the need for governments to better monitor road safety, due to the data that automated vehicles will provide. Second, there is a strong need for research by governments to identify new risks, to understand their likelihood and severity, and to react accordingly—in relation to the human–machine interface (HMI) between the vehicle and the passengers/driver/fallback-ready user inside the vehicle, how other road users interact with these vehicles, and how their behavior evolves over time, and what this might mean for safety.

24.4 HUMAN-CENTERED DESIGN OF ACIVS (SOLUTIONS)

As was made clear throughout the earlier chapters, the design of the HMI is central to the driver maintaining SA and trust, to the driver understanding the operational design domain, and to helping the driver maintain the right level of workload. The HMI should be designed to ensure that changes in drivers' fitness or capabilities are considered and the appropriate responses are taken. Where possible, the HMI should also actively serve to train the driver how to operate the vehicle, given the usual ways of informing the driver (manuals, dealerships) about the features of automation do not seem to be working and given that the features of the vehicle are constantly changing through real-time software upgrades. As has been previously noted in the Handbook, there is much more to the human-centered design of ACIVs other than just a consideration of the HMI. Some of these considerations are discussed in the chapter on capabilities, but the issues are much larger than that and could be a Handbook in itself.

24.4.1 HMI Design for ACIVs (Chapter 15)

Design guidelines for interfaces that remain fixed and for vehicle hardware and software that remain fixed were discussed at length by the authors in Chapter 15. As highlighted there, the design guidelines will need to be updated and modified for automated vehicles. The opportunities for teaming the human and the automated vehicle through the use of artificial intelligence (AI) are huge here (Kamar, 2016), not only in the original conception of the software but also for updates to the software. In such a teamed system, the driver will take actions based on recommendations from the AI partner. The combined system (human, automation, and AI) can arguably make better decisions than either component alone. What remains particularly problematic, and has been identified in a recent report as such (Bansal, Nushi, Kamar, Lasecki, & Horvitz, 2019), is the fact that updates to the software are often incompatible with a driver's previous mental model of the software. Thus, the driver ends up making a decision that is incorrect with the updated software that would have been correct with the original software. Even though the updates improve the AI performance they might not improve the combined AI–human system. So, ideally there needs to be backward compatibility of the software updates with the existing mental models. But it is not always the case that such can happen. In such cases one could potentially retrain the driver or share the AI's confidence in a prediction. However, these two approaches come with real drawbacks (Bansal, Nushi, Kamar, Lasecki, & Horvitz, 2019). Research is needed to deal with the backward compatibility problem and all of its ramifications for HMI design.

24.4.2 HMI DESIGN FOR FITNESS-IMPAIRED POPULATIONS (CHAPTER 16)

With automation, the role of the driver will change in the context of an automated system (Chapter 8), and this in turn will impact driver workload and in-vehicle driver behaviors (Chapters 6 and 9). It follows that an understanding of the state of the driver, including their current behaviors, will be an integral part of future vehicle design. This chapter examined the intersection between driver state monitoring (Chapter 11) and adaptive automation, with a particular focus on drivers who are fitness impaired (e.g., distracted, drowsy, under influence of drugs and alcohol). The framework for adaptive automation offers the potential to improve the safety of the systems, or perhaps more accurately, the safety of the human–automation interactions. However, as the author rightly notes, such systems will only be useful if they can effectively leverage the capabilities of the automated system to complement or compensate for the momentary change in driver capacity. As with other potential design approaches (i.e., "solutions"), there is a dire need for data to corroborate the overall effectiveness of adaptive automation in terms of overall safety and performance as well as driver decision-making, in-vehicle behaviors, system use, trust, and acceptance. As it relates to impaired drivers, there are also many other related questions regarding human behavior. For example, how will the existence of (and, by extension, the use and reliance on) such systems impact drug and alcohol usage? As adaptive automation reacts to the momentary needs and capacities of an individual driver, will there be cascading effects throughout the entire system (e.g., Chapter 19)?

24.4.3 AUTOMATED VEHICLE DESIGN FOR PEOPLE WITH DISABILITIES (CHAPTER 17)

Chapter 17 highlights some of the design challenges for people with disabilities. This includes a more deliberate consideration of accessibility. The social model of disabilities and many of the tenets of universal design provide some inroads for addressing the needs of these very different driving populations. They also reinforce the notion of the whole trip; for these and many other individuals, getting to and from the vehicle and getting into the vehicle are as important as what the automated vehicle does while enroute. For them it is not the first mile/last mile which is the only problem; rather, it is the first 100 and last 100 ft. Neglecting research that addresses the whole trip can amplify rather than reduce the inequities of those who are transportation disadvantaged. While many of the design principles discussed can improve driver's experiences, there is a general need for research that documents and quantifies these improvements. Given the breadth of drivers with disabilities, it will be important to understand how different driver characteristics interact with system effectiveness. Moreover, as the technology creates the potential for new drivers who were previously unable to drive, there will need to be a more profound understanding of how automation impacts their safety and mobility.

24.4.4 Importance of Training for ACIVs (Chapter 18)

Not all of the difficulties that face drivers can necessarily be overcome with good HMI design. The authors in Chapter 18 point to the importance that training can play in the successful deployment of various advanced technologies, addressing both the wide variation in driver's mental models and capabilities and the real challenges of learning the complex features of the advanced technologies. A number of recommendations were made given the current state of the art. First, training needs to be adaptable, changing in content with the constantly changing capabilities of the automated vehicles on the road. Second, training programs (however delivered) need to be evaluated. Such is generally not the case now. It is not clear just which types of training might eventually prove most efficient and effective. Third, driver state monitoring systems may well contain elements that are important to training programs and of which training programs could take advantage. For example, imagine a program that attempts to train the driver to remain engaged. It would be important for the driver to know when he or she became disengaged, something which can be difficult to self-monitor. A driver state monitoring system could provide drivers with information on their performance which might not otherwise be available. Fourth, guidelines need to be developed by state transportation officials and other stakeholders which detail just what essential elements need to be covered in a training program. Although such guidelines now exist in at least one state (California), they apply only to individuals who are field testing automated vehicles, not to the general population of drivers.

24.5 SPECIAL TOPICS

The special topics that were discussed in this section are the ones which pushed the envelope of our understanding of and proposed use for ACIVs, either by looking towards the future or by taking a step backwards and considering what has been learned in other domains. We now look back on these chapters and single out those issues that we see in most need of attention among the many that were mentioned.

24.5.1 CONNECTED VEHICLES IN A CONNECTED WORLD: A SOCIOTECHNICAL SYSTEMS PERSPECTIVE (CHAPTER 19)

It is fitting that this section starts with a discussion of the need to consider the overall sociotechnical system in which drivers are embedded, and that only by inspecting and acting upon the human factors concerns that arise out of this consideration can one truly experience the full promise of ACIVs (Chapter 19). At one level, this chapter can be considered a broadening of the importance of DSA that was discussed Chapter 13. The focus is on the overall system because it is only by doing this that emergent properties such as system safety, resilience, and overall effectiveness can be identified and promoted. We agree and, along with the author of Chapter 19, end up where he does. In particular, methodologies for system analysis and joint optimization are urgently needed to create the foundations that promote positive emergent properties such as the above.

24.5.2 CONGESTION AND CARBON EMISSIONS (CHAPTER 20)

Just as a consideration of systems in Chapter 19 is a broadening of the focus of the majority of chapters in the Handbook on individual vehicles to system safety, so too is a consideration of congestion and carbon emissions in Chapter 20, a broadening of the focus of the Handbook from the individual vehicles to system efficiency. Reductions in congestion and carbon emissions are critical, and the authors discuss ways to do so that rely on understanding psychological decision making. The authors start with a discussion of congestion. They describe how interventions that aim at behavior modification only—such as congestion pricing or techniques of nudging—without boosting underlying processes and competencies, might fail to promote pro-environmental driving-related behaviors, that reasoning and decision-making about one's own or others' driving seems to be predicted by simple rules of thumb, and that these simple rules of thumb, at least for parking, can increase system efficiency, compared to standard game-theoretic proposals. They suggest that research is needed on the design of the HMI that displays information to the driver in a way that influences their simple rules of thumb. Second, the authors go on to discuss carbon emissions. The editors have themselves taken note of the renewed research interest in eco-driving (Mcllroy & Stanton, 2018). There is clear evidence that eco-driving can reduce carbon emissions by up to 45% with relatively low implementation costs (Sivak & Schoettle, 2012). However, the authors show that being motivated is not enough to undertake a pro-environmental behavior. Rather, providing drivers with clear information on their eco-driving performance appears to be the key. So, they recommend again a focus in future research on the design of the HMI that displays this information.

24.5.3 AUTOMATION LESSONS FROM OTHER DOMAINS (CHAPTER 21)

Humans have been interacting with automated systems in other domains for decades. In spite of the differences in operating environments, tasks, and user populations (to name only a few), many of the same challenges exist in these other domains as are now being discussed in the context of surface vehicles. While many of the relevant issues and human factors concepts focused on automation are discussed in other parts of the

Handbook, this chapter reminds us that there is important knowledge to be gleaned from other applications—aviation, air traffic control, military, process control—especially concerning some of the solutions that have been tried and tested. While the translation to driving might not be perfect in every case, it is worthwhile to reflect on this adjacent body of knowledge, especially given its sheer magnitude relative to the driving context. An open question remains: How to identify what lessons from other domains translate to what elements of vehicle automation?

24.6 EVALUATION OF ACIVs

Ultimately, one will want to evaluate ACIVs, not only on simulators but also in the field of both controlled and naturalistic studies. Many countermeasures to the human factors problems that might arise for drivers of such vehicles were discussed in the above chapters. However, no matter how principled, any solution is only a potential one until it is tested and evaluated. The remaining two chapters focus on evaluation.

24.6.1 HF Considerations in Testing and Evaluating ACIVs (Chapter 22)

The authors in Chapter 22 discuss in detail the many considerations which go into the design of evaluations of ACIVs, including iterative evaluations first in driving simulators, then in field demonstrations, and finally naturalistic studies. The authors emphasize the need in such evaluations to characterize the automation accurately for participants in order to develop training materials appropriate to the automation. In the absence of the 100s of millions of miles of observations that are needed to get meaningful information on crashes, we the editors believe the most critical determination still needs to be made of just what dependent variables should be used to evaluate the safety of the various systems. As just one example, at the macroscopic level there is still considerable debate on whether the dissection of near crashes can provide information relevant to the understanding of actual crashes (Knipling, 2015). How can we ever hope to evaluate the safety of automated vehicles when we have relatively little information on exposure if we cannot come to some agreement about what dependent variables best predict safety outcomes when such limitations arise? At the microscopic level, we are now relying on the distribution of especially long glances inside the vehicle to determine how risky are glances away from the forward roadway (Klauer et al., 2014). Yet, increasingly, information suggests that sequences of especially short glances on the forward roadway are also very risky (Samuel & Fisher, 2015). In short, we believe that more research is needed to isolate the dependent variables that best predict crashes and the behaviors that lead to crashes when exposure data are limited. The limited exposure data are a particularly acute challenge with increasingly automated vehicles because the automation and the automation–driver system have different failure mechanisms than drivers of conventional vehicles.

24.6.2 Techniques for Making Sense of Behavior in Complex Datasets (Chapter 23)

The author in Chapter 23 provides abundant examples of tools that can be used to inspect complex datasets and tools that can be used, once a theoretical model is available, to analyze the complex dataset that are appropriate to the questions being asked (appropriate to the theoretical model). These complex datasets can help provide much more complete answers to research questions than were previously available, questions related to the human operator's engagement and performance in a vehicle over time and space. The research questions that can now be addressed (and need to be addressed) include: How do drivers respond to transitions in automation states? Will the human operator know when the automation fails? Will the human operator have sufficient time to take over when the automation fails? How quickly can drivers resume control from a highly automated vehicle, and does this resumption change with greater system exposure? What are the negative or positive effects of automation on driver's performance over time?

24.7 CONCLUSIONS

We want to conclude by thanking once again all of the authors who contributed to this Handbook. The creation, development, and completion of the Handbook have been a journey for many years and have enriched us as well as we hope the contributors and ultimately our readers. We have already probably gone on too long. So we leave you with one theme which has played centrally throughout the entire Handbook.

ACIVs are one key to reducing some of society's greatest problems. The sheer magnitude of the 1.4 million annual vehicle fatalities around the world is astronomical in terms of economic costs and psychological burden. On a more personal level, tragically so many of us know only too well someone who has fallen victim to a distracted driver, a driver who has fallen asleep, or perhaps a driver who has simply accelerated when he or she had meant to decelerate. The economic costs and psychological burden of carbon emissions are all becoming too clear. Congestion is reaching levels that were almost unbelievable ten years ago. More generally, commuting opportunities are the key factors in social mobility, even more so than factors related to crime and education (Bouchard, 2015). Individuals with mobility impairments could for the first time be freed from the very real constraints on transportation needs that come with those impairments. But the promise of ACIVs cannot be fully realized until the human factors concerns are addressed; in fact, the promise could be delayed considerably unless these concerns are addressed before they become an issue ("dread risk," Chapter 4).

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