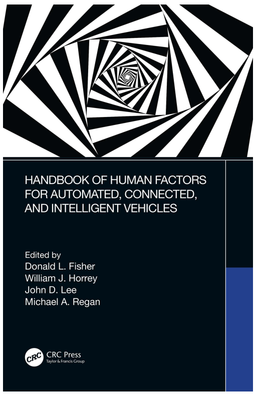

Handbook of Human Factors for Automated, Connected, and Intelligent Vehicles

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Introduction

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1 Introduction

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CONTENTS

KEY POINTS

- Automated, connected, and intelligent vehicles hold great promise—increasing safety for all and mobility for underserved populations while decreasing congestion and carbon emissions.
- There may be unintended consequences of advances in automated technologies that affect the benefit that drivers can derive from these technologies, potentially slowing the development of the technologies themselves.
- Many of these unintended consequences center around human factors issues, issues between the driver and the vehicle, other road users, and the larger transportation system.
- Human factors research can be used to identify and seek to explain the unintended consequences, to develop and evaluate countermeasures, and to decrease, if not entirely avoid, any delay in the deployment of these technologies.

1.1 BACKGROUND

We as humans cannot help but wonder what the future will hold and how it will unfold in time. When it comes to the effect of advanced technologies on our behaviors and on the behavior of the vehicles that we drive, the public speculation has been especially intense over the last ten years, starting in 2009 when Google[1] began its self-driving car program, now called Waymo. Such vehicles have the potential to substantially reduce the number of crashes, the level of carbon emissions, the congestion in our road systems, and the spread of wealth inequality, while at the same time increasing substantially opportunities for those who are mobility impaired (National Highway Traffic Safety Administration, 2017; Department of Transportation, 2019; Chang, 2015). Although some individuals are skeptical about early presumptions regarding the benefits of automated, connected, and intelligent vehicles (ACIVs) (Noy, Shinar, & Horrey, 2017; Bonnefon, Shariff, & Rahwan, 2016), the introduction of vehicles with advanced features continues to increase exponentially. As with the advent of the smartphone, anticipating the long-term positive and negative consequences of new technology is nearly impossible (e.g., Islam & Want, 2014; Twenge, Martin, & Campbell, 2018). It may be some time before we actually know the real benefits of such vehicles and features.

However, it is possible to take the bumps out of the road to full automation even without knowing the long-term consequences. This Handbook will focus specifically on the changes that will be wrought and the corresponding human factors challenges that need to be addressed by advances in the autonomy, connectivity, and intelligence of the vehicles that are being introduced into the fleet today and are likely to be introduced over the next several years. For readers relatively new to the discussion of why human factors concerns might be relevant to advanced technologies in the automobile, a simple example from one of the editors' and authors' long list of examples might help. This particular editor was driving 60 mph on a highway with two travel lanes in each direction and for a brief second or two fell asleep (had what is technically referred to as a "microsleep"). He drifted into the adjacent lane, woke up, and returned to his own lane. Had there been a large truck overtaking him in the adjacent lane, he might not be here to tell the story. Others' lives may have been destroyed as well. But, fortunately, there was no truck and all was well. This speaks directly to the lifesaving potential of technologies which, in this case, could have kept the car in the lane and maintained speed adaptively. But it also points out just how beguiling these technologies can be.

Most vehicles on the road today that keep the car centered and adjust the speed require the driver to constantly monitor the driving environment (SAE International, 2018). Why? If we consider just automatic steering, there are many situations in which it may unexpectedly deactivate. The driver really does need to be in the loop. But, we also know that, perversely, automation can make it easier for the driver to fall out of the loop and become disengaged (Endsley, 2017; Endsley, 1995). Are we just trading off situations in which the technologies can be lifesaving for situations in which the technologies actually create conditions that increase the likelihood that a driver will crash if the technology cannot handle a particular scenario? This is the fundamental paradox of automation. While it can provide unparalleled opportunities, it comes with its own set of challenges.

Perhaps this paradox is best exemplified by a recent study of driver's trust in automation. A field study was run in which the drivers were asked to navigate a network

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[1] Now Alphabet.

of roads on a closed course using a vehicle with both automatic steering and adaptive cruise control (ACC) (Victor, Tivestan, Gustafsson, Sangberg, & Aust, 2018). The drivers were told that they needed to monitor the driving environment and were warned by the vehicle driver state monitoring system if they did not comply. At the end of the drive, either a car or a large garbage bag was placed in their path. Both were easily crushed (e.g., a balloon car), but not obviously so to the driver before striking them. Driver's trust in automation was measured after the drive on a scale of 0 (no trust) to 7 (high trust). Fully 21 of 76 drivers crashed (28%). All of the drivers who crashed had trust scores of 5 or higher (Victor, 2019). In short, the drivers became so reliant on the technology that they assumed it would avoid obstacles even when the technology encountered situations it was not designed to accommodate.

For readers familiar with the ongoing issues, you will find material in this Handbook which we believe will help set the stage for a human focus on future discussions about ACIVs. To date, the definition that vehicle manufacturers and major standards organizations have put forth concerning automation defines it primarily from a vehicle-centric point of view: as the technology capabilities increase, so too does the level of automation of the vehicle (SAE International, 2018). But this can easily mislead drivers into believing that their role in the driving process decreases as the levels of automation increase, despite warnings to the contrary, to the point where drivers actually feel that they can safely disengage from driving for long periods of time. A more driver-centric viewpoint is essential to extending automation safety benefits, one which defines and supports the new roles that drivers face.

The goal of this Handbook is to identify the real gains that can be achieved by identifying the various human factors, challenges, and opportunities that ACIVs pose and then, whenever possible, to suggest countermeasures (and opportunities for needed research), recognizing that the rapid advances in technology are changing both the challenges and the countermeasures. It is arguably the case that, even if these challenges were not addressed, there would be a net benefit to incorporating advanced technologies into new automobiles (Najm & daSilva, 2000), especially active safety systems like automatic emergency braking (AEB) and electronic stability control. But it is also arguably the case that, if these challenges are addressed, the net benefits will only increase. Moreover, by addressing these challenges, one reduces the real likelihood that the development of the technologies will be hobbled, if not halted, by crashes such as the one that occurred in Phoenix, Arizona (National Transportation Safety Board, 2018).

That a scenario similar to the above might unfold and put temporary brakes on the development and deployment of automated technologies already seems to have occurred, at least in part. At the start of 2018, before the crash in Phoenix, it looked like vehicles with advanced technologies were on the verge of becoming a widespread reality. Uber prepared to launch a robo-taxi service. Waymo indicated that individuals would be able to ride in a driverless car by the end of the year. General Motors touted a demonstration it would undertake in New York City. None of these (and several other similar initiatives) have come to pass, at least yet. In fact, the public has become ever more skeptical about a self-driving vehicle, with some 71% now afraid to ride in such a vehicle compared to 61% before the crash (Edmonds, 2019).

In summary, the paradox of automation is that it can radically reduce human errors while also itself introducing opportunities for new types of human errors. These new types of errors can lead to crashes which slow the introduction of lifesaving technologies. The chapters in this Handbook are just one of many attempts to address this potentially negative feedback cycle, providing both insight into why new types of errors arise and what can be done to overcome them before they do, creating more skepticism about the technology. But before we can speak about the fundamental sources of the automation paradox, some definitions are in order.

1.2 DEFINITIONS

There is an understandable confusion around the terms used in the discussion of automation, human factors, and driving. The terms do change with each passing year, in part because the technologies change and in part because the field becomes more expert and nuanced at understanding how best clearly to differentiate among the various terms. As editors and authors, we have tried with each chapter to make sure that the same terms are used in the same way and, if we deviate, to make it clear how we are refocusing the definition of a term.

1.2.1 Levels of Automation and Active Safety Systems

Several taxonomies have been developed that differentiate among the levels of automation (e.g., SAE International, 2018; NHTSA, 2016). It is arguably the case that the SAE definition of the levels of automation is the one most commonly used. It is worth spending some time on understanding these levels and how they relate to other vehicle systems.

1.2.1.1 Levels of Automation

As conceptualized in vehicle-centric taxonomies (SAE International, 2018), the level of automation at which a vehicle is currently operating depends on three critical factors (Table 1.1): (1) whether only one, both, or neither of the lateral (automatic steering) and longitudinal (ACC) features are activated; (2) the role of the driver (must monitor or need not monitor the forward roadway); and (3) the time that is given to the driver to resume control (immediate to never). The first three levels of automation are easy enough to define: neither lateral nor longitudinal control features are activated (SAE Level 0), just one of these features is activated (SAE Level 1), or both of these features are activated (SAE Level 2). The role of the driver is always to monitor the roadway at each of these levels. The remaining three levels require additional considerations. Specifically, assuming that the vehicles are not geofenced (confined to operating in a particular location), the last three levels are differentiated most clearly on the basis of when it is necessary and how much time the driver has before it is necessary for him or her to resume control: at any moment, somewhere on the order of several seconds warning (SAE Level 3); only when transitioning from inside to outside the operational design domain, somewhere on the order of minutes (SAE Level 4); never needs to take over control (SAE Level 5) (Table 1.1). As described in the sub-sections that follow, there is considerable variability in the

TABLE 1.1
Active Safety Systems and SAE Levels

				Driver Role		
Active Safety System	**Category**	**SAE Level**	**Definition**	**Manual Control**	**Active Monitoring**	**Take Over**
AEB PCW FCW ESC BSW	Driver Support Features (DSF)	0	**No** AS **No** ACC	Both steering and slowing/accelerating	Yes	N/A
		1	AS or ACC, but **not both**	Steering or slowing/accelerating, but not both	Yes	Yes, limited warning*
		2	**Both** AS and ACC engaged	Hands on wheel or eyes on road.	Yes	Yes, limited warning*
	Automated Driving System (ADS) Features	3	AS and ACC	No inputs while at Level 3	No	Yes, several seconds of warning
		4	AS and ACC	No inputs while at Level 4	No	Yes, minutes of warning (if driver chooses to drive the vehicle outside of the ODD)
A subset of the above		5	AS and ACC	No inputs ever	No	No

Note: AEB: automatic emergency braking; PCW: pedestrian collision warning; FCW: forward collision warning; ESC: electronic stability control; BSW: blind spot warning; AS: automatic steering; ACC: adaptive cruise control.

* Warnings may indicate that the system or systems are no longer functioning, and drivers are responsible for monitoring the traffic environment and taking control when needed.

complexity and range of possible automation types. As just one example, consider a vehicle which has no steering wheel or pedals and is confined to operate only in a circumscribed location. By definition it is a Level 4 vehicle (since it cannot operate in all locations), but the driver is never asked to take over control since the vehicle is confined to an area in which it is assumed to be totally capable.

There are at least four critical, related, details to understand about these definitions in order to keep clear the underlying concepts. First, the level of automation assigned refers to the features which currently are active, not to the vehicle itself. Thus, a car that could operate at Level 3 may also be operating at times at Level 0, being no different in any way in terms of driver inputs than a car with no automated features. Second, the features associated with the first three levels are referred to frequently as *driver support features* (DSF). They are called DSFs because the driver still needs to be continuously monitoring the roadway. Lateral and longitudinal control by themselves do not replace the driver at Levels 1 or 2; there are many other driving functions and tasks that still need to be performed by the driver at these levels. Third, related to this, the features which need to be added in order to achieve the three highest levels are now referred to as Automated Driving System (ADS) features. (SAE International, 2018; Department of Transportation, 2019). Fourth, the term *advanced driver assistance systems* (or *ADAS*) is now no longer used by many researchers because it has become so broad that it is no longer clear to what features an individual is referring when they speak about such systems. In many cases, the systems that are described elsewhere as being ADAS would overlap with many of those portrayed in Table 1.1 under active safety systems, DSF, or ADS.

1.2.1.2 Active Safety Systems

Operating in parallel with or without automatic steering and ACC are what are referred to as *active safety systems*, like AEB. Active safety systems aim to prevent crashes, either warning the driver or taking over the control of the vehicle, often in emergency situations. Thus, active safety systems differ from passive safety systems that aim to mitigate the injury impacts of crashes on vehicle occupants. Moreover, unlike ACC and automatic steering, active safety systems are not continually providing input to the vehicle. Active safety systems can be present at any one of the SAE Levels (left side of Table 1.1). Because, in theory, any one of the SAE Levels 1–4 can revert to any lower level, all active safety systems that interface with the driver must remain operable. However, because SAE Level 5 is imagined to be fully automatic, it will include only a subset of the active safety systems (e.g., it will include AEB, but not blind spot warnings for the driver, because the driver never needs himself or herself to change lanes). Active safety systems are sometimes identified with SAE Level 0, though this can create confusion because, as noted, this technology can operate in parallel with higher levels of automation (e.g., a Level 2 vehicle might also have Level 0 vehicle technology if AEB was labeled as Level 0 rather than as an active safety system).

In this Handbook, we focus not only on the challenges for the driver that are generated at each of the different SAE levels but also on the problems created by the different active safety systems, recognizing that the primary focus is on the entire system with which the driver needs to interact (directly or indirectly as part of the vehicle and larger transportation system). So, for example, the driver is almost never faced with a vehicle which has, for example, just automatic steering and no active safety systems. The driver is instead immersed in a system with many different features, with the human factors challenges becoming correspondingly more complex.

1.2.2 AUTOMATED, CONNECTED, AND INTELLIGENT VEHICLES

When we started work on this Handbook, “automated” usually preceded “connected” and one would refer to automated (or autonomous) connected vehicles and intelligent vehicles. Now one more frequently encounters the reverse, connected and automated vehicles (or CAVs). By the time the Handbook is published, there may be an entirely different acronym. For various reasons, we have chosen to stay with the original order (ACIV) whose motivation is hopefully made clear below.

1.2.2.1 Automated Vehicles

By automated (or autonomous) vehicles we mean those vehicles that have automatic steering, ACC (adaptive speed, braking, acceleration, and deceleration), or both. Depending on the level, they can be activated separately, in concert, or not at all (e.g., if a driver elects to turn them off; Table 1.1). They almost certainly have active safety systems, especially at higher levels, as such systems are an essential ingredient—at least conceptually—to the proper functioning of the higher levels (e.g., AEB is essential, though it may not exist as a separate safety system but as an integrated component in the overall system).

1.2.2.2 Connected Vehicles

Connected vehicles as a term is typically used to refer to vehicles that can communicate with one another via vehicular ad hoc networks (VANET or inter-vehicle connectivity; V2V). But more generally, connected vehicles as entities in and of themselves can have upwards of 200 sensors that need to communicate with each other (intra-vehicular connectivity or vehicle-to-sensor, V2S) (Lu, Cheng, Zhang, Shen, & Mark, 2014). Vehicles can also connect with the roadway infrastructure (V2R), to the internet (V2I), and to the ubiquitous Internet of Things (IOT). Each of these different types of connectivity creates its own human factors challenges.

Note that vehicles can be connected without having any lateral or longitudinal control features. So, for example, intersection collision warning systems require vehicles to communicate with one another and, by definition, warn the driver of a potential collision, but they do not require that the vehicles have automated features. Similarly, a vehicle can be automated without having any connectivity to other vehicles or the changing infrastructure (e.g., signal status).

1.2.2.3 Intelligent Vehicles

We include the term intelligent vehicles to account for the additional features of future vehicles that do not align with the features of automated and connected vehicles. These include driver state monitoring algorithms that can tune the vehicle to the driver's current level of disengagement, the smart human–machine interface (HMI) algorithms that can alter the HMI to provide the driver with a more comfortable and safe journey, and the all-knowing road transportation system networks that can help the driver select the route from one point to another that maximizes the driver's goals, the collective goals of all drivers, or some combination of the two (be it speed, a reduction in carbon emissions, or whatever).

Just as was the case with CAVs, there could be vehicles with any combination of intelligence, automation, and connectivity. For example, an intelligent HMI might appear in a Level 0 vehicle with no connectivity or ADSs.

1.2.3 Operational Design Domain

Finally, it is important to describe what is meant by the operational design domain (ODD) of a given feature, whether that feature is a DSF, an ADS feature, or an active safety system feature. First, consider an active driver safety system and, in particular, AEB; or, what is called by Toyota, a pre-collision braking system (Toyota, 2017).[2] The system consists of a pre-collision warning, a pre-collision brake assist, and an actual pre-collision braking when no force has been applied by the driver to the brake pedal and the vehicle detects a possible collision with another vehicle or pedestrian. The components are active at only certain vehicle speeds and at only certain relative speeds between the driver's vehicle and a lead vehicle. Moreover, the speeds differ for pedestrians and vehicles and the speed constraints differ across the components.

The driver not only needs to remember the various conditions in which the system is active but also needs to know the conditions in which the system might suddenly and unexpectedly activate if there is no possibility of a collision. The owner's manual lists a total of 23 different scenarios in which this might occur. Such scenarios include passing under an object (e.g., billboard) at the top of a long, uphill road; approaching a vehicle, pedestrian, or object by the roadside located at the beginning of a sharp curve; and driving on a winding road where there is another vehicle in the opposing lane. These are not uncommon occurrences.

Second, consider a DSF (Table 1.1, SAE Levels 1–2). It should be noted up front that the owner's manuals make clear that the driver has to be monitoring the roadway at all points in time for each of the various DSFs. As an example, consider ACC in a Cadillac CT6.[3] Adaptive cruise allows the driver to select a speed and a following gap. Like AEB, ACC is active only under certain conditions (Cadillac, 2018). In particular, the speed cannot be set using ACC if the vehicle is traveling less than 15 mph, though ACC can be resumed at speeds lower than 15 mph. Just as AEB can unexpectedly activate, so too can ACC if the driver does not understand the ODD. For example, after the ACC is set the driver's vehicle may immediately apply the brakes if the lead vehicle is closer than the time headway that has been selected by the driver. Perhaps, more critically, ACC may not activate when the driver expects it to. For example, if the Traction Control System or the Electronic Stability Control System activates while

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[2] Note that the systems are in constant flux. New systems may have different operational design domains.

[3] Again, please be aware that the systems are in constant flux. New systems may have different operational design domains.

the ACC is also activated, the ACC could automatically disengage. Additionally, the ACC will not detect or brake for children, pedestrians, animals, or other objects. It may not detect a vehicle ahead on winding and hilly roads. The list goes on.

In summary, it is important for the driver to understand the ODD for all of the reasons listed above. Whether the driver can actually do so is one of the many questions we will address in the chapters in the Handbook, a brief discussion of which follows.

1.3 THE HANDBOOK: A QUICK GUIDE

Up to this point we have focused on the definitions we will need in order to concentrate them in one place (rather than have the reader search throughout the chapter or Handbook). Now that we have a working definition of the levels of automation, active safety features, and ACIVs we can return to a discussion of the automation paradox, to the countermeasures designed to reduce the unintended effects of automation, and to the more general topics that are covered in the Handbook. Perhaps the most central theme running throughout the Handbook centers on whether the driver is or is not engaged in the driving task. Although engagement and disengagement are two sides of the same coin, it is useful to separate the discussion of the primary factors affecting both, realizing that they are necessary complements of one another. User, task, vehicle, and environmental characteristics influence both engagement and disengagement (Figure 1.1). We will refer back to this figure as we make our way through a brief discussion of the chapters in the Handbook.

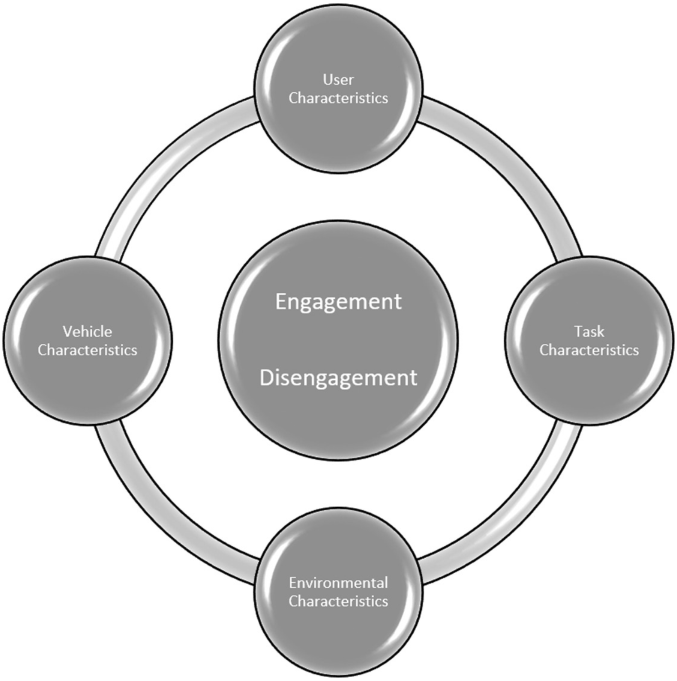

FIGURE 1.1 Engagement and disengagement and the factors which influence them.

We have organized the Handbook into five sections. The first section, including the Introduction, provides the reader with a basic understanding of the human factors issues surrounding ACIVs along with a comprehensive discussion of the many ongoing and future activities targeting the research, development, and deployment of such vehicles. The second section focuses on developing an understanding of the unintended consequences of automation for the human driver. These issues emerge from more fundamental human characteristics that can be used both to identify the source of potential problems and to serve as the foundation for solutions. For example, the mental models that drivers have of automation are fundamental characteristics that can not only lead to problems but also point to how to train people and how to design better HMIs. The third section focuses on the possible solutions to these unintended consequences. The fourth section introduces additional topics that do not neatly fit into the above categories. And, finally, we conclude with a section on the evaluation of the safety benefits of ACIVs.

1.3.1 The State of the Art: ACIVs (Chapter 2)

Although it will be many years before almost all vehicles will have Level 2 and above capabilities, most people are simply not aware of the extraordinary efforts that are going into making ACIVs a reality. In Chapter 2, the author provides us with a window into the history of, and current efforts centered on, the development and deployment of ACIVs. In addition, detailed and informative discussions are provided that focus on the advent of active safety systems, the different technological advances that have been necessary in order for automated driving to become a reality, the business case for the development and deployment of commercial fleets, and the direction in which the automobile industry is heading in terms of levels of automation both for passenger cars and for commercial vehicles. Both readers familiar with and readers not familiar with advances in ACIVs will find the breadth and depth of the discussion in Chapter 2 truly revealing of the state of the art.

1.3.2 Issues in the Deployment of ACIVs (Problems)

Understanding the human factors problems with the deployment of ACIVs is not unique to passenger cars. The problems appear when almost any automation is deployed, whether it be in some other mode of transportation (e.g., aviation) or on the factory floor. Thus, there is a breadth and depth of understanding that would not otherwise be available, and the authors draw on this experience as well as the knowledge generated by the increasing number of experimental, field, and naturalistic studies of automated driving. The first ten chapters in this section focus largely on user characteristics (Figure 1.1), where the user is largely isolated within the vehicle (Chapters 3–12) or is an element in a much larger system (Chapter 13). The last chapter (Chapter 14) in this section focuses on the broader human factors issues in the regulation of deployment.

1.3.2.1 Driver's Mental Model of Vehicle Automation (Chapter 3)

To begin our tour through the forest of human factors problems that may contain landmines for the deployment of ACIVs, we start with a discussion of mental models of driving (user characteristics, Figure 1.1). Mental models inform almost everything the driver does, from deciding at what speed to travel to what route to take and, now, what level of automation to engage, and whether the systems currently activated are operating within the envelope of the ODD. In this chapter, the authors review the various mental models of automation and driving, showing how fundamental psychological biases contribute to their formation, especially when automation is entered into the picture, and then explaining how those mental models govern driver's short (e.g., sudden braking), intermediate (e.g., level of automation), and long-term (e.g., mode choice) behaviors.

1.3.2.2 Driver Trust in ACIVs (Chapter 4)

It is one thing to have technologies that can greatly benefit the driver and society at large and to have an understanding of driver's latent mental models. However, it is an entirely different matter to make sure that these technologies are actually used by the driver. The use of the technologies depends on the trust the driver has in the system. Trust is a complex construct influenced by many different factors. In Chapter 4, the author delves into these different factors. This chapter also addresses the issue of how one goes about building, calibrating, losing, and repairing trust.

1.3.2.3 Public Opinion about ACIVs (Chapter 5)

In the previous chapter, the authors described why the issue of trust among drivers in automation is so important to the adoption and safe operation of automated vehicles. However, it is not only the individual driver's trust in the automated technologies that will influence their widespread adoption but also the public's acceptance of such technologies. The public here includes not only drivers but also vulnerable road users and other stakeholders in the transportation system. The public's acceptance of such technologies includes larger ethical issues as well. In Chapter 5, the authors discuss the factors that influence public acceptance of automated technologies, the measurement issues associated with evaluating acceptance, and the relevant research findings.

1.3.2.4 Workload, Distraction, and Automation (Chapter 6)

Once drivers trust their vehicle's automation enough to actually use it, one must next consider the cognitive, visual, and manual workload required of the driver. The workload requirements will change dramatically as different levels of automation, connectivity, and intelligence along with different types of active safety systems enter the vehicle (task characteristics, Figure 1.1). The basic laws underlying the relation between workload and performance (e.g., modeled after the Yerkes–Dodson law) should presumably remain the same. However, automation does not uniformly decrease workload as might at first be assumed. In fact, automation can both increase and decrease the different types of workload and do so over both very short and very long time horizons. The first question addressed in Chapter 6 by the authors is how the various types of workload are influenced by the different categories of automation and active safety systems. The second question addressed is how to achieve an optimal workload so that drivers are neither over engaged nor under engaged. Distraction figures centrally in an understanding of workload and automation and this concept is woven into the chapter throughout.

1.3.2.5 Situation Awareness in Driving (Chapter 7)

If the driver trusts the system, the driver will presumably use the system. Ideally the workload can be adjusted to the degree needed to keep the driver engaged while not overburdening the driver. But this does not always happen and the driver can lose situation awareness and become disengaged from the driving task. The loss of situation awareness can lead to a spike in automation surprises, either because the driver fails to perceive an event, fails to understand what he or she sees, or fails to predict what actions should be taken based on an understanding of an event. In Chapter 7, the author discusses situation awareness in general, how increases and decreases in cognitive workload can degrade situation awareness and driving performance at each of the six levels (Levels 0–5), and how it can impact the transfer of control from the vehicle to the driver, and conversely, from the driver to the vehicle.

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

Both driving performance (when the driver is in total control or partial control) and the transfer of control can be impacted by the loss of situation awareness. As discussed in Chapter 8, the issues of driver trust, workload, and situation awareness need to be considered (among others) when functions are allocated to the driver and the system at each of the various levels of automation. The correct allocation promotes both safety and efficiency, as well as adding synergistically to trust and situation awareness. Moreover, since in most systems the automation and the human operator will be sharing control and supervisory functions, it is important that the transfer of control be seamless. A discussion is offered of how best to temporally transfer control of different functions between automation and the human operator, both when it is assumed that the operator is fully attentive and when situation awareness is compromised.

1.3.2.7 Driver Fitness in the Resumption of Control (Chapter 9)

The loss of situation awareness can occur for many reasons. When that occurs, driver safety can be greatly impacted, especially when he or she is trying to monitor a vehicle or actually resume control of the vehicle. In Chapter 9, the authors delve into the three primary causes of the loss of situation awareness: distraction, sleepiness, and impairment (user characteristics, Figure 1.1). Information is provided on the fundamental characteristics of distraction, sleepiness, and impairment and how they interact differently with the different levels of automation, especially when control is being transferred between the driver and the vehicle. Research is also summarized on the detection of each of these different states. This research is evolving rapidly and, not surprisingly, has led to an entire cottage industry of driver state monitoring algorithms in order to make sure that the driver is really engaged in the driving task, and may be thought of as a precursor to current automation solutions. Finally, the various countermeasures that are available, or those that will soon be available, are discussed. In some cases, such as sleepiness, the possible countermeasures are counterintuitive, including having drivers engage in what would otherwise be distracting activities.

1.3.2.8 Driver Capabilities in the Resumption of Control (Chapter 10)

Drivers can be capable of resuming control, but temporarily lack fitness to do such as discussed in Chapter 9. In contrast, in Chapter 10 the authors focus on populations of drivers that find themselves in longer term situations that can lead to the loss of the most basic driving skills, which in turn makes it difficult for them to resume control. Such populations include those affected by the normal aging process and various medical conditions. Automated vehicle technology, including in-vehicle information systems, active safety systems, and other automated technologies, hold plausible opportunities for drivers who may be at risk for continued independent and safe driving. The authors frame the discussion in the context of the medical condition, the core clinical characteristics of the condition, the resulting functional performance deficits, their effect on driving, and the hypothetical use of automated vehicle technologies to facilitate fitness to drive abilities in drivers wanting to resume control of the vehicle (i.e., wanting to resume driving).

1.3.2.9 Driver State Monitoring for Decreased Fitness to Drive (Chapter 11)

While Chapters 9 and 10 discuss the various types of reductions in the fitness and the capability to drive, the question of how one detects the various driver states associated with these reductions is central. The discussion in Chapter 11 is by necessity a more technical discussion, one focusing on the sensors and algorithms used to detect driver state. But it is also a discussion grounded in a deeper understanding of the behaviors which characterize a given state. There have been a number of advances in the detection of driver state, advances due in part to the miniaturization of very powerful sensors and computing capabilities and in part to a better understanding of the physiological and behavioral characteristics that are associated with a given state. In Chapter 11, the authors discuss these advances in driver state monitoring as well as the human factors issues that will arise as these advances work their way into the market.

1.3.2.10 Behavioral Adaptation (Chapter 12)

We have spoken about behavior with regard to the technologies with which the driver must interface at each of the various levels of automation. We have assumed that the behavior remains static across time. In Chapter 12, the author discusses if, and how, the behavior of drivers changes over time after the introduction of a given technology. Research suggests that drivers learn to adapt to safety technologies, sometimes leading to risk homeostasis, a phenomenon where drivers will engage in a more risky behavior when a technology is introduced that is meant to reduce the risk, thereby keeping the overall risk constant. Risk homeostasis is only one of the several theories that are used to explain behavioral adaptation and which are discussed in the chapter.

1.3.2.11 Distributed Situation Awareness (Chapter 13)

As noted, situation awareness is an important consideration in the design of automated vehicles and the road systems in which they will operate. In Chapter 7, it was the situation awareness of the individual driver that was primarily at issue. But it is not only the driver that needs to be situation aware as the driver is embedded in a larger transportation system. In Chapter 13, the authors argue that considering the situation awareness requirements of both human and non-human agents is critical, as well as how they can exchange and connect their awareness with one another in different road environments. To demonstrate their approach, the authors present an overview of their distributed situation awareness model and an analysis of the recent Uber–Volvo fatal collision in Tempe, Arizona.

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

We have assumed up until this point that automated vehicles will somehow just magically appear on the roads. However, there will arise a number of complex, human factors issues in the pilot testing, lengthy deployment, and regulation of ACIVs. In Chapter 14, the author attempts to answer the question "What human factors issues need to be considered in preparing policy and regulation for the deployment of automated vehicles?".

1.3.3 HUMAN-CENTERED DESIGN OF ACIVS (SOLUTIONS)

A number of automation-induced problems have been identified above along with some solutions (e.g., driver state monitoring). In this part of the Handbook, we turn to solutions based on the design of the HMI.[4] Issues central to the design of the HMI include concerns associated with both the displays that present information to the driver (including warnings) and the controls that facilitate the driver's interactions with the vehicle as a whole and indicate the status of various vehicle components and sub-systems. In the context of vehicle safety systems in particular, the HMI should effectively communicate information while assessing and managing driver workload and minimizing distraction. A broader discussion of how one might actually configure the ODD of the advanced technologies to improve safety or how one might design the control algorithms to reduce the potential of fully automated vehicles causing riders to exhibit symptoms similar to simulator sickness are part of the larger picture of what is meant by human-centric design (Fridman, 2018), but are not covered in this Handbook due largely to issues of space.

1.3.3.1 HMI Design for ACIVs (Chapter 15)

In Chapter 15, the authors discuss the general HMI design requirements for ACIVs. Such design requirements must be determined in the context of many factors, including their influence on safety, public perception, and perceived value; the mix and behaviors of legacy vs. connected vs. automated vehicles over time within the vehicle fleet; and the degree and type of automation associated with the HMI. Within this context, the safe and efficient operation of any motor vehicle requires that the HMI be designed in a manner that is consistent with driver needs, limitations, capabilities, and expectations. As another example of the automation paradox, as automation takes

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[4] The literature generally uses the terms HMI and Driver–Vehicle Interface (DVI) interchangeably; we will use HMI throughout this paper but view HMI and DVI to be synonymous for our purposes.

on more of the driving task, the HMI might need to become more complex to properly support the driver. A continuing challenge is to identify just what these changes to complexity are amidst the changing and uncertain landscape of advanced vehicle technology. Despite these challenges, the objective of this chapter is to summarize what is known regarding HMI design principles for ACIVs. Many of these principles are aimed at addressing the important issues raised in the preceding chapters.

1.3.3.2 HMI Design for Fitness Impaired Populations (Chapter 16)

The HMI will be used not only by the general population but also by drivers whose fitness is impaired. Assuming one can monitor for driver state, then one could potentially adjust the relationship between automation and the driver dynamically. This concept is referred to as adaptive automation. In Chapter 16, the author considers the application of adaptive automation in the context of driver impairment. First, the author introduces the topic of adaptive automation and important questions that must be addressed by an HMI designer. This discussion is then extended to adaptive vehicle automation in the context of driver impairment, specifically, distraction, drowsiness, and drugs and alcohol. Overall, the chapter provides a framework for the implementation of adaptive interfaces in the automated vehicle, which hinges on understanding the interaction between the nature and degree of driver impairment and the capabilities of vehicle automation.

1.3.3.3 Automated Vehicle Design for People with Disabilities (Chapter 17)

Impairments to a driver's fitness reduce the driver's normal range of safe operations, but generally do not impact the driver's ability to obtain a motor vehicle license. However, drivers with disabilities who cannot obtain a driver's license may be able to obtain one when fully automated vehicles (SAE Levels 4/5) are available, potentially providing them with much greater mobility and independence. In Chapter 17, the author describes what is needed from a human factors standpoint in order for this potential to be realized. In particular, it is argued that accessibility for persons with various disabilities needs to be considered early in the design process. Although accessibility has not traditionally been a design focus for passenger vehicle manufacturers, there are lessons to be learned from other modes of transportation that can be leveraged in the design of fully automated vehicles. The first part of the chapter introduces readers to the social model of disabilities, which is a philosophy that views disabilities as an individual difference similar to height and gender. The second part of the chapter provides an overview of the universal design and its seven principles for developing products and systems that are usable by all. The third and final section of the chapter discusses what aspects of a highly automated vehicle are new and unique and how to make these accessible to persons with disabilities.

1.3.3.4 Importance of Training for ACIVs (Chapter 18)

Even if one could design the best of all possible interfaces for a driver, ACIVs differ enough in their operating requirements from the vehicles currently on the roadway that training is likely to be a recommended, if not a necessary requirement. Despite potentially dramatic changes to the driving task, there has been relatively little work examining how training and learner-centered, HMI design can positively impact the safety of ACIV systems. In Chapter 18, the authors summarize the general concept of learner-centered HMI design for ACIVs and provide information on specific training-related factors. Training is potentially useful for everything from learning how to respond to the warnings, to learning how to monitor the dynamic driving task when in Level 2 and above, and to re-familiarizing oneself with driving skills that might have atrophied. The chapter serves as a foundation for driver training stakeholders, technology developers, consumers, and legislatures to address the growing need to include relevant and effective training for ACIV systems as these technologies are developed and deployed.

1.3.4 SPECIAL TOPICS

The special topics included here are the ones which push 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.

1.3.4.1 Connected Vehicles in a Connected World: A Sociotechnical Systems Perspective (Chapter 19)

Much of the discussion in the Handbook is focused on understanding the behaviors of the driver isolated from the larger system in which he or she is embedded. Yet, the driver and his or her vehicle will be inevitably integrated within the broader, connected network of smart cars, smart cities, and smart homes, with all of the associated social and technical system components. In Chapter 19, the author discusses the need to regard the connected vehicle within a broader sociotechnical framework. A sociotechnical perspective involves creating a detailed system framework, identifying the various social and technical sub-systems to reveal critical interdependencies, and then defining design requirements and resolving potential conflicts. It is argued that methodologies for system analysis and joint optimization are urgently needed to create the foundations that promote positive emergent properties such as system safety, resilience, and overall effectiveness.

1.3.4.2 Congestion and Carbon Emissions (Chapter 20)

The Handbook has focused on the advances ACIVs can make in the areas of safety and mobility, largely because those are the issues most often considered. However, ACIVs are also proposed as a way to reduce congestion, and hence to reduce carbon emissions. Unless people completely surrendered driving control to ACIVs, researchers must understand how driver behavior is affected by vehicle intelligence, connectedness, and automation. The authors in Chapter 20 review such work. Congestion is the focus of the first part of the chapter. It is shown that knowledge that the vehicle has, such as information about route travel times and parking spot availability, seems to induce driver decisions based on the simple rules of thumb. Vehicle connectedness can be leveraged to decrease congestion if drivers can reason and predict other's behavior—be they human or automated drivers—and, surprisingly, such decision skills should not necessarily follow standard game-theoretic rationality. Carbon emissions are the focus of the second part of the chapter. The authors discuss to what extent such carbon-emissions-reducing ACIVs currently exist, when one takes a life cycle perspective.

1.3.4.3 Automation Lessons from Other Domains (Chapter 21)

There is much that can be learned from accident analysis and research in other domains about human behavior and safety when using automation. This is especially true in aviation, which is arguably the pioneer of the systematic investigation of human automation as it pertains to operators in general. In Chapter 21, the author reviews the lessons that can be learned from human interaction with automated systems other than vehicles, including not only human flight in aviation but also unmanned air vehicles, space, Air Traffic Control, military systems, consumer products, business systems, process control, robotics, and others.

1.3.5 EVALUATION OF ACIVS

The authors in the previous chapters have discussed the details of ACIVs (vehicles, Figure 1.1). They have explored the problems that are fundamental to both a human operator driving in general as well as a human operator driving automated vehicles at each of the different levels of automation (users, Figure 1.1). The discussion has focused both on the general population of users as well as those whose fitness to drive or capability of driving is reduced for whatever reasons. And the discussion has included not only the individual driver but also the driver as part of a larger system. Potential solutions including driver state monitoring and advanced HMI designs (tasks, Figure 1.1) that may solve those problems have also been presented. However, no matter how principled, any solution is only a potential one until it is tested and evaluated.

1.3.5.1 Human Factors Considerations in Testing and Evaluating ACIVs (Chapter 22)

In Chapter 22, the authors provide an overview for testing various aspects of automated and connected driving automation systems (broadly the complete sweep of warning systems, active safety systems, DSFs, and ADSs), including considerations for commercial vehicle testing. The chapter includes reviews of vehicle testing methodologies (e.g., data analytics, experimentation, and naturalistic driving) and advocates for a graduated approach in which systems are tested iteratively throughout the development cycle. In particular, it is necessary to accurately characterize the driving automation system(s) present in a platform, which can inform the training material developed for drivers of the particular vehicles being evaluated and the associated testing scenarios. What is actually tested can also be informed by the analysis of existing naturalistic driving data. Simulator testing provides a method of evaluating early feature designs with a large degree of experimental control, but reduced external validity. Other testing approaches include on-road testing, using a prototype or Wizard of Oz approach to increase the external validity of testing. Finally, late stage testing can include the analysis of large datasets of drivers actively using automation.

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

As described in Chapter 22, there are many important considerations when evaluating and testing ACIVs, and many approaches, such as simulation, on-road tests, and naturalistic studies, which can be taken. New and emergent issues concern the management and analysis of data that are derived from these evaluations, especially issues centered on big data. In Chapter 23, the author describes the techniques that can help the analyst make sense of these complex datasets. First, the author describes methods for understanding complex datasets, including how to manipulate, visualize, and examine the data. Second, the author describes the research questions that can be answered about both the operator and the system with large datasets. Finally, the author describes both the techniques and tools needed to make sense of the behavior given the context, user, and the technology itself and the questions that should be asked to check/validate the correctness of the outcomes.

1.4 CONCLUSION

This introduction and overview is not meant to distill the wisdom, experience, and knowledge that are conveyed within the Handbook. Rather, our goal as editors has been to provide the reader with the motivation for the Handbook, which follows from the paradox of automation and the basic terminology. We hope this handbook leaves the reader less rather than more confused about the ACIV landscape as it is relevant to human factors.

We leave where we began, hopefully having provided substance to our initial remarks. Automation has saved, does save, and will continue to save lives. A great majority of the reasons for crashes have been traced back to the driver (National Highway Traffic Safety Administration, 2008). Yet as the chapters make clear, the larger system of which the driver is a part is almost never designed with the characteristics, strengths, and weaknesses of the human front and center. And in those cases where the human driver clearly is at fault, this does not mean that the automation that is being introduced in today's vehicles will necessarily produce the benefits everyone hopes it will. First, the type of automation that has saved so many lives is largely of a different kind (active safety features) than the type of automation which is working its way into Level 1 and 2 cars (automatic steering and ACC). Thus, the automation itself could introduce errors. Second, the type of automation that is being introduced is being used to replace driver operations in areas where the human driver is phenomenally successful, having only 1.25 fatalities per 100 million miles of vehicle travel. Thus, the automation needs to meet an especially high threshold of safety. Third, increasingly autonomous systems do not remove humans and their errors, but simply displace them. Future crashes might be due to programmer, remote operator, or maintenance errors. This is perhaps the most nefarious instance of the automation paradox: automation might eliminate the current driver errors, but might create new opportunities for even more dangerous "human errors." This creates challenges for the driver and others in the sociotechnical system of transportation that do not exist with vehicles in the recent past. Understanding these challenges and providing insight into the potential countermeasures is the purpose of the Handbook. It is a purpose in service of the goal sought by all concerned: achieving the maximum benefits of ACIVs. There is so much promise.

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