Drivers and the driverless vehicle revolution: Understanding the changing role of the driver

By David M. Cades, Ph.D., Michael R. Carey, Esq.*, Caroline Crump, Ph.D., Christina Cloninger, Ph.D., and Douglas E. Young, Ph.D.
*Exponent Inc., *Bowman & Brooke*

MAY 31, 2017

Vehicle technology is advancing at a whirlwind pace. How are regulators, insurers, litigators, and drivers going to keep up?

On May 7, 2016, a Tesla Model S, while operating in the semi-autonomous "autopilot" mode, struck the broad side of the trailer portion of a tractor-trailer that had turned left in front of its path on a clear and sunny day.

The driver of the Tesla was killed, the first reported fatality involving a highly automated vehicle in "autopilot" mode.

In this case, neither the driver of the vehicle nor the automatic braking system applied the brakes. The technology had reached a limit condition in which its sensors could not differentiate the trailer from its background, and the driver was reportedly watching a movie.

> It remains uncertain as to when these technologies will be accepted by consumers, and how quickly regulators, insurers, and litigators address safety considerations.

This situation demonstrates a critical mismatch between the driver's expectations and understanding of the automated technology's capabilities and the vehicle's requirements for driver oversight and intervention.

The advent of the automobile has forever changed where people live and how they travel. The introduction of advanced vehicle technologies and autonomous vehicles is set to reshape transportation yet again.

As with the introduction of any new technology, there have been (and will undoubtedly be more) challenges to the industry as consumers begin to use these new vehicles and systems.

This article discusses the effect of these new technologies on both the driver and the task of driving in the context of what these systems do to facilitate the driving task, and the challenges and opportunities they pose for research, development, and the insurance and legal industries.

AVAILABLE TECHNOLOGIES AND MARKET INTEGRATION

The Advanced Driver Assistance Systems (ADAS) that have already hit the market are the foundational components of tomorrow's fully autonomous vehicles. These "high-tech" systems are becoming more widely available with each new model manufactured.

A review of current automobile advertisements demonstrates that many manufacturers are now focusing significant marketing efforts their introduction of these technologies to the public. Although the available technology differs among manufacturers, several systems are already prevalent, including:

- Electronic Stability Control. This system monitors the steering input from the driver relative to the direction of vehicle to improve driver control of the vehicle. If the vehicle's travel path does not match the driver's steering input, the vehicle will selectively apply the brakes and/or reduce engine power to mitigate against the loss of control.

- Adaptive Headlights. This technology functions to illuminate turns and curvatures on the road in a dark environment. The headlights swivel in the direction of the turn by monitoring the speed, steering, and yaw of the vehicle.

- Adaptive Cruise Control. This advanced speed control system is a modified version of traditional cruise control. It controls headway distance as well as desired vehicle speed through autonomous braking and acceleration. The system uses a combination of camera, radar and laser or LIDAR systems to scan the distance to lead vehicles when cruising, and is one of the most common ADAS technologies.

- Rearview Back-Up Camera. This technology displays the conditions behind a vehicle and includes areas that are not otherwise visible when backing up. The view is usually provided from a wide-angle camera mounted on the back center of a vehicle, generally displayed to the driver in the rearview mirror, center console, or in the instrument cluster, and is activated when the vehicle is in reverse.

In addition to the more widely available ADAS technologies described above, there are other systems, which are more recent innovations that exert independent control over certain driving functions. These include:

- Park Assist. As indicated by the name, this system uses optical and other sensor technology to automatically park the car without any interaction from the driver. Some systems can parallel park or park in a perpendicular spot.

- Lane Departure Warning and Lane-Keep Assist Systems. These technologies warn the driver when the car is drifting out of its lane, and can either inform the driver or control

vehicle heading to help the driver maintain the vehicle's travel lane. Warnings for these systems consist of auditory (e.g., series of tones), visual (e.g., blinking light in dashboard), and/or haptic (e.g., steering wheel or seat vibrations) stimuli, and are triggered when the vehicle nears or crosses edge lines without the activation of a turn signal.

- Forward Collision Warning and Autonomous Emergency Braking. These technologies utilize a combination of camera, LIDAR and/or radar systems to scan the path ahead of the vehicle and calculate time and distance to potential impact with a lead vehicle or other object. If the driver is approaching an impending obstacle and does not respond prior to reaching a certain time-to-collision threshold, the forward collision warnings will activate. The system may also prime the brakes to enhance braking power for driver response, or tighten seatbelts in case of collision. If the vehicle continues toward the collision point without driver response and passes a time-to-collision threshold, the vehicle will apply braking power to reduce the severity of a collision or potentially avoid the collision altogether.

Finally, automated, specialized "self-driving systems" are currently available in select vehicles manufactured by Tesla. Those presently available for use on the roadway include:

- "Summon." This technology utilizes a form of Park Assist that allows the operator to summon the car to a specific location without being in the vehicle. This function is currently limited to driving a distance of 39 feet, and requires the operator to be within 10 feet to activate.[1]

- AutoPilot. This technology affords autonomous or "self" driving in many situations, using a system of technological advances that merge computers, electronics, cameras and sensors for active lane-keeping, adaptive cruise control, lane changing, self-parking, and other functions. It is presently only available for use at highway speeds and functions for limited traffic maneuvers (e.g., matching traffic speed and lane changing).

In describing ADAS and related technologies, NHTSA has adopted the Society of Automotive Engineer's (SAE) Levels of Driving Automation for On-Road Vehicles.[2] SAE's J3016 provides definitions for automated driving. These levels range from 0 (No Automation) to 5 (Full Automation). Many of the ADAS technologies described in this paper fall in levels 1 (Driver Assistance) to 3 (Conditional Automation).

While some ADAS components are becoming part of standard vehicle packages, it remains uncertain as to when these technologies will be accepted by consumers and thus how quickly regulators, insurers, and litigators respond to the demand by addressing safety considerations associated with the new innovations.

Historically, the progression of technology has been measured by the speed of proliferation and standardization. For example, electronic stability control systems were introduced in the late 1990s,[3] but were not required as standard in passenger cars and light trucks until model year 2012.[4]

The pace of adoption, however, seems to be substantially increasing. For example, rearview back-up cameras were introduced in the early 2000s.[5] By 2014, the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) issued a rule requiring rear viewing technology to be included as standard in all vehicles under 10,000 pounds by 2018.[6]

And more recently, an automotive manufacturers group representing more than 99 percent of the U.S. vehicle market,[7] has committed to speed the pace of adoption for autonomous technologies; specifically, these automakers agreed with NHTSA and the Insurance Institute for Highway Safety (IIHS) to make forward collision warning and autonomous emergency braking standard in passenger vehicles by 2022.[8]

> In partially automated and possibly even in fully automated vehicles, the driver will still be responsible for the vehicle's operation.

This industry-led agreement is a novel approach aimed at broadly and quickly introducing ADAS technology to a wide consumer base. While the deadline for autonomous emergency braking integration is still several years out, many manufacturers have already begun offering forward collision warning and automatic emergency braking as optional or standard equipment within their fleets.

In addition, various companies (e.g., Uber, Google and Tesla) have been working to be the first to bring *fully-autonomous* vehicles to the marketplace.

Others in the industry are not far behind, also pledging to bring fully autonomous vehicles to public roadways in the near future. Volvo, for example, pledges to test self-driving cars on public roads in multiple countries by 2017.[9]

There has been a natural time lag of two to three decades between technology introduction and large-scale adoption or regulatory mandate, as exemplified by Electronic Stability Control and rearview technologies.

During this time-period, the technologies are refined and improved by the manufacturers. This adoption period also gives the industry the opportunity to evaluate the technologies' potential benefits to performance and safety.

These benefits, and the associated risks inherent in all new developments, can also be studied in detail before any type of regulatory mandate. In addition, by the time a regulatory mandate comes to fruition, because the industry tends to

outpace the regulatory oversight, the advancements in question are normally already standard in many vehicles or provided as an option in most (e.g., rearview back-up cameras).

This period of time — between introduction and regulation — further permits insurers, litigators, and researchers to observe potential issues and concerns with the technologies and develop strategies on how to best respond.

The retrofitting of the infrastructure to accommodate autonomous and connected vehicles is lagging behind the development of the vehicles themselves.

In marked contrast to this model, however, the introduction and inclusion of autonomous vehicle technology has taken a different path. For example, the autonomous emergency braking systems as well as highly automated vehicles are currently available to the public in various forms, and have not experienced any hold back for regulatory orders.

As these and other similar ADAS technologies are developed and introduced, a trend of shorter time periods, from introduction to widespread inclusion may continue and thereby reduce the time available for the industry and public to observe, analyze, and react.

CHALLENGES WITH INTEGRATION

There are a number of hurdles that manufacturers, consumers, researchers, and regulators face before the full offering of ADAS technologies are truly accepted and integrated into mainstream transportation. One set of challenges relates to the interaction between vehicles with various levels of autonomous technology on roadways.

As an example, according to Google's Self Driving Car Reports,[10] of the 25 reported accidents between May 2010 and July of 2016, six occurred while the Google car was in manual mode. Others involved a vehicle driver who was deemed to be at fault in all but one of the 19 that occurred while the Google cars were in autonomous mode.

It is likely that this trend will continue as long as there are human drivers acting in sometimes unpredictable or atypical ways.

Similarly, there are challenges related to cost barriers for ownership of an autonomous or semi-autonomous vehicle, as well as cost barriers to improving infrastructure that can better accommodate such vehicles.

Discussions of the future of autonomous driving and connected vehicles often refer to fleets of vehicles that can communicate with each other ("V2V") and with the roadway infrastructure ("V2I"), allowing for faster speeds, less separation between vehicles on the road, and a more efficient utilization of the roadway system. However, that level of investment in infrastructure will be substantial.

Other challenges relate to consumers' acceptance and understanding of ADAS technologies. If consumers do not prefer, understand or trust the technologies, they will not be likely to purchase vehicles equipped with the technologies. For example, consumers have been found to regularly disable lane departure warning systems.[11,12]

Exponent Human Factors researchers have also conducted a survey of naïve and experienced driver perceptions of and desire to own autonomous vehicle technologies.[13] They found that only 1 in 5 consumers surveyed was interested in fully autonomous vehicles, and that 44percent of consumers surveyed would prefer vehicles with no self-driving capability.[14]

Poor acceptance and trust of existing technologies may be related to drivers' expectations and the extent to which they understand the systems.

For example, there have been a number of incidents with currently-available ADAS technologies, including the Tesla fatality mentioned above, wherein the operator thought the vehicle was in one mode and would take one action, only to find the vehicle was actually in another mode and took a different action (e.g., the system did not brake when the operator thought it would).

This mismatch between a user's understanding of how a system does or should function and how that system actually functions, has led users to either not use or misuse the technologies.

Historically, research has shown that humans are quite sensitive when it comes to trusting and accepting automated systems and that even infrequent violations of their expectations can have a lasting impact on their acceptance of automated systems.[15]

Thus, consumer expectations of system functioning are intimately related to acceptance and trust. A critical feature in introducing ADAS and automated vehicles technologies is doing so in a way that allows the users to understand how the technologies work and when they will be active and inactive.

To this end, researchers, manufacturers and industry members will need to focus on what information consumers are getting and how they are getting it, perhaps including the development of new methods of training and instruction.

Without this consumer understanding, there is a danger that introducing technologies might result in users not only misusing, but entirely rejecting autonomous technologies.

THE ROLE OF THE DRIVER WITH 'SELF-DRIVING' VEHICLES

One of the most crucial challenges relating to driver acceptance is the behavioral shift that drivers must make to operate a vehicle with autonomous or semi-autonomous technologies.

Specifically, the role and importance of active control over vehicle functions has been reduced and made less demanding with assistive technology (e.g., power steering), or removed from the driver's purview completely (e.g., automatic transmissions).

As a result of these technologies, less active control is required of the human driver when operating a vehicle. Instead, the responsibility for safe navigation of a vehicle is distributed between the driver and the vehicle itself. The primary hope is that increasing automation will reduce or eliminate driver error, and thus prevent a large number of accidents.[16]

However, the driver is still required to operate at least some aspects of the driving task. The driver in a semi- or fully-automated vehicle becomes a less-active operator, who performs fewer movements that govern the vehicle and instead monitors the outcome information of the systems.

As such, a driver's attention shifts from processing the environmental stimuli outside the vehicle to performance-related characteristics available inside the vehicle.

For example, in ADAS technologies that monitor the environment for pedestrians, the driver's attention is directed to the vehicle's alert system (e.g., auditory warnings) and in-vehicle display only when a pedestrian becomes a hazard. In this way, the change in the driver's role and responsibilities while driving introduces a variety of issues, which are discussed in turn below.

While the driver's role will necessarily be changing as these technologies are implemented, it is important to remember, and should be clear from the discussion above, that, at least in partially-automated vehicles and possibly even in fully-automated vehicles, the driver will still be responsible for the vehicle's operation.

What will change is the way in which the driver interacts with the vehicle to wield that responsibility.

ACCEPTANCE AND TRUST

A major hurdle to a driver's transition to a less active role when operating a vehicle is acceptance. On the one hand, drivers with too little trust in the systems are unlikely to use them, rendering the systems useless or even interrupting their function.

For example, forward collision warning and mitigation systems can detect and respond faster to an impending collision than most human drivers can identify and react to hazards.[17]

Yet, the system's response can be interrupted by driver intervention, such as braking or movement of the steering wheel. Drivers who do not sufficiently trust that the vehicle will perform as intended can interfere with the systems, and consequently interfere with the safety benefits.

While this behavioral pattern is not typically observed in scientific investigations, many studies, in fact, suggest the opposite — consumers exhibit too much trust when interacting with the systems.

In particular, drivers often expect that they do not need to be as vigilant when only monitoring the state of the vehicle, compared to when they are actively driving the vehicle.

For example, drivers naïve to the limitations of automated vehicle technologies perform secondary non-driving tasks as much as
261 percent more frequently in "self-driving" vehicles as compared to a vehicle without ADAS.[18,19,20]

Another related issue in drivers with too much trust in ADAS technologies is that they may operate the vehicle at its limits and assume he (or she) remains protected by the vehicle, a concept known as "risk compensation."

Consistent with this, drivers in partially-automated vehicles have sometimes been observed to drive at increased speeds with decreased headways, and exhibit less control of lane position.[21,22,23,24]

It should be noted that scientific studies indicate that behavior is moderated by experience, such that drivers with increasing experience generally demonstrate more reasonable expectations and levels of trust.[25,26,27]

LOSS OF SITUATIONAL AWARENESS/AUTOMATION HANDOFF

Studies of driver interaction with autonomous systems in vehicles indicate that the systems are very effective in improving performance for simple driving tasks, such as driving straight on highways.

However, if the systems suffer a mechanical impairment, or reach their limits, drivers are often unable to take over control of the vehicle in a timely manner.[28,29] This may be related to a driver's inattention to the driving task and/or performance of secondary tasks when driving a partially- or fully-automated vehicle.[30,31]

Disengagement from the driving task makes it difficult for the driver to respond in sudden emergencies because they are "out-of-the-loop" (i.e., they have lost awareness of their environment and situation).[32]

Findings from simulator[33] and on-road, closed course[34] studies indicate that drivers spend less time gazing at the road ahead when utilizing adaptive cruise control and that they exhibit increased reaction times to emergent situations when various parts of the driving task are automated as compared to when they are not.[35]

Further, when drivers in ADAS-equipped vehicles are presented with an emergency situation without warning, their responses to the emergency tend to be more aggressive and less controlled than if they had been driving manually.[36] Consequently, NHTSA[37] has recommended a warning signal be put in place to notify drivers when they will need to take over for the vehicle.

Studies into the effects of such a warning signal indicate that it is generally effective in encouraging smooth takeover by the human driver, but may require some training for the driver to achieve smooth takeover.[38]

Exponent has similarly found that drivers engaged in a secondary task (namely, mental arithmetic problems administered over a cell phone) show a benefit in terms of reaction times following visual and auditory forward collision warnings that alert them to impending obstacles as compared to drivers who do not receive such warnings.[39]

However, they have also found that drivers engaged in a mental arithmetic task do not benefit from lane departure warnings;[40] thus, warnings may be selectively effective in redirecting driver attention depending on factors such as the significance of the warning (e.g., imminent collision versus a more innocuous lane drift) and exposure to the warning (i.e., effects of habituation).

TRAINING

The efficacy of a new technology ultimately relies on the users' ability to understand its purpose and interact with it appropriately. For example, some vehicles with autonomous emergency braking systems work effectively when the driver remains passive and does not interfere with the system's sophisticated braking mechanism.

In these situations, drivers need to inhibit their trained response (i.e., depressing the brake) because it interrupts the vehicle's optimal performance capability.

Exponent has previously shown that drivers naïve to forward collision warning and mitigation systems do not rely on them when presented with a surprise lead vehicle braking event; instead, drivers are likely to activate the brakes, which is the result of training and many years of experiences in non-ADAS-equipped vehicles.[41]

While this is an appropriate response in many cases, interrupting the vehicle system's emergency response process can purposefully or inadvertently result in unexpected vehicle movements and handling.

For example, in early 2016, one Tesla driver inadvertently pressed the brake and interrupted the vehicle's emergency response, resulting in a rear-end accident on a highway.[42] Therefore, proper training on best practices for responding with the vehicle systems, rather than against them, is necessary.

Drivers also may need training to search and respond to new information provided by the vehicle. Information provided in a heads-up display can be confused with relevant road features, such as traffic lights and signage.[43]

In the case of audible warning alarms, such as those associated with lane departures or backing, the observer must be able to detect the warnings and identify their meaning.[44,45]

It can be difficult for consumers to learn to associate abstract sounds with the warnings they intend to convey;[46] thus, training and experience are required to encourage proper interaction with the alarm.

Studies of driver interaction with automated vehicle technologies indicate that even limited experience with the systems appears to help drivers understand how to best utilize and interact with the systems.[47,48,49,50]

As people become more familiar with and better trained on new automated vehicle technology, they will be faced with the prospect of having to switch between active and semi-passive roles depending on the level of technology present in the vehicle they operate.

Specifically, drivers may become familiar with automated technologies in their primary vehicle, but drive a secondary vehicle without the technologies.

Reliance on a new technology may re-train attention to work with the technology, at the expense of older habits required in non-automated vehicles. For example, rearview back-up cameras encourage visual search behaviors toward the display, rather than turning around to look behind the vehicle when reversing.[51]

Such training may show persistent effects, changing patterns of driver gaze behavior over time. Consistent with this, intermittent removal of a lane departure warning system in one study was not associated with worse lane-keeping behavior, suggesting that the effects of the lane departure warning system continued in its absence.[52]

While this is a positive effect for lane departure systems, it could present potential risks for rearview back-up camera system-taught behaviors. The issue would present most saliently in situations wherein drivers are temporarily driving a vehicle, such as a rental car.

INDIVIDUAL DIFFERENCES

It is generally expected that certain populations, such as elderly drivers, will disproportionately benefit from partially- or fully-autonomous systems.[53,54,55] Exponent has found some support for this contention in a large online survey of naïve and experienced driver preferences, as well as in a post-test survey of driver preferences after initial exposure to forward collision warning and mitigation systems.[56]

Older drivers who already have high levels of experience with ADAS generally report that they like the systems. Somewhat surprisingly, older drivers are more likely than younger drivers to report that they would purchase similar technologies, even after a single exposure to forward collision warning and mitigation.

However, older drivers were also more likely to report difficulty understanding the forward collision warning and mitigation system than were younger drivers. Consistent with this, older drivers do not show an overall benefit from technologies such as heads-up display systems.[57]

Furthermore, older naïve drivers report lower preferences for more automated vehicles.[58] Thus, it is unclear how and whether older drivers will experience the intended safety benefits, perhaps due to the well-established apprehension of naïve users to use and rely on new products.

BENEFITS OF ADAS AND AUTONOMOUS VEHICLE TECHNOLOGIES

ADAS technologies are designed to increase safety, reduce driver workload, reduce crashes (and by proxy injuries and fatalities), and increase the overall efficiency of vehicle

performance on the roadway. Initial reports suggest that ADAS technologies are successful in their aims.

One study from IIHS[59] found that vehicles equipped with automatic braking showed a reduction in rear-end crashes of about 40 percent as compared to vehicles without the technology. The Highway Loss Data Institute (HLDI) reported reductions of about 10 percent in property damage claims and reductions of approximately between 20-45 percent in bodily injury claims in vehicles equipped with forward collision warning and lane departure warning systems as compared to vehicles without these ADAS features.[60]

Other benefits to the proliferation of ADAS technologies in consumer vehicles include advances in the data collected on driving behavior, vehicle operation in different circumstances, and information on what the vehicle and driver were doing in the moments surrounding an accident.

Data from sources such as the air bag control module, electronic data recorder, crash data recorder, or the vehicle's controller area network (CAN) BUS continue to improve and track the state of more vehicle systems.

Tesla, for example, has used data it has collected to show the state of its Autopilot and Summon features at the time of incidents, allowing investigators insight in to the role of those systems during incidents.[61,62]

Specifically, on more than one occasion, Tesla has shown that in crashes where the driver thought these systems were active, they were in fact not and the vehicle was under the control of the driver and not the automated system.

As discussed above, these incidents highlight the importance of an operator's understanding of an automated system and the necessity of vehicle performance data that details the activity of both the operator and system technologies.

Another potential benefit associated with increased data collection comes in the form of rate adjustment for vehicle insurance.

Traditionally, rate determinations have primarily accounted for specific driver's demographics and personal driving history (e.g., driving record and claims history), with the *type* of vehicle the person drives being only a secondary consideration.

As vehicles become more automated, however, the driver may play less of a role in this determination. Insurers will be faced with entirely new questions and issues when determining insurance risk and rates.

At the same time, they will also have the benefit of new data to help understand the risks. These benefits may be passed on to consumers; for example, at least one insurer in the United Kingdom is offering incentives to its customers who have vehicles with assistive technologies and has plans to offer further rate adjustments as the demonstrated safety increases and thus risk of loss decreases.[63]

However, other factors will need to be considered when determining insurance rates for ADAS equipped and highly automated vehicles. While the new technologies are aimed at reducing both the number and severity of crashes, the equipment used to realize these systems can be quite expensive and is often located in areas of the vehicle most susceptible to damage in collisions, such as bumpers.

As a result, the cost to repair ADAS equipped vehicles may be significantly more expensive than for similar repairs on a non-ADAS equipped vehicle.[64] It is still unclear how these conflicting paths will bear out, but these are important considerations to account for when trying to understand the totality of the effects of advanced vehicle technologies on our infrastructure.

CONCLUSIONS

While the safety-related data are certainly encouraging, there is a certain amount risk of accidents involving vehicles equipped with automated technologies. Human interaction with technology cannot completely eliminate the element of human error.

As the technology matures, it is possible that any number of issues may arise, including: a vehicle may not be equipped with a particular ADAS that a customer might assume is "standard equipment," a particular ADAS did not function as expected, ADAS produced false alarms, and that ADAS was confusing, not understood, or impaired a driver's ability to operate the vehicle. In light of these potential challenges, it is imperative that the proper tools are used to evaluate those incidents.

For original equipment manufacturers, component part suppliers, researchers, insurers, and litigators alike, staying abreast of current scientific findings and real-world incidents and accidents is imperative.

A thorough understanding of the ever-changing role of the driver, from active controller to passive supervisor, in the context of using ADAS is one essential step in meeting the challenges that lie ahead.

As discussed above, an immediate need is addressing how users and consumers will gain knowledge and training in the use of these technologies. Mode confusion, over- or under-reliance, trust in automation and misunderstanding of the capabilities and limitations of ADAS and automated vehicle technologies can lead to crashes and have other unintended consequences including misuse and nonuse of safety critical systems.

The automotive experience is moving towards an eventual end state of fully autonomous vehicles. If perfectly implemented, full autonomy means moving to zero crashes and zero fatalities or injuries from crashes, faster commutes, greater efficiency on the roadway, and more time for commuters to engage in other activities.

However, there are a number of hurdles that must be overcome before full connectivity and autonomy can be realized. The current fleet of non-autonomous,

non-connected vehicles on the roadway will be around for many more years and the retrofitting of the infrastructure to accommodate autonomous and connected vehicles is lagging behind the development of the vehicles themselves.

Substantial advances across multiple domains must be completed in order to deploy wide-spread autonomous and connected vehicles on the road. Nevertheless, so long as consumers demand the promise of increased safety and travel efficiency, we must continue to prepare for the almost driverless revolution.

NOTES

[1]   Tesla Model S Software Release Notes 7.1. Accessed September 9, 2016.

[2]   https://www.sae.org/misc/pdfs/automated_driving.pdf; https://one.nhtsa.gov/nhtsa/av/av-policy.html

[3]   NHTSA (2008). *Technology Applications for Traffic Safety Programs: A Primer.*

[4]   49 CFR Part 571 – Federal Motor Vehicle Safety Standards; Rear Visibility; Final Rule.

[5]   Toyota Global. "History of Safety Technology." Accessed March 2014.

[6]   49 CFR Part 571.

[7]   NHTSA (2016). Remarks: Announcement on Automatic Emergency Braking Commitments. March, 17, 2016. McLean Virginia.

[8]   https://www.nhtsa.gov/press-releases/us-dot-and-iihs-announce-historic-commitment-20-automakers-make-automatic-emergency

[9]   https://www.ft.com/content/5b76aba2-0bc4-11e6-9456-444ab5211a2f

[10]   https://www.google.com/selfdrivingcar/reports

[11]   IIHS (2016). Crashes avoided. Status Report, 51(1).

[12]   Reagan, I. J., & McCartt, A. T. (2016). Observed activation status of lane departure warning and forward collision warning of Honda vehicles at dealership service centers. *Traffic injury prevention,* (just-accepted), 00-00.

[13]   Crump, C., Cades, D., Lester, B., Reed, S., Barakat, B., Milan, L., & Young, D. (2016). Differing perceptions of Advanced Driver Assistance Systems (ADAS). *Proceedings of the Human Factors and Ergonomics Society* 2016; 60(1):861-865.

[14]   Crump (2016) et al.

[15]   Schaefer, K. E., Chen, J. Y., Szalma, J. L., & Hancock, P. A. (2016). A Meta-Analysis of Factors Influencing the Development of Trust in Automation Implications for Understanding Autonomy in Future Systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 0018720816634228.

[16]   Brookhuis, K. A., De Waard, D., & Janssen, W. H. (2001). Behavioural impacts of advanced driver assistance systems – an overview. *European Journal of Transport and Infrastructure Research,* 1(3), 245-253.

[17]   Muhrer, E., Reinprecht, K., & Vollrath, M. (2012). Driving with a partially autonomous forward collision warning system how do drivers react?. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 54(5), 698-708.

[18]   Jamson, A. H., Merat, N., Carsten, O. M., & Lai, F. C. (2013). Behavioural changes in drivers experiencing highly-automated vehicle control in varying traffic conditions. *Transportation research part C: emerging technologies,* 30, 116-125.

[19]   Carsten, O., Lai, F., Barnard, Y., Jamson, A. H., & Merat, N. (2012). Control Task Substitution in Semiautomated Driving Does It Matter What Aspects Are Automated?. *Human Factors: The Journal of the Human*

Factors and Ergonomics Society, 0018720812460246.

[20]   De Winter, J. C., Happee, R., Martens, M. H., & Stanton, N. A. (2014). Effects of adaptive cruise control and highly automated driving on workload and situation awareness: A review of the empirical evidence. *Transportation research part F: traffic psychology and behaviour,* 27, 196-217.

[21]   Muherer, et al. (2012).

[22]   Brookhuis, et al. (2001).

[23]   Merat, N., & Lee, J. D. (2012). Preface to the special section on human factors and automation in vehicles designing highly automated vehicles with the driver in mind. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 54(5), 681-686.

[24]   Merat, N., Jamson, A. H., Lai, F. C., & Carsten, O. (2012). Highly automated driving, secondary task performance, and driver state. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 54(5), 762-771.

[25]   Xiong, H., Boyle, L. N., Moeckli, J., Dow, B. R., & Brown, T. L. (2012). Use patterns among early adopters of adaptive cruise control. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 54(5), 722-733.

[26]   Kidd, D.G., Nelson, E.T., & Baldwin, C.L. (2010). The effects of repeated exposures to collision warnings on drivers' willingness to engage in a distracted secondary task. *Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting,* 2086-2090.

[27]   Gold, C., Körber, M., Hohenberger, C., Lechner, D., & Bengler, K. (2015). Trust in automation–Before and after the experience of take-over scenarios in a highly automated vehicle. *Procedia Manufacturing,* 3, 3025-3032.

[28]   Onnasch, L., Wickens, C. D., Li, H., & Manzey, D. (2013). Human Performance Consequences of Stages and Levels of Automation An Integrated Meta-Analysis. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 0018720813501549.

[29]   Merat & Lee, et al. (2012).

[30]   Jamson, et al. (2013).

[31]   Carsten, et al. (2012).

[32]   Endsley, M. R., & Kiris, E. O. (1995). The out-of-the-loop performance problem and level of control in automation. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 37(2), 381-394.

[33]   Carsten, et al. (2012).

[34]   Crump, C., Krake, A., Lester, B. D., Moorman, H. G., Cades, D.M., Young, D. (2017). Driver behavior with passive and active vehicle safety systems. *TRB 2017 Annual Meeting.*

[35]   Brookhuis, et al. (2001).

[36]   Louw, T., Merat, N., & Jamson, H. (2015). Engaging with Highly Automated Driving: To be or Not to be in the Loop? In *8th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, At Salt Lake City, Utah, USA.*

[37]   NHTSA (2013). *Preliminary Statement of Policy Concerning Automated Vehicles.*

[38]   Clark, H., & Feng, J. (2016). Age differences in the takeover of vehicle control and engagement in non-driving-related activities in simulated driving with conditional automation. *Accident Analysis & Prevention.*

[39]   Crump, C., Cades, D., Rauschenberger, R., & Hildebrand, E. (2015). Driver reactions in a vehicle with collision warning and mitigation technology. SAE Technical Paper 2015-01-1411.

[40]   Cades, D., Crump, C., Lester, B., Reed, S., Barakat, B., Milan, L., & Young, D. (2016). Differing perceptions of advanced driver assistance systems (ADAS*). Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 265-269.

41   Crump, et al. (2015).

42   http://arstechnica.com/cars/2016/05/another-driver-says-teslas-autopilot-failed-to-brake-tesla-says-otherwise/

43   Kim R, Rauschenberger R, Heckman G, Young D, Lange R. Efficacy and usage patterns for three types of rear-view camera displays during backing up. SAE 2012-01-0287, 2012.

44   Young, D., Huntley-Fenner, G., Trachtman, D., & Krauss, D. (2005). Human performance issues in auditory collision-avoidance systems. *Proceedings of the 10th Annual Conference on Industrial Engineering – Theory, Applications and Practice, Clearwater, FL,* December 4-7, 2005.

45   Khan, F.S., Sala, J.B., & Arndt, S.R. (2009). *Proceedings of the 14th Annual International Conference on Industrial Engineering Theory, Applications and Practice.* 569-574.

46   Leung, Y. K., Smith, S., Parker, S., & Martin, R. (1997). Learning and retention of auditory warnings. In *Proceedings of International Conference on Auditory Displays,* 288-299.

47   Xiong, et al. (2012).

48   Kidd, et al. (2010).

49   Larsson, A. F. (2012). Driver usage and understanding of adaptive cruise control. *Applied ergonomics*, 43(3), 501-506.

50   Crump, et al. (2016).

51   Kim, et al. (2012).

52   Breyer, F., Blaschke, C., Farber, B., Freyer, J., & Limbacher, R. (2010). Negative behavioral adaptation to lane-keeping assistance systems. *IEEE Intelligent Transportation Systems Magazine*, 2(2), 21-32.

53   Ahtamad, M., Gray, R., Ho, C., Reed, N., & Spence, C. (2015, June). Informative collision warnings: Effect of modality and driver age. In *Proc. of the Driver Assessment Conf* (pp. 324-330).

54   Davidse, R. J. (2006). OLDER DRIVERS AND ADAS: Which Systems Improve Road Safety? *IATSS Research*, 30(1), 6-20.

55   Rakotonirainy, A., & Steinhardt, D. (2009, September). In-vehicle technology functional requirements for older drivers. In *Proceedings of the 1st international conference on automotive user interfaces and interactive vehicular applications* (pp. 27-33). ACM.

56   Crump, et al. (2016).

57   Gish, K. W., & Staplin, L. (1995). *Human factors aspects of using head up displays in automobiles: A review of the literature.* Transportation Research Board, Washington D.C.

58   Schoettle, B., & Sivak, M. (2015). Potential impact of self-driving vehicles on household vehicle demand and usage. *The University of Michigan Transportation Research Institute.*

59   https://www.sbdautomotive.com/en/us-insurers-say-adas-prevent-crashes

60   IIHS, (2016).

61   http://money.cnn.com/2016/07/14/technology/tesla-autopilot-crash-pennsylvania/

62   http://www.theverge.com/2016/5/11/11658226/tesla-model-s-summon-autopilot-crash-letter

63   https://www.theguardian.com/business/2016/jun/07/uk-driverless-car-insurance-policy-adrian-flux

64   https://www.wsj.com/articles/why-your-extra-safe-car-costs-more-to-insure-1491211803

This analysis first appeared in the May 31, 2017, edition of Westlaw Journal Automotive.

ABOUT THE AUTHORS

(L-R top row) **David M. Cades** of **Exponent Inc.** in Chicago specializes in human factors investigations of pilot and driver behavior, including response time, visual perception, nighttime visibility and advanced driver assistance systems. He recently performed an on-road evaluation of auto-braking, collision mitigation, blind-spot and lane-departure warning systems. **Michael R. Carey**, a partner with **Bowman & Brooke** in Minneapolis, concentrates his practice on high-stakes product liability litigation. He has tried numerous cases to verdicts in state and federal courts across the country and is considered a thought leader on emerging issues in the automotive industry. **Caroline Crump** is a senior scientist in the human factors practice at Exponent Inc. in Los Angeles, where she applies her expertise in cognitive and sensory processing to analyses of human performance, including driver behavior and vehicular accidents. (L-R bottom row) **Christina Cloninger** is a scientist in the human factors practice with Exponent Inc. in Chicago. She specializes in the study of visual and auditory sensation and perception, and applies her expertise to investigating human factors in advanced vehicle technologies, transportation accidents, warning compliance, and slips, trips and falls. **Douglas E. Young** of Exponent Inc. in Los Angeles has over 25 years of experience examining issues related to human performance, human factors, biomechanics and ergonomics in accidents, injuries and safety. He has evaluated the human behavior and safety of operation for products manufactured in the automotive and other consumer product industries and has studied factors that cause human error and accidents. This expert analysis was originally prepared as a Bowman & Brooke webinar presentation. Republished with permission.

Thomson Reuters develops and delivers intelligent information and solutions for professionals, connecting and empowering global markets. We enable professionals to make the decisions that matter most, all powered by the world's most trusted news organization.