U.S. Department of Transportation
National Highway Traffic Safety Administration

NHTSA

DOT HS 813 577 September 2024

Assessment of Driver Monitoring Systems for Alcohol Impairment Detection and Level 2 Automation

This page is intentionally left blank.

DISCLAIMER

Suggested APA Format Citation:

Prendez, D. M., Brown, J. L., Venkatraman, V., Textor, C., Parong, J., & Robinson, E. (2024, September). *Assessment of driver monitoring systems for alcohol impairment detection and level 2 automation* (Report No. DOT HS 813 577). National Highway Traffic Safety Administration.

This page is intentionally left blank.

Technical Report Documentation Page

1. Report No. DOT HS 813 577	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Assessment of Driver Monitoring Systems for Alcohol Impairment Detection and Level 2 Automation		**5. Report Date** September 2024
		6. Performing Organization Code
7. Authors David M. Prendez, James L. Brown, Vindhya Venkatraman, Claire Textor, Jocelyn Parong, Emanuel Robinson		**8. Performing Organization Report No.** DOT-VNTSC-NHTSA-xx- xx
9. Performing Organization Name and Address Battelle Memorial Institute 505 King Avenue Columbus, OH 43201		**10. Work Unit No. (TRAIS)**
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE Washington, DC 20590		**13. Type of Report and Period Covered** Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report reviews and assesses driver monitoring systems (DMS) and related technologies for alcohol impairment detection and SAE International Level 2 partial driving automation systems. For the review of technologies to identify driver alcohol impairment, 331 technologies were reviewed. The systems were classified as physiology-based, tissue spectroscopy-based, camera-based, vehicle kinematics-based, hybrid, and patent-stage systems. A key focus was to review systems that are being developed to detect alcohol-related driving impairment, as well as systems that can estimate blood alcohol concentrations. Of the systems reviewed, no commercially available product was found to estimate the presence or amount of alcohol or identify alcohol impairment in the driver during the driving task. Behavioral indicators investigated included eye glances, facial features, posture, and vehicle kinematic metrics. Camera-based and most physiology-based DMS are still in stages of preliminary research and design for alcohol impairment detection. The efficacy of vehicle kinematic measures in identifying alcohol impairment is currently undetermined. Finally, hybrid systems that use two or more types of detection technologies are promising in being able to discern between driver states, due to the number of different measures used in making state determinations. The review of DMS for Level 2 partial driving automation systems involved a literature review, technology review, and interviews with subject matter experts. The literature review discusses driver attention, distraction, and drowsiness, and identifies measures that can be used to estimate driver state. The technology review identified two primary approaches to DMS for Level 2 partial driving automation: hands-on-wheel and eyes-on-road systems. The interviews included nine subject matter experts representing automotive manufacturers and suppliers as well as safety research organizations. Interviews addressed implementation approaches, alerting strategies, and capabilities and limitations of these approaches.

17. Key Words driver state monitoring, driver monitoring system, driver state detection, L2 driving automation, partial driving automation, driver impairment, alcohol, technology, distraction, drowsy driving, BAC		**18. Distribution Statement** Document is available to the public from the DOT, BTS, National Transportation Library, Repository & Open Science Access Portal, https:/rosap.ntl.bts.gov.	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 118	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

This page is intentionally left blank.

Table of Contents

List of Tables

This page is intentionally left blank.

List of Acronyms and Abbreviations

ACTS	Automotive Coalition for Traffic Safety
ADAS	advanced driver assistance system
AECS	average eye closure speed
BAC	blood alcohol concentration
BrAC	breath alcohol concentration
DADSS	Driver Alcohol Detection System for Safety
DDT	dynamic driving task
DMS	driver monitoring system
HDA	highway driving assist
HMI	human machine interface
MADD	Mothers Against Drunk Driving
MEANCLOS	mean closure of eyelid over the pupil over time
OEDR	object and event detection and response
OEM	original equipment manufacturer
ODD	operational design domain
PERCLOS	percentage of eyelid closure over the pupil over time
PPG	photoplethysmography
RFI	request for information
SAE	SAE International, formerly the Society of Automotive Engineers
SME	subject matter expert

This page is intentionally left blank.

Executive Summary

This report describes two related lines of research that investigated driver monitoring systems and related technologies for the detection of alcohol impairment in drivers, and DMS to monitor driver state for SAE International Level 2 partial driving automation systems (SAE International, 2021).

<u>DMS and Related Technologies for Alcohol Impairment Detection</u>

This research identified and described current and prototype DMSs and related technologies, with a focus on those that may be applied to the identification of driver alcohol impairment, either by estimating driver blood alcohol concentration or by detecting/measuring other driver or vehicle characteristics that may be associated with alcohol impairment. Ignition interlock devices (e.g., breathalyzers), which require a directed breath sample from the driver to start the vehicle, are beyond the scope of this review.

The objectives of the review were to:

1. Perform a thorough search and scan of available DMSs, compiling their system or brand names and market-readiness into a tabular format;
2. Categorize technologies based on the primary method by which the systems collect data and estimate driver state;
3. Gather publicly available information on measures of driver behaviors, physical and affective states, and physiological states that are used by the reviewed systems to estimate driver state;
4. Document systems developed to detect alcohol-based driver impairment, and systems that are currently used to determine distraction, or drowsiness that may have implications for alcohol impairment detection; and
5. Draw inferences about systems' current development status and potential in the domain of driver monitoring as related to impairment.

While strengths and limitations of technologies, measures, and metrics are highlighted throughout, it was *not* a goal of this review to evaluate the efficacy of individual implementations. A total of 331 technologies were reviewed using source material from the National Highway Traffic Safety Administration's request for information responses (NHTSA, 2020), manufacturer websites, patent databases, and engineering and technology databases. Forty-four technologies were excluded for reasons such as expired patents or insufficient information available to conduct a review, leaving more than 280 technologies to be reviewed in this report. While manufacturers listed which measures, they collected, insufficient information was available about many of the systems to know exactly how they estimate driver state. If the manufacturer did not describe specific driver states, the system's measures were used to infer the intended state. Additionally, specificity of assessments made by these systems is difficult to evaluate from a listing of measures, requiring deeper investigation into how the algorithms estimate driver state. None of the systems reviewed in this report provide that level of detail. Thus, this review checks if manufacturers make any *claims* for alcohol detection. The technologies reviewed were current as of October 10, 2022.

While many of the systems and technologies outlined in this review are not designed for or currently used in passenger vehicles, they are included because they might have the potential to be applied in this way with some additional development.

In addition to this technology review, nine industry stakeholders were interviewed, and their insights were considered along with the technologies reviewed in this line of research. Finally, representatives of the Driver Alcohol Detection System for Safety Research Program were interviewed (DADSS, n.d.). The DADSS research program is a public-private partnership working to “advance the state of alcohol detection technology by developing a system that is fast, accurate, reliable and affordable — all without affecting normal driving behavior.”

The review of DMS and related technologies for alcohol impairment detection sought only to determine if the measures being used have the potential to detect alcohol impairment, rather than to make conclusive evaluations on the effectiveness or sensitivity of the measures for impairment detection. It is important to provide context around measuring alcohol and the concept of impairment. The most common measure of alcohol in the bloodstream is blood alcohol concentration. The BAC is measured as the weight of alcohol in a certain volume of blood, usually expressed in grams per deciliter (g/dL).[1] However, BAC is only one estimate of impairment and is not a direct proxy for impairment. In fact, impairment of driving-related skills can occur at low BAC levels, and the effects of alcohol vary from person to person. In the United States, 49 States and the District of Columbia consider BAC of .08 g/dL and higher in drivers as the per se standard for impairment (in Utah, the per se standard is .05 g/dL). Systems that can precisely measure BAC are useful because the measurements can be compared against per se standards and used as a basis for safety interventions, but DMS that can identify driver impairment may also have the potential to improve safety.

DMS that can reliably detect alcohol impairment are still in research and development. Consequently, these systems continue to evolve, and any findings in this report risk being inaccurate later as the technologies progress. With that caveat, key findings from the review of the known measures used in each system, the potential for the systems to detect alcohol and its effects on the driver, and the commercial availability of the systems are stated below. This review provides insight into how far along various DMS are in the research and development process. It is beyond the scope of this report to provide recommendations on which technology is likely to be most successful in practice.

The information gathered in this report should not be considered complete or exhaustive. Many systems use several approaches for collecting data that are used to estimate driver state. Publicly available information is limited, and only includes features noted in manufacturers’ websites, patents, device manuals, publications, or reports. Because of this, some systems have no detail on how driver state is inferred other than an indication that a specific method for monitoring is used. Therefore, throughout the review process, the research team inferred system capabilities based on specifications outlined by manufacturers. Some manufacturers did not specify which driver states they were attempting to assess. In these cases, researchers determined which states were being estimated based on the types of measures collected. Given that most of the

[1] Editor’s Note: The 50 U.S. States and the Territories use differing nomenclature to describe BACs, but they all equal the same thing, i.e., a BAC of .08 is the same everywhere, whether expressed as g/dL, mm, g/100 ml, g/100 cu cm, etc. NHTSA uses g/dL. Breathalyzers typically measure alcohol (BrACs) as grams of alcohol per 210 liters of breath, g/200L, but are commonly “converted” to blood concentrations measured as g/dL.

technologies described in this report are not commercially available, it was also not possible to independently evaluate the technologies or to verify claims made by manufacturers and developers.

The reviewed technologies were categorized into the following six categories.

Physiology-based systems: These use biometric measures (e.g., heart rate, respiration rate) from the driver to determine driver state. Two reviewed systems are in the research and development stages for alcohol impairment detection, with one system (breath-based vapor detection system developed by the DADSS program) projected to be available to be licensed for widespread use in the coming years.

Tissue spectroscopy-based systems: Tissue spectroscopy is an emerging method of estimating alcohol in the bloodstream. BAC is determined via a touch-based sensor measuring the absorption and emission of light from the interstitial fluid present under the dermal tissue layer (Ridder et al., 2009). One reviewed system is in the late stages of research and development and expected to be available to be licensed for widespread use in the next several years.

Camera-based systems: Certain camera-based measures such as eye closure over time, pupil diameter, saccades [rapid eye movements between points of fixation], and fixations are known to be correlated with alcohol impairment, but there is a lack of clinical and psychophysiological evidence to support the detection of driver alcohol impairment solely from camera-based measures. Three reviewed systems claimed alcohol impairment detection as the objective but the timeline for commercial availability of these systems is unknown.

Vehicle kinematics-based systems: These estimate driver state by monitoring the driver's inputs to the steering wheel, or the overall vehicle motion (speed and steering inputs), possibly including motion relative to lane position (i.e., lane stability). Vehicle kinematics-based systems are widely available for the detection of changes in the ability to drive (e.g., lane drifts due to potential distraction or drowsiness) but not yet known to be used for identifying alcohol impairment. While vehicle kinematic measures can indicate changes in driving ability, their ability to specify the cause—drowsiness, distraction, or alcohol-impairment—is limited without the use of other behavior measures.

Hybrid systems: Hybrid systems take a multi-method approach to driver state detection. Descriptions of two prototype hybrid systems (Nissan, Toyota) indicate the use of physiological measures (breath alcohol concentration and sweat) along with camera-based measures to determine impairment. The effectiveness and timeline of availability of these systems for alcohol impairment detection are unknown.

Patent-stage systems: The patent-stage systems included in this review fall into the categories outlined above. Patent information is included in its own category because it is not always clear if a patented technology has been realized in an actual system, and even if it has, patents cannot be easily linked to the systems they are implemented in. While many patents exist that relate to technologies or methods to detect alcohol in a driver, indicators of alcohol intoxication, and detection of other impairment states, the details do not support determination of the suitability or availability of the systems for detecting alcohol impairment.

Based on the reviewed publicly available information, the DADSS program's contactless zero-tolerance-directed breath sensor, which was developed in conjunction with Senseair, is the only production-ready technology within the scope of this research that can detect the presence of alcohol in a driver, as of the time that this review was conducted.

Furthermore, although there are some prototype claims about camera-based and hybrid systems being used in determining alcohol impairment, there is insufficient information available publicly to determine the veracity of these claims. Camera-based systems have been in some vehicles since model year 2018 for monitoring driver inattention to the forward roadway for SAE Level 2 driving automation systems, as well as other vehicle-based sensors such as lane monitoring, steering wheel torque monitoring, etc. However, these systems are still in the early research stages for alcohol impairment detection and are not yet available for widespread deployment.

Currently, the most well-developed and reliable approaches to determining the presence and amount of alcohol involve detection of alcohol in breath, sweat, or through the skin. For example, the DADSS program started releasing its systems' design specifications in 2021 and will continue to do so (first as a directed breath sensor for commercial fleets, then as passive licenses for widespread use in all vehicles). The DADSS technologies have the potential to provide a means of passively establishing the presence of alcohol in the driver's breath (through breath vapor measurement) or bloodstream (through tissue spectroscopy). Research is being conducted to develop technologies to determine the precise amount of alcohol in the driver's bloodstream.

The other types of systems reviewed may have various limitations as standalone methods for use in establishing alcohol impairment. Camera-based and most physiology-based DMS systems are still in the stages of preliminary research and design for alcohol impairment detection. Vehicle kinematic measures are known to be sensitive to a range of driver states (e.g., alcohol impairment, distraction, drowsiness) and unlikely to establish the specific cause of impaired driving performance without other supplementary measures.

In contrast to a single system (i.e., a standalone approach), hybrid systems may be better suited to discern between driver states due to the number of different indicators/measures considered in making determinations. The efficacy and effectiveness of hybrid systems will become clearer with the ongoing research on these measure combinations by DMS manufacturers and technology developers.

DMS for Level 2 Partial Driving Automation

Level 2 systems are driver support features that allow the vehicle to perform acceleration, braking, and lane keeping functions simultaneously, under certain conditions (e.g., within their operational design domains) (SAE International, 2021). While these systems can support the driver by performing portions of the dynamic driving task, they are not responsible for all aspects of safe driving. Importantly, the driver is still required to supervise the automation, remain attentive to the road and surrounding road users, and remain ready to intervene and resume manual control when necessary. This change in human involvement in the driving task when using a Level 2 partial driving automation system can have unintended consequences such as reduced situation awareness, driver distraction, and drowsiness. DMSs are critical in mitigating the potential negative effects of implementing Level 2 systems. This section of the report provides an overview of the current operations, abilities, and limitations of DMSs through a literature review, technology review, and interviews with subject matter experts.

The literature review summarizes previous research on driver distraction, drowsiness, and the DMS approaches to mitigate risks. Camera-, sensor-, and less commonly physiologically based systems assess driver state. While physiological metrics are robust, they are currently less practical to implement than other system types and are primarily used in research settings. Camera-based systems can be effective in capturing gaze information, but they are limited in their ability to infer cognitive attentiveness or readiness to respond. For example, a series of test track experiments found that drivers using supervised automation frequently failed to respond promptly to an emerging threat, even if they had their eyes on the road and hands on the wheel (Victor et al., 2018). That is, drivers' eyes-on-road is not synonymous with cognitive engagement. Neurophysiological bases of distraction and drowsiness during driving are also described and can offer deeper insight into key state indicators. Overall, monitoring driver state is a complex process involving several areas of the brain and has been assessed using a variety of methods, including eye gaze, head positions, steering or braking behaviors, and biological indices, such as skin conductance.

The technology review assessed six commercially available Level 2 systems and their associated DMS strategies, including hands-on-wheel and eyes-on-road monitoring to determine whether the driver was engaged in the driving task. If the systems detected engagement below a prescribed threshold, visual, haptic, and/or auditory alerts were issued.

Finally, nine interviews were conducted with researchers or representatives from original equipment manufacturers or research organizations to inquire about industry trends, design policies, and challenges associated with DMS technologies. Currently, hands-on-wheel and eyes-on-road are the most common DMS technologies implemented in vehicles with Level 2 features. Interviewees identified challenges seen in hands-on-wheel systems including distinguishing whether steer patterns reflect changes in the driver or changes in the environment. Challenges associated with eyes-on-road systems include constantly detecting the driver's face and eyes, which may be difficult in certain types of lighting or if parts of the driver's face are covered.

This page is intentionally left blank.

Introduction

This report describes two related lines of research to investigate DMS and related technologies for the detection of alcohol impairment in a driver and DMS for Level 2 partial driving automation systems. Each line of research is described in a separate section of the report.

This page is intentionally left blank.

DMS and Related Technologies for Alcohol Impairment Detection

Alcohol intoxication can lead to altered and negative behaviors, as well as physical conditions that increase the risk of unintentional injuries and fatalities, particularly when driving. Alcohol is known to impair various driving-relevant abilities such as perception, visuomotor coordination, psychomotor performance, information processing and decision-making, and attention management (Moskowitz & Burns, 1990).

BAC and Impairment

When consumed, alcohol is absorbed from the stomach and distributed by the blood stream throughout the body (Paton, 2005). The amount of alcohol in the bloodstream—BAC—is considered an objective measure used to estimate alcohol impairment. BAC is measured as the weight of alcohol in a certain volume of blood and expressed in grams per deciliter (g/dL) (NHTSA, 2016). The rise and fall of alcohol in the bloodstream (and thus, the BAC) depends on the interplay between various factors that determine the metabolization of alcohol in the person's body including frequency and amount of alcohol consumed, age, gender, body mass, consumption of other food, genetic factors, and time since alcohol consumption (Zakhari, 2006). Forty-nine States and the District of Columbia consider BACs of .08 g/dL and higher in drivers as legally impaired and a condition for arrest. (In Utah, a BAC of .05 g/dL is the legal limit). Alcohol impairment of various driving-related skills can occur at much lower concentrations, however, and intoxicated drivers can pose serious injury risks to themselves and others with any amount of alcohol in their bodies. Table 1 provides an overview of the driving-relevant impairments across different BACs.

Table 1. Effects of alcohol on driving (adapted from NHTSA, 2016, and AAC, 2021)

Blood Alcohol Concentration (g/dL)	Predictable Effects on Driving
.02	• Decline in visual functions (especially, slowed tracking of moving targets) • Decline in ability to perform two tasks at the same time (divided attention) • Decline in judgments and decision-making
.05	• Reduced visuomotor coordination • Difficulty steering • Reduced ability to manage emergency driving situations
.08	• Reduced concentration • Short-term memory loss • Reduced and erratic speed control • Reduced speed of response to objects (longer reaction times) • Reduced information-processing and decision-making
.10	• Reduced steering and speed maintenance
.15	• Substantial impairment in vehicle control, attention, visual and auditory information processing
~ .30 and greater	• Loss of consciousness, and in some cases death

While the driving skill decrements in Table 1 provide a means of approximating the impairment against BAC levels, the BAC is a measure of the amount of alcohol in the bloodstream rather than a reliable indicator of the degree of impairment (e.g., Fillmore & Vogel-Sprott, 1998; Nicholson et al., 1992). At least two factors contribute to the lack of consistent person-to-person relationship between BAC and impairment. Regular drinkers may learn strategies for more cautious driving to compensate for their perceived skill decrements (Burian et al., 2003; Vogel-Sprott, 1997). There is also empirical evidence that some regular drinkers develop a higher tolerance to alcohol that results in less apparent declines in cognitive and motor performance after consuming low to moderate doses (Vogel-Sprott, 1997). Thus, BAC provides a measure of probable impairment (e.g., Table 1) with some person-to-person symptom variability. Table 1 should be used as a reference point for making population-level decisions and judgments but not necessarily on an individual basis. The outlined effects may apply to certain people but for the reasons discussed above, should not be applied to every person. It should also be noted that while some effects are listed at several BACs (e.g., difficulty steering), the effects are more likely to occur and more severe at higher BACs.

The objective of this review is to document the measures used in DMS, assess the state of knowledge for each system, and determine how effective they may be in reliably indicating alcohol impairment.

Review and Assessment of Technologies

A total of 331 technologies were reviewed and more than 280 are included in this report. Details on each technology were collected from various sources, including NHTSA's Request for Information responses (NHTSA, 2020). A response from the Mothers Against Drunk Driving organization included a report that "details 241 examples of technology that NHTSA should consider as part of a rulemaking to prevent impaired driving" (MADD, 2021). Other sources of information for this review included manufacturer websites, patent databases, and engineering and technology databases. Only publicly available material was used to determine information about each system. There are ongoing improvements to DMS sensor technologies, and the field continues to evolve. It is expected that new technologies and state estimation methods will continually emerge. The technologies, their sensing methods and measures used, and availability status in this report were current as of October 2022.

Interviews with nine industry stakeholders (eight OEMs and one non-OEM, nonprofit scientific and educational organization) were conducted, and the key considerations for DMS, as stated by the stakeholders, were incorporated into the findings in this report. Feedback from the eight OEMs added context to this report and was aligned with information gathered from the literature and technology review. In addition to reviewing available source material, interviews were conducted with representatives of the DADSS program, a cooperative agreement between NHTSA and the Automotive Coalition for Traffic Safety. Findings from the DADSS program were incorporated because the program is in the final stages of development for two independent technologies that detect the presence of alcohol: (1) a breath-based alcohol detection system, and (2) a touch-based tissue spectroscopy system. The DADSS program aims to develop these technologies as passive detectors of alcohol intoxication. In 2021 the DADSS program released its first reference design for a zero-tolerance, directed-breath sensor developed for commercial vehicles and accessory sales. Commercial fleet systems will identify only the presence of alcohol, without specifying precise BACs. The fleet-directed breath-based system (released in

2021) requires the driver to provide a direct breath sample (like blowing out a candle) at the beginning of the drive. Passive breath and touch sensor applications that can precisely and accurately measure BrAC or BAC in a driver are in development and are expected to become available for commercial fleet and passenger vehicle licensure in the next few years. The technologies are described in the physiology-based system section (breath-based technology) and the tissue spectroscopy-based system section (touch-based technology).

Once licensed for widespread use, the goal of the breath-based system is to detect alcohol passively from in-cabin vapors and not require any directed breath samples.

The DADSS breath and touch technologies available for widespread deployment are smaller than the commercial fleet-based versions. The smaller size will make the devices easier to integrate into an in-vehicle cabin environment. In addition, these devices are being developed to specify precise BACs, rather than just indicate the presence of alcohol in the cabin. The DADSS devices for widespread deployment are currently under active testing and validation.

Categorization of DMS Technologies

The reviewed DMS technologies were classified into five primary methods by which each system was reported to estimate driver state. A sixth category was added to include patents that have been filed for DMS technologies.

1. ***Physiology-based systems***: The primary means of estimating driver state is by using sensors that measure biometric signals from the driver's body such as heart rate, BrAC, blood pressure, and presence of alcohol in sweat. Measurement of alcohol presence in directed-breath/vapor can provide a surrogate for BAC (Jones & Andersson, 2003).
2. ***Tissue spectroscopy-based systems***: The primary means of estimating alcohol presence in the bloodstream is by shining infrared light into the driver's skin and measuring the wavelengths of the reflected light. The alcohol concentration is determined from the interstitial fluid present under the dermal tissue layer (Ridder et al., 2009; Tuchin, 2008).
3. ***Camera-based systems***: The primary means of estimating driver state is using in-cabin cameras that can monitor one or more of the following features—the driver's face, eyes, hands, feet, and posture. Camera-based systems are widely used to determine driver gaze direction and infer driver inattention.
4. ***Vehicle kinematics-based systems***: The primary means of estimating driver state is by monitoring the driver's inputs to the steering wheel, or the overall vehicle motion (speed and steering inputs).
5. ***Hybrid systems***: The primary means of estimating driver state is by using cameras along with one or more physiological or vehicle kinematic sensors.
6. ***Patents***: This category lists patents filed on methods and technologies relevant to driver monitoring systems. This category was added to broaden the search and to uncover, to the extent possible, promising new technologies that have not entered the publicly available pipeline of development literature. In addition, many of these patents are likely associated with systems that were reviewed in the previous five categories because systems evolve as they near production and may not be clearly linked with a particular patent (based purely on the patent description). The research team did not want to make assumptions

about which patents map to which systems, so patent information is included in its own category.

Upcoming sections of this report list systems under each of the six categories, the measures used to estimate driver state in each system, and any claims made by the manufacturers of the systems of detecting alcohol in the bloodstream or alcohol impairment. Tables are used to document this information in an easily digestible format. Some systems discussed throughout the report are referred to by names given by the manufacturer while others are listed by the name of their manufacturer.

The information on features used to determine driver state **should not be considered a complete or exhaustive list**. Many systems use measures that, in combination, estimate driver state. However, the detail available in public descriptions is sparse. Thus, the tables only list features that were documented on the manufacturers' websites, patents, device manuals, publications, or reports. To this end, a few systems have no detail on what specific features are used to determine driver state other than the indication that a primary method for monitoring is used. Other systems, while not currently being used for driver impairment detection, are included in the report as they theoretically could be used for this purpose based on system descriptions.

Each system's intended driver state detection was recorded in the tables. It should be noted that information across several columns in these tables has sometimes been grouped for ease of presentation. Driver states include various undesirable conditions such as distraction, drowsiness, fatigue, and alcohol consumption/impairment. Delineating the intended state detection for each system is important when considering the system in the context of alcohol impairment. For example, most of the reviewed systems are not designed to directly detect alcohol in the driver. However, they may still be relevant if the measures they use overlap or correlate with indicators of alcohol impairment. In cases where manufacturers made claims that their systems could detect alcohol consumption and/or impairment, this was recorded. The process began by identifying the explicit states noted in the manufacturer's descriptions of the system. These explicit states were then assessed by the research team based on the measures that the system used. For example, if the system measured long eyelid closures, this was more likely to indicate drowsiness than distraction. If the manufacturer did not describe specific driver states, the system's measures were used to infer the intended state.

Similarly, the availability of the system — *available, likely available*, *unclear*, *prototype*, or *patent stage*—was retrieved from reviews of sources including the manufacturer websites, a web search for vehicle manufacturers that use a given DMS, manuals, web-based promotional material and news, and reviews of the NHTSA RFI material. The five stages of availability were defined during the review.

1. ***Available:*** There is sufficient evidence (based on reviews of manufacturer websites, web searches, manuals, web-based promotional material, and news articles) to conclude that the system is available in the market.
2. ***Likely Available:*** The system is assumed to be available in the market, but information is sparse or vague.
3. ***Unclear:*** The system appears to be past the prototype stage, but there is no available information to confirm production.

4. ***Prototype:*** Information on the system confirms that it is in the testing stage and not ready for production.
5. ***Patents:*** The only information available about the system is a filed patent. Patents that were filed and granted or active are included in the review.

The determination of availability is based on the current or last known state of development (as of October 10, 2022); however, this information is expected to become outdated as sensor and computational technologies advance.

Evaluation of DMS for Use in Detection of Alcohol Effects in a Person

While all systems included in the review are listed in tables, a subset is also discussed in the body of the text. Systems were discussed in greater detail if they were specifically intended for driver alcohol impairment detection or potentially effective in this domain according to relevant literature or expert review. The review distinguishes between systems that can directly estimate driver BAC from systems that can detect driver impairment (or effects of alcohol on behaviors and physical movements). Two factors are key in evaluating the applicability of the reviewed systems to alcohol impairment.

1. ***Sensitivity****:* Sensitivity denotes the ability of the method/DMS to determine that alcohol is present in the driver's bloodstream and/or that the driver's behaviors and physical condition are impaired due to alcohol (i.e., the system correctly identifies driver state).
2. ***Specificity****:* Specificity denotes the ability of the system to differentiate alcohol-impairment from other conditions such as drowsiness, fatigue, and inattention. Specificity in a DMS means that the system correctly attributes a driver as not impaired by alcohol (and has a different state) when the driver is not impaired.

Sensitivity of the DMS System to Alcohol

The presence of alcohol in blood depends on factors, including the frequency of alcohol use, alcohol dose ingested, time since consumption, age and gender, ethnicity and genetics, and other metabolic and pharmacokinetic factors (e.g., Oscar-Berman & Marinković, 2007). A few systems can estimate presence and quantity of alcohol in the bloodstream (e.g., breath-based systems, tissue spectroscopy), and these are considered sensitive detection methods in this review.

Specificity of the DMS to Alcohol

Specificity is a challenge. Often, behavioral indicators of alcohol impairment are also potential indicators of other conditions. For example, percentage of eyelid closure can indicate both drowsiness and alcohol impairment, but these conditions may need to be addressed differently. Drowsy drivers can quickly recover with adequate rest as an intervention, but drunk drivers may need a much longer recovery time due to the sedative effects of intoxication (e.g., Hancock, 2013). Specificity is difficult to evaluate from a listing of measures and requires deeper investigation into how the algorithms estimate driver state. None of the systems reviewed in this report provide that level of detail. Thus, this review checks if manufacturers make any *claims* for alcohol detection.

Physiology-Based Systems

Physiology-based systems use biometric measures to assess driver state. Some of these system sensors can be integrated into steering wheels, seat belts, or the driver seat itself. Many physiological measures may be impractical or intrusive to collect or require a baseline for implementation. It should be noted that while physiological indicators may be able to detect the presence of alcohol, they are imperfect predictors of alcohol impairment. Some people may exhibit the effects of alcohol (see Table 1) at lower levels of intoxication than others.

Physiology-Based Alcohol Impairment Indicators

Physiology-based systems can provide bodily measures of the driver, including heart rate, blood pressure, and brain activity. These measures can then be used to evaluate the state of the driver.

Breath Alcohol Concentration: The most used measure to determine sobriety, both in roadside tests and in ignition interlocks, is BrAC. BAC is determined using a conversion factor from the BrAC reading. Devices that determine BrAC typically use electrochemical methods.

Sweat/Perspiration: Monitoring of sweat/perspiration has long been considered an effective method to determine BAC (Hawthorne & Wojcik, 2006). Various non-invasive methods have been developed to determine the presence of ethanol/alcohol in sweat, as well as approximations of the magnitude of BAC (e.g., Hawthorne & Wojcik, 2006; Lawson et al., 2019).

Heart Rate, Heart Rate Variability, and Blood Pressure: Alcohol consumption temporarily leads to increases in heart rate. Heart rate variability is an indicator of acute alcohol intoxication and can be estimated by systems that measure heart rate (Romanowicz et al., 2011).

Alcohol consumption also leads to temporary increases in blood pressure. In addition, a multinational study reported that blood pressures of heavy, chronic drinkers were significantly higher than non-drinkers (Marmot et al., 1994). This effect was found in both males and females.

Heart rate variability and blood pressure may indicate the presence of alcohol in blood; however, both measures are correlated with other health and arousal conditions such as stress, exertion, and workload or chronic health conditions such as vascular issues. Each of these measures, or their combination, are thus not specific measures of BAC. Note that recent technological developments have also made it possible to detect these measures using camera-based technology. The use of cameras to detect measures related to vital signs is addressed separately in the camera-based Systems section.

Other factors: Factors, such as speech (acoustic-phonetic properties, e.g., Klingholz et al., 1988; Pisoni & Martin, 1989; Schiel & Heinrich, 2009), brain activity, skin conductance, and body temperature are promising but not fully established as robust indicators of alcohol consumption. The effects of alcohol on respiratory rate have been found to be generally irregular, and the measure does not show much promise in determining alcohol impairment.

System Capabilities and Availability

Table 2 lists primarily physiology-based systems. Many of the reviewed systems claim intention to measure general health and drowsiness using a variety of physiological sensors. The key physiological measures used in systems designed to directly detect alcohol in a person are BrAC and sweat/perspiration. BrAC is a robust measure of BAC (Jones & Andersson, 2003). Table 2 only lists features that were indicated on the manufacturers' websites, patents, device manuals, publications, or reports. To this end, some systems may have no detail on what features are used to determine driver state other than that a specific method for monitoring is used. Some systems listed in Table 2 and throughout the report may have no detail on which features are used to determine driver state beyond the primary monitoring method. For this reason, some systems are described as "unclear" across columns. These systems were included with the goal of providing complete and comprehensive information with the resources available.

Availability of the system in Table 2 was determined using the guidelines.

Table 2. Physiology-based systems[2]

System	System Availability	Intended Detection[3]	Heart Rate	Blood Pressure	Brain Activity	BrAC/ Vapor	Respiratory Rate	Skin Conductance	Sweat
Adient Seat Monitor	Prototype	General health, drowsiness	X				X		
CardioID	Prototype	General health, drowsiness	X						
CORE for Tech	Unclear	Drowsiness	X						
Faurecia Alcohol Air Sensors	Unclear	Alcohol impairment	X	X		X	X	X	
Gentex In-Cabin Sensing	Prototype	Alcohol impairment				X			
AlcoStop/Cintalapa Technology Institute & Hyundai	Prototype	Alcohol impairment							X
Hyundai Mobis M.Brain	Prototype	Inattention			X				
Impirica Inc	Available	Unclear			X				
Jaguar Land Rover Sixth Sense Project	Unclear	Inattention, drowsiness	X		X		X		
Lear Driver Monitoring	Prototype	Inattention, drowsiness	X				X		
Magneti Marelli Vital Signs Monitor	Likely available	General health, drowsiness	X				X		
Olythe Breathalyzer	Available	Alcohol impairment				X			
Plessey Semiconductors	Prototype	General health, drowsiness	X						

[2] Rows with no markers for any variables indicate systems that did not present information on the specific variables and features that are used to determine driver state. The highlighted rows represent systems that can detect alcohol in the driver (according to the manufacturer's claim).
.

System	System Availability	Intended Detection[3]	Heart Rate	Blood Pressure	Brain Activity	BrAC/ Vapor	Respiratory Rate	Skin Conductance	Sweat
Senseair (DADSS Breath Sensor)	Prototype	Alcohol impairment				X			
Somno Alert Drowsiness Detection	Prototype	Drowsiness					X		
Sumitomo Riko Driver Monitoring	Prototype	General health	X				X		
Toyota Heart Based Monitor	Prototype	General health, drowsiness	X						
TS Tech Monitoring System	Prototype	Drowsiness					X		
Xander Kardian	Available	General health, drowsiness	X				X		

Summary of Physiology-Based Systems

Technologies that purport to measure BrAC are currently furthest along in development and have demonstrated efficacy in measuring the amount of alcohol in a person's system. Olythe breathalyzers, for example, can be used by law enforcement or by individual drivers to measure their own BrACs. The status of two other systems—Faurecia and Gentex—is unclear.

A prototype sweat-based system jointly developed by the Cintalapa Technology Institute (Mexico) and Hyundai, AlcoStop, measures sweat through sensors integrated into the steering wheel. Sweat is considered a promising measure of BAC in lab-based settings; however, the primary use case challenge is the long measurement time needed to establish intoxication, and a requirement that drivers not wear gloves. The appearance of alcohol in sweat can take as long as 90 minutes after initial consumption.

The DADSS program developed a prototype directed breath-based alcohol detection system that detects the presence of alcohol but does not estimate BrAC (Senseair in Table 2). A passive breath-based system that can precisely and accurately measure BrAC is in development and is expected to be available for use in commercial fleets and passenger vehicles within the next few years.

In going from directed breath samples to passive samples (i.e., ambient sensing from cabin vapor/air), the key challenges to implementation are in isolating the breath of the person in the driver's seat, isolating vapors from other diluting factors such as HVAC systems and open windows and conducting periodic measurements of the cabin air rather than only at ignition of the vehicle. The DADSS program is currently testing and validating the performance of its breath-based sensor against these factors. Although some systems are marked as "Available" in Table 2, they are not discussed in the text. These technologies are not currently used in driving-specific domains or are not intended to detect alcohol impairment.

Tissue Spectroscopy-Based Systems

Tissue spectroscopic methods work by measuring alcohol concentration from skin tissue using sensors that typically function by near-infrared spectroscopy. The sensor shines an infrared light into the person's skin (usually fingertip/finger surface) and measures the returned wavelengths of light reflected from the tissues to the skin surface. The alcohol concentration is determined from the interstitial fluid present under the dermal tissue layer (Ridder et al., 2009).

System Capabilities and Availability

Two systems were reviewed (Table 3), each of which is at a different stage of the development process. The TruTouch 2500 is a tabletop instrument designed to be used in the workplace. While this model is designed to detect alcohol, it is not designed to be built into vehicles. The DADSS program is also currently in the testing and validation phase to develop a touch-based system designed for automotive applications.

The availability of the systems in Table 3 was determined using the guidelines above.

Table 3. Tissue spectroscopy-based systems[4]

System	System Availability	Intended Detection	Infrared-Based	Contact-Based/Touch-Based
TruTouch 2500	Available	Alcohol impairment	X	X
DADSS Touch Sensor	Prototype	Alcohol impairment	X	X

Summary of Tissue Spectroscopy-Based System

Tissue spectroscopy is considered a reliable albeit currently expensive method to determine the presence of alcohol in blood. Known challenges with this technique are the fashioning of the sensor and detection system into a size and form easily integrable in the vehicle cabin, which is currently expensive. Tissue spectroscopy will also require drivers wearing gloves to remove a glove to provide a reading.

The DADSS program has advanced this technology to the point that the design specifications of the touch-based system for implementation in commercial fleet vehicles and licensure for use in passenger vehicles at even further reduced size and form factors is expected within the next few years. The DADSS program has additional plans to reduce the sampling and measurement times.

Camera-Based Systems

Camera-based DMS typically feature one or more interior, inward-facing cameras that monitor the driver in real-time. Commonly, camera-based systems measure movement of the driver's eyes, eyelids, neck, and/or head. A few systems also include measures of pupil and facial features (e.g., pupil diameters, facial muscular movements, drooping eyebrows and lips, and composite expression recognition and emotion estimation). Camera-based measurement of body posture, and hand and foot placement and movement, are also used to determine driver state in some DMS.

Camera-based systems are very common, and most of the reviewed DMS use camera-based monitoring as one of the methods to determine driver state. Other methods, such as hand position, are also often used to assess driver state. Distracted drivers may occasionally take their hands off the steering wheel to perform other tasks. Drowsy or alcohol-impaired drivers may take their hands off the wheel for long periods or have a lower or looser grip on the wheel, due to relaxation of muscles with increasing drowsiness or intoxication (Lee et al., 2016).

Camera-Based Alcohol Impairment Indicators

Eye movement patterns, eye-body coordination and motor reaction times, eye closure, and blinking activity are known indicators of alcohol impairment. Note that the associations of these measures with impairment have been primarily determined from lab-based studies in both driving-relevant and non-driving settings. Alcohol's effects on these measures are detectable at BACs of .08 (Silva et al., 2017) and lower (Moser et al., 1998). While the measures described here may be indicators of alcohol impairment, it is important to note that they have not been

[4] The highlighted rows represent systems that can detect alcohol in the driver (according to the manufacturer's claim).

implemented in DMS to detect alcohol impairment knowledge, nor have their sensitivity and specificity been demonstrated in actual driving conditions. Therefore, the feasibility of camera-based systems for alcohol impairment detection, particularly in the absence of supplementary measures, has not been demonstrated to date.

Eye movement: Various characteristics of eye gaze are associated with alcohol-based driver impairment; however, research is still needed to ensure that these measures are reliable and generalizable across different persons and dosing characteristics. Saccades and fixations of the eye gaze are two fundamental eye behaviors used in advanced camera-based systems to determine driver state. Saccades are rapid movements of the eyes between points of fixation; fixations are durations when the eye gaze is focused or "rests" on a target.

Alcohol intoxication can lead to instability in eye movements that provides a potential measure that can be used in driver state estimation algorithms to indicate alcohol impairment. With the consumption of alcohol, there can be a lag between the speed of the driver's eye movements and associated body movements, and a decreased ability for smooth orientation of eye gaze towards a target object (Maurage et al., 2020). Such slow, smooth pursuit glances are followed by jerky "catch-up" saccades as the brain tries to compensate for the lag. Alcohol can also contribute to horizontal gaze nystagmus (HGN), which is widely used in Standardized Field Sobriety Tests to detect the potential of intoxication. Typical tests for HGN associated with the presence of alcohol in blood involve visual object tracking with glances up to 45° from head center. Glances of such high eccentricity, however, rarely occur naturally in driving.

Attentional bias toward preferred tasks and cues increases with acute intoxication (Maurage et al., 2020). This bias is characterized by increases in gaze fixation times and the effect lasts a few hours after peak BAC. Alcohol intoxication leads to latency and velocity increases in first saccades toward a visual target.

Pupil function: Pupil size and pupillary light reflex can be used to identify alcohol impairment. Amodio and colleagues (2018) demonstrated a method to detect alcohol impairment in drivers by recording pupillary light reflex in response to controlled light stimuli prior to participants consuming alcohol and after they consumed alcohol (dosed BrAC readings varied by participants, but all participants were above .05). The baseline pupil video was compared to the dosed video for each driver. This method correctly identified whether participants had consumed alcohol with an overall misclassification rate below 10 percent.

Eye-body coordination: As eye scanning movements central to driving performance, such as lane keeping, start to deteriorate with increasing BAC, the associated visuospatial performance also gets impaired. This decrement is known to occur at BACs as low as .03. Specifically, eye-hand coordination timing as well as the degree of association between eye positions on the forward scene and intended steering are compromised (Marple-Horvat et al., 2008). Acute intoxication leads to decreased motor skills and motor coordination, as well as premature motor preparation responses (Marinkovic et al., 2000).

Blinks and eye closure: The duration of blinks increases with alcohol intoxication as compared to sober drivers (Beideman & Stern, 1977). In addition, slow closures of the eyelid also indicate alcohol impairment (Jackson et al., 2016) and can be exacerbated at high doses. Note that blinking activity and slow eye closures are also significant indicators of drowsiness and fatigue.

Vital sign monitoring: Emerging camera-based technologies have demonstrated the capability to detect biological indicators related to alcohol intoxication such as heart rate and respiration rate (Guo et al., 2022), and vasoconstriction and vasodilation (e.g., Harford et al., 2022) without the need for additional contact sensors.

Other indicators: Other indicators that may be tracked by camera-based DMS include facial muscle relaxation, neck/head orientation, posture, hand/foot movements, emotions, and gestures. There is weak evidence on the effectiveness of these measures in discerning the effects of alcohol. Indications of body and posture sag and pupil dilation in indicating alcohol impairment have been explored with some corroborating evidence (e.g., Arora et al., 2012; Campbell et al., 2001; Castro et al., 2014).

System Capabilities and Availability

Table 4 lists camera-based systems. The specified key features monitored by cameras in each system include eye and eyelid movement, pupil diameter, neck and/or head orientation, posture, hand/foot placement and/or movement, and composite measures of facial features. Note that this table only lists features that were explicitly mentioned or indicated on the manufacturers' websites, patents, device manuals, publications, or reports. To this end, some systems may have no detail on what features are used to determine state other than the indication that a specific method for monitoring is used.

Availability of the systems in Table 4 was determined using the guidelines above.

Table 4. Camera-based systems[5]

System	System Availability	Intended Detection	Eye/ Gaze	Eyelid/ Eye Closure	Pupil Measure	Neck/ Head	Posture	Hand/ Foot	Facial/ Emotion
Abto Software	Prototype	Drowsiness		X		X			X
ADAM	Prototype	Inattention, alcohol impairment	X	X		X	X		
Aisin Seiki Face-Based Driver Monitoring	Unclear	Inattention, drowsiness	X	X		X			
Ambarella	Likely available	Inattention, drowsiness	X	X		X			X
AMS	Unclear	Inattention, drowsiness	X	X		X			
Aptiv Driver State Sensing	Prototype	Inattention, drowsiness	X			X			
Autoliv/Seeing Machines Driver Monitoring System	Available	Inattention, drowsiness	X			X			
Baidu Apollo	Available	Drowsiness							X
BharatBenz Driver State Monitoring System	Likely available	Inattention, drowsiness	X	X		X			X
BMW Driver Attention Monitor	Available	Inattention		X		X			
Cadillac Super Cruise	Available	Inattention	X			X			
Cadillac Ultra Cruise	Available		X			X			

[5] Rows with no markers for any variables indicate systems that did not present information on the specific variables and features that are used to determine driver state. Highlighted rows represent systems that can detect alcohol in the driver (according to the manufacturer's claim).

System	System Availability	Intended Detection	Eye/ Gaze	Eyelid/ Eye Closure	Pupil Measure	Neck/ Head	Posture	Hand/ Foot	Facial/ Emotion
Caterpillar Inc./Seeing Machines Driver Safety System & Guardian 2	Available	Inattention, drowsiness	X	X		X			
Cipia	Available	Inattention, drowsiness	X	X		X			
Delphi/BorgWarner Eye Driver Monitoring System	Unclear	Inattention, drowsiness	X						
DENSO Driver Status Monitor	Available	Inattention, drowsiness	X				X		X
Dot Netix NEXUS	Available	Inattention, drowsiness				X			X
DS Automobiles Driver Attention Monitor	Available	Inattention, drowsiness	X	X					
DTS AutoSense	Unclear	Inattention, drowsiness							
Edge3 Drive	Unclear	Inattention, drowsiness	X						
Eyegaze Inc	Prototype	Communication for disabled people	X	X					
Ford Bluecruise	Available	Inattention	X						
GazeSense	Available	Inattention, drowsiness	X	X		X			
Genesis Forward Attention Warning	Available	Inattention, drowsiness	X			X			
Gentex Biometrics System	Unclear	Unlocking vehicle							
Grupo Antolin Driver Monitoring	Prototype	Inattention, drowsiness	X	X	X	X			
Hikvision	Available	Inattention, drowsiness							

System	System Availability	Intended Detection	Eye/ Gaze	Eyelid/ Eye Closure	Pupil Measure	Neck/ Head	Posture	Hand/ Foot	Facial/ Emotion
Honda Sensing Elite Safety System	Available	Unclear							
Hyundai Mobis Driver State Warning	Prototype	Inattention, drowsiness	X		X				X
Jabil Driver Monitoring	Available	Inattention							
Jaguar Land Rover Driver Monitoring System	Unclear	Inattention, drowsiness	X			X			
Joyson Safety Driver Monitoring	Available	Inattention, drowsiness	X			X			
Jungo Connectivity VuDrive	Prototype	Inattention, drowsiness	X	X					
Jungo Connectivity CoDriver	Prototype	Inattention, drowsiness	X	X		X			
Lexus Driver Attention Monitor	Available	Inattention, drowsiness	X	X					
Lexus Driver Monitor Assist	Available	Inattention, drowsiness	X			X			
LG Electronics Driver State Monitoring Engine	Unclear	Inattention, drowsiness, unlocking vehicle	X	X		X			X
Lumeway EyeAlert Driver Fatigue Monitor	Available	Inattention, drowsiness	X	X					
Magna Driver Monitoring	Unclear	Inattention, drowsiness	X						
Meitrack	Available	Inattention, drowsiness		X		X			X

System	System Availability	Intended Detection	Eye/ Gaze	Eyelid/ Eye Closure	Pupil Measure	Neck/ Head	Posture	Hand/ Foot	Facial/ Emotion
Melexis	Available	Inattention	X	X		X		X	
Mitsubishi Electric Inca Jay Driver Monitoring	Available	Inattention, driver comfort	X			X			X
Nauto Inc	Available	Inattention, drowsiness	X	X		X			X
Netradyne Inc	Available	Inattention, drowsiness							
Nissan Pro-Pilot 2.0	Available	Inattention	X			X			
Nuance Communications/ Affectiva	Likely available	Emotion, drowsiness	X			X			X
NVIDIA	Available	Inattention, drowsiness	X	X		X			X
NXP	Available	Inattention, drowsiness	X	X		X			
Omnitracs LLC SmartDrive	Likely available	Risky driving, inattention, drowsiness	X			X			
Omnivision OV9284, OV2312	Likely available	Inattention, drowsiness	X	X					
Omron Corp. Driver Statius Estimation System	Prototype	Inattention, drowsiness	X	X		X			X
Optalert	Available	Inattention, drowsiness	X	X					
Osram OS	Unclear	Unlocking vehicle, inattention, drowsiness	X	X		X			
Paccar	Unclear	Inattention, drowsiness	X	X					
Panasonic Driver Monitoring System	Prototype	Drowsiness	X	X		X			X
PrevictDrugs	Available	Alcohol impairment, drug impairment			X				

System	System Availability	Intended Detection	Eye/ Gaze	Eyelid/ Eye Closure	Pupil Measure	Neck/ Head	Posture	Hand/ Foot	Facial/ Emotion
Primax	Available	Inattention, drowsiness	X	X	X	X			
RoboGaze	Unclear	Inattention, drowsiness	X	X		X	X		
SafeCams SC200 AI, SCDS02, and SC400	Likely available	Inattention, drowsiness	X	X				X	X
Seat	Available	Inattention, drowsiness	X			X			
Seeing Machines	Available	Inattention, drowsiness	X	X		X			X
Senseye, Inc.	Unclear		X	X	X				
SenseTime	Available	Inattention, drowsiness							
Sighthound	Available	Inattention, drowsiness	X	X		X			X
Smart Eye	Available	Inattention, drowsiness	X	X		X			X
Sony Depthsensing Solutions	Available	General health, inattention, drowsiness	X	X		X	X	X	
Sony Driver Monitoring	Unclear	Inattention, drowsiness					X		X
Speedir Driver Fatigue Monitoring System	Available	Drowsiness	X			X			
SRI	Unclear	Drowsiness	X				X		X
ST Microelectronics	Prototype	Drowsiness	X			X	X		
Stonkam	Available	Inattention, drowsiness	X	X					
Subaru Driver Focus	Available	Inattention, drowsiness	X			X			
Tata Elxsi	Unclear	Inattention, drowsiness	X			X			X
Tesla Driver Monitoring System	Available	Inattention, drowsiness	X			X			

System	System Availability	Intended Detection	Eye/ Gaze	Eyelid/ Eye Closure	Pupil Measure	Neck/ Head	Posture	Hand/ Foot	Facial/ Emotion
Tobii DMS	Prototype	Inattention, drowsiness, unlocking vehicle, risky driving	X	X		X			
Toyota Boshoku Drowsiness Suppression Seat System	Available	Drowsiness							X
Toyota Driver Monitoring System	Available	Inattention, drowsiness	X			X			
Toyoda Gosei Driver Monitoring	Likely available	Inattention, drowsiness		X					
Trimble Video Intelligence	Available	Inattention, drowsiness							
Valeo Driver Monitoring	Unclear	Inattention, drowsiness	X						X
Veoneer	Available	Inattention, drowsiness	X	X		X			
VinAI	Likely available	Inattention, drowsiness, alcohol impairment	X			X			
Visteon Driver Monitoring	Unclear	Inattention, drowsiness	X			X			
Volvo In-Car Cameras	Unclear	Inattention, alcohol impairment	X					X	
VT Solution	Available	Inattention, drowsiness							
Wipro	Available	Inattention	X			X			
Xilinx Automotive XA Zynq-7000 and Zynq UltraScale+™ MPSoC	Likely available	Inattention, emotion	X	X	X	X			X

System	System Availability	Intended Detection	Eye/ Gaze	Eyelid/ Eye Closure	Pupil Measure	Neck/ Head	Posture	Hand/ Foot	Facial/ Emotion
Xperi	Available	Inattention, drowsiness	X	X		X			X
Yanfeng Driver Monitoring	Unclear	Drowsiness							X
ZF Friedrichshafen driver monitoring	Unclear	Inattention	X			X			

Summary of Camera-Based Systems

Of the camera-based systems reviewed, only three claim to be developed for detecting alcohol impairment—ADAM, PrevictDrugs, and the Volvo camera-based system. ADAM and PrevictDrugs, however, are not designed for in-vehicle use. All are currently considered to be in prototype stages (though a website update from 2019 for PrevictDrugs mentions that commercialization is ongoing with no more detail).

ADAM monitors various measures including eye movement, eyelid closure, head position/orientation, and posture, to make determinations of intoxication; the exact mechanism by which the system determines sobriety versus intoxication is not clear from available material.

PrevictDrugs primarily uses pupil function measures. According to the system description, drivers will be asked to record 10-second videos of their eyes and pupil function measures, and these videos will be used to determine sobriety. The web material for the system only mention "eye biomarkers" as measures used in the determination of driver state and no further details are provided.

The Volvo camera-based system was initially advertised as having the potential to monitor distraction and intoxication using signals that include eye gaze and hand and foot movements. However, the known in-car implementation of this system has been updated since the initial release of news articles. This updated implementation only claims the measurement of distraction and broadly, inattention.

Overall, most camera-based systems reviewed in this report use measures of eye movements, eyelid closure, and head orientation to determine distraction. From lab-based research, it is expected that certain camera-based measures have the potential to indicate impairment, particularly when their temporal patterns are used in state estimation (e.g., saccade and anti-saccade patterns over a period). However, there is a lack of clinical research that establishes how camera-based vision and physical measures signal various levels of intoxication, and how specific these measures are to alcohol impairment versus other driver states.

Vehicle Kinematics-Based Systems

Vehicle kinematics denote the measures of vehicle motion. These include the time-continuous measures of velocity, acceleration, and deceleration. In this review, this category of measures is also considered to include steering inputs and the resultant lane positioning.

Particularly in instances where the driver is performing manual control of the vehicle (i.e., no driving automation system is engaged in vehicle control), measures of vehicle motion give valuable indication of the drivers' vehicle control skill and capacity. Among the many requirements of the driving task, maintaining both lane position and speed requires a certain level of precision. Poor precision as indicated by deviations from intended states (e.g., unintended lane excursions or speeding) might indicate unsuitable driver states, including alcohol impairment.

Vehicle Kinematics-Based Alcohol Impairment Indicators

Alcohol is known to have detrimental effects on drivers' ability to perform smooth and safe vehicle control actions. Alcohol effects on vehicle control have been determined primarily from driving-simulator based studies, by studying driver control performance against varying doses of alcohol (Helland et al., 2013).

It should be noted that speed and lane position control measures are very sensitive to various driver states, including drowsiness, visual distraction, cognitive distraction, stress, and other emotional and health conditions. There is no evidence of these measures being unique to alcohol impairment (i.e., able to distinguish alcohol impairment from other states).

Speed: Speed maintenance is generally affected by increasing BAC. Research has found that BAC greater than .05 can significantly impair an individual's ability to maintain appropriate speed, particularly in complex environments (Veldstra et al., 2012; Mets et al., 2011). While some studies report increased speeds by alcohol-impaired drivers, others reported speed decreases (Rezaee-Zavareh et al., 2017; Lee et al., 2010; West et al., 1993; Irwin et al., 2017; Lenne et al., 2010). The reduced ability to maintain consistent speed is referred to as the standard deviation of speed deviation, which is commonly used to measure relative performance of impaired drivers compared to control groups. While findings concerning speed directionality (i.e., increase or decrease) are mixed, studies have consistently shown that speed deviation from posted speed limits tends to increase in alcohol-impaired driver groups (Arnedt et al., 2001; Yadav & Velaga, 2020; Irwin et al., 2017).

Lane Position and Steering Input: Alcohol reduces driving precision, and lane positioning is a key skill that is affected (even at low doses). Deviation of lane position from the lane center increases with increasing doses of alcohol (e.g., Harrison & Fillmore, 2005; Lee et al., 2010; Calhoun & Pearlson, 2012; Irwin et al., 2017). The standard deviation of lateral position is considered a sensitive (but not specific) measure of alcohol impairment (Irwin et al., 2017). Relatedly, measures of steering inputs may correlate with alcohol impairment (Das et al., 2012). Specifically, drivers who are impaired due to alcohol may exhibit more erratic driving patterns with tendencies to deviate from their lane position (Kersloot et al., 2003).

System Capabilities and Availability

Table 5 lists the key features used by various vehicle kinematics-based DMS to determine driver state. Intended detection and system availability are based on currently available information. This table only lists features that were mentioned or indicated on the manufacturers' websites, patents, device manuals, publications, or reports. To this end, complete information regarding what features a given system may use to determine driver state was not feasibly obtainable. Note that while many vehicles and systems detect the variables included in the table, the table only shows an X for systems where that variable is explicitly used to determine driver state.

The availability of each system in Table 5 was determined using the guidelines above.

Table 5. Vehicle kinematics-based systems[6]

System	System Availability	Intended Detection	Speed	Acceleration	Brake Activity	Lane Position	Steering Input
Acura Lane Keeping Assist System (LKAS)	Available	Unintentional lane drift				X	
Acura Driver Awareness Monitor	Unclear	Inattention					X
Alfa Romeo Driver Attention Assist	Available	Drowsiness				X	
Alfa Romeo Lane Keeping Assist	Available	Unintentional lane drift				X	
Audi Attention Assist	Likely available	Drowsiness					X
Audi Active Lane Assist	Likely available	Inattention		X	X	X	
Bentley Lane Assist	Available	Unintentional lane drift				X	
BMW Active Lane Keeping Assistant	Available	Unintentional lane drift				X	
BMW Lane Departure Warning	Available	Drowsiness				X	
Buick Lane Keep Assist with Lane Departure Warning	Available	Unintentional lane drift				X	
Buick Lane Departure Warning	Unclear	Unintentional lane drift				X	
Cadillac Lane Keep Assist with Lane Departure Warning	Available	Unintentional lane drift				X	
Chevrolet Lane Keep Assist with Lane Departure Warning	Available	Unintentional lane drift				X	
Chrysler LaneSense Lane Departure Warning with Lane Keep Assist	Available	Unintentional lane drift				X	

[6] Rows with no markers for any variables indicate systems that did not present information on the specific variables and features that are used to determine driver state.

System	System Availability	Intended Detection	Speed	Acceleration	Brake Activity	Lane Position	Steering Input
Dodge Lane Sense	Available	Unintentional lane drift				X	
Fiat Attention Assist	Available	Drowsiness					X
Fiat LaneSense Lane Departure Warning	Available	Unintentional lane drift				X	
Ford Driver Alert	Unclear	Inattention, drowsiness				X	
Ford Lane-Keeping System	Available	Unintentional lane drift				X	
Fuso Lane Departure Warning	Available	Unintentional lane drift				X	
Genesis Lane Keep Assist	Available	Inattention, unintentional lane drift				X	
Geotab Inc. Driving Mentor TSP	Available	Risky driving, inattention	X	X	X		
GMC Lane Keep Assist with Lane Departure Warning	Available	Unintentional lane drift				X	
Honda Driver Attention Monitor	Available	Inattention, drowsiness					X
Honda Lane Departure Warning	Available	Unintentional lane drift				X	
Honda Lane Keeping Assist System	Available	Unintentional lane drift				X	
Hyundai Driver Attention Alert	Available	Drowsiness				X	X
Hyundai Lane Keep Assist	Available	Unintentional lane drift				X	
Infiniti Lane Departure Prevention	Available	Unintentional lane drift				X	

System	System Availability	Intended Detection	Speed	Acceleration	Brake Activity	Lane Position	Steering Input
Jaguar Driver Condition Monitor	Available	Drowsiness					
Jaguar Lane Departure Warning	Available	Unintentional lane drift				X	
Jaguar Lane Keep Assist	Available	Unintentional lane drift				X	
Jeep Active Driving Assist	Available	Inattention				X	
Jeep LaneSense	Available	Unintentional lane drift				X	
Kia Driver Attention Warning	Available	Inattention, drowsiness				X	
Kia Lane Departure Warning	Available	Unintentional lane drift				X	
Kia Lane Keep Assist	Available	Unintentional lane drift				X	
Land Rover Driver Condition Monitor	Available	Drowsiness					
Land Rover Lane Keep Assist	Available	Unintentional lane drift				X	
Lexus	Likely available	Inattention, general health				X	X
Lexus Lane Departure Alert	Likely available	Unintentional lane drift				X	
Lexus Lane Departure Alert with Steering Assist	Unclear	Unintentional lane drift				X	
Lincoln Lane Keeping System	Available	Inattention, drowsiness				X	X
Mazda Driver Attention Alert	Available	Drowsiness				X	
Mazda Lane Departure Warning System	Available	Inattention, drowsiness				X	

System	System Availability	Intended Detection	Speed	Acceleration	Brake Activity	Lane Position	Steering Input
Mazda Lane Keep Assist System	Available	Inattention, drowsiness				X	
Mercedes-Benz (Daimler AG) Active Emergency Stop Assist	Available	Inattention, general health					X
Mercedes-Benz (Daimler AG) Attention Assist	Available	Inattention, drowsiness					
Mercedes-Benz (Daimler AG) Active Lane Keep Assist	Unclear	Unintentional lane drift				X	
Mitsubishi Driver Attention Alert	Unclear	Inattention, drowsiness					X
Mitsubishi Lane Departure Warning	Available	Inattention, drowsiness				X	
Mobileye Lane Departure warning	Available	Inattention, drowsiness				X	
Nissan Driver Attention Alert System	Available	Inattention, drowsiness					X
Nissan Intelligent Lane Intervention	Available	Inattention, drowsiness, unintentional lane drift				X	
Nissan Lane Departure Warning	Available	Inattention, drowsiness				X	
Pernix ASTiD	Available	Inattention, drowsiness		X	X		
Porsche Lane Keeping Assist	Available	Inattention, drowsiness, unintentional lane drift				X	

System	System Availability	Intended Detection	Speed	Acceleration	Brake Activity	Lane Position	Steering Input
PSA Groupe Lane Keeping Alert and Lane Keeping Assist	Available	Inattention, drowsiness, unintentional lane drift				X	
Seat Lane Assist	Available	Inattention, drowsiness, unintentional lane drift				X	
Seat Travel Assist	Available	Inattention, drowsiness				X	X
Somno Alert System	Prototype	Drowsiness	X		X		
Subaru EyeSight	Available	Inattention, drowsiness				X	
Tesla Emergency Lane Departure Avoidance	Available	Inattention, drowsiness				X	
Tesla Lane Departure Avoidance	Available	Inattention, drowsiness				X	X
Toyota Lane Departure Alert	Available	Inattention, drowsiness				X	
Toyota Lane Departure Alert with Steering Assist	Available	Inattention, drowsiness				X	
Toyota Lane Tracing Assist	Available	Inattention, drowsiness				X	
Volkswagen Driver Alert System	Available	Inattention, drowsiness					X
Volkswagen Lane Assist	Available	Inattention, drowsiness				X	
Volvo Driver Alert Control	Available	Inattention, drowsiness					X

System	System Availability	Intended Detection	Speed	Acceleration	Brake Activity	Lane Position	Steering Input
Volvo Driver Alert System	Available	Inattention, drowsiness				X	
Volvo Oncoming Lane Mitigation	Available	Inattention, drowsiness				X	
Volvo Pilot Assist and Lane Keeping Aid	Available	Inattention, drowsiness				X	
Volvo Run-Off Road Mitigation	Available	Inattention, drowsiness				X	

Summary of Vehicle Kinematics-Based Systems

Vehicle kinematic measures are generally good measures of decrements in driving performance, but not very good at distinguishing between decrements caused by alcohol, distraction, drowsiness, or other undesirable driver states and conditions. Achieving specificity towards alcohol impairment will be a challenge in systems that use only vehicle kinematic measures; this is reflected by the fact that none of the reviewed systems in Table 5 claim to measure alcohol impairment.

Hybrid Systems

Many driver monitoring systems use different combinations of measures, but the documentation of such multi-measure approaches is rare, and when present, the details are sparse. These "hybrid" systems typically use some form of camera-based monitoring, along with other measures, such as vehicle kinematics, spectroscopy, or physiological signals.

System Capabilities and Availability

Tables 6, 7, and 8 present known multi-measure systems across three categories:

1. Camera- and vehicle kinematics-based hybrid systems
2. Camera- and physiology-based hybrid systems
3. Camera-, vehicle kinematics-, and physiology-based hybrid systems

Table 6. Camera- and vehicle kinematics-based hybrid systems[7]

System	System Availability	Intended Detection	Camera-Based Measures			Vehicle Kinematics-Based Measures	
			Eye/Gaze	Eyelid/Eye Closure	Neck/Head	Lane Position	Steering Input
Bosch Mobility Solutions Interior Monitoring System/Driver Monitoring System	Likely available	Inattention, drowsiness		X	X		X
Fuso Active Attention Assist	Available	Unclear	X	X	X	X	X
Genesis Driver Attention Warning	Available	Inattention, drowsiness				X	
Joyson Safety Systems SafeTraK 3	Likely available	Inattention, unintentional lane drift		X		X	
Volvo Intoxication Driver Monitoring System	Available	Intoxication, distraction, drowsiness	X	X		X	X

[7] The highlighted rows represent systems that can detect alcohol in the driver (according to the manufacturer's claim).

Table 7. Camera- and physiology-based hybrid systems[8]

System	System Availability	Intended Detection	Camera-Based Measures				Physiological Measures			
			Eye/Gaze	**Eyelid/Eye Closure**	**Neck/ Head, Posture**	**Facial/ Emotion**	**Heart Rate**	**Speech**	**BrAC, Respiratory Rate**	**Sweat**
Affectiva	Likely available	Emotion		X	X	X		X		
Autocruis Technology	Likely available	General health	X		X	X				
FZI Research Center for Information Technology	Prototype	Drowsiness, emotion	X	X	X	X	X			
Gentex Driver Monitoring System	Likely available	Inattention, drowsiness	X	X					X	
Harman	Likely available	Inattention, drowsiness	X	X	X	X	X		X	
Infineon Technologies	Likely available	General health	X			X	X		X	
Nissan Alcohol Sensors Driver Monitoring	Prototype	Alcohol impairment		X					X	X
Samsung driver monitoring system	Prototype	Inattention	X				X		X	
Senseye	Available	PTSD diagnosis	X				X			
Toyota Boshoku	Prototype	Emotion, inattention	X	X	X		X	X		

[8] The highlighted rows represent systems that can detect alcohol in the driver (according to the manufacturer's claim).

Table 8. Camera-, physiology-, and vehicle kinematics-based hybrid systems[9]

System	**System Availability**	**Intended Detection**	**Camera-Based Measures**			**Physiological Measures**		**Vehicle Kinematics-Based Measures**		
			Eye/ Gaze	**Eyelid/Eye Closure**	**Neck/ Head**	**Heart Rate/ Blood Pressure**	**Sweat**	**Lane Position**	**Steering Input**	**Headway**
Bentley EXP GT 100	Prototype	Driver comfort	X		X	X		X	X	
Toyota	Prototype	Alcohol impairment	X				X	X	X	
Pioneer	Likely available	Inattention, drowsiness		X	X			X		X

[9] The highlighted rows represent systems that can detect alcohol in the driver (according to the manufacturer's claim).

Summary of Hybrid Systems

Hybrid systems use several types of sensors to estimate driver state. The details available currently on the sensor types and variables used in hybrid systems are sparse.

Note that all the reviewed hybrid systems use camera-based measures in addition to vehicle kinematic or physiological measures. This augmentation of camera-based measures with other measures is expected to be a trend in driver monitoring systems. The two systems reviewed here—Toyota and Nissan's alcohol sensor use variables that are sensitive to alcohol impairment, including eye closure measures, sweat, and BrAC. Neither appear to have progressed beyond the prototype stage.

In the future, hybrid systems may be able to identify and discern between driver states due to the number of different indicators and measures considered in making determinations. In addition, the effectiveness of various combinations, along with the implementation and driver and user acceptance challenges, will become clearer with the ongoing research on these measure combinations by DMS system manufacturers and technology developers.

Patent-Stage DMS

This section provides a summary of patents with direct or indirect relevance to the detection of impairment from alcohol. The information contained in this section was acquired from a review of patents identified in the responses to the NHTSA Request for Information on Impaired Driving Technologies (NHTSA, 2020), especially MADD's second submission to the docket (Mothers Against Drunk Driving, 2021), as well as searches using Google Patents.[10]

Tables of System and Technology Patents

Tables 9 to 15 list the various types of patent-stage systems and technologies for each major category of sensing approach. While most patents covered in this review are U.S.-based, some were filed outside the United States. The highlighted rows in the table indicate the systems that can detect alcohol in the driver, according to applicant claims. The tables indicate the patent's organization, title, patent number, general category or categories of impairment addressed (i.e., intended state), measures the patent claims could be used by the technology, and the abstract provided by the inventors. Note that some abstracts include numerical references (e.g., to figures or other sections of the patent) that are present in the original patent text but not necessarily understandable in the context of this report.

There are some important caveats to consider regarding the information in these tables. First, the information in the tables was sourced from the patents themselves, and therefore is based on the inventor's claims and does not include any objective, third-party assessment. Second, the information in the patents is sometimes ambiguous or limited in detail, therefore it was not always possible to ensure that the information in the tables was entirely accurate or complete. Third, the patent information does not indicate the status of technological development, so the existence of a patent should not be interpreted to mean that a described technology or method exists, is in development, or even is necessarily feasible as described. Fourth, the impairment measures identified in the table entries are in some cases only hypothetical (i.e., there is no

[10] https://patents.google.com

specific technology or method stated to acquire or use the measure named), and even where specific technologies or methods are described, there is no means to validate the inventors' claims. Fifth, some of the patents include an intervention component in which the vehicle can issue alerts, warnings, or other countermeasures to reduce the possible risks associated with an impaired driver; however, these tables do not address the intervention components. Finally, given the large number of patents directly or indirectly related to detection of alcohol presence or impairment in a driver, these tables provide a sampling of relevant patents rather than a complete census.

Table 9. Physiology-based system patents

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Heart Rate	Blood Pressure/ low	Brain Activity	BAC	BrAC	Respiratory Rate	Speech	Temperature, Skin Conductance, Sweat	Abstract *The following material in this column has been copied directly from the patent.*
ACTS (DADSS Program): Sensor system for passive in-vehicle breath alcohol estimation, U.S. 20,170,274,768 A1(Hök et al., 2017)	Alcohol impairment					X				Methods and apparatus allow for passive determination of a driver's Breath Alcohol Concentration (BrAC). Alcohol concentrations can be determined from exhaled breath, however inconvenience to a driver is often a barrier for incorporation of BrAC sensors into vehicles. The methods and apparatus allow for passive determination of a driver's BrAC, while detecting and accounting for a wide range of environmental conditions that may reduce the accuracy of a passive BrAC reading.
ACTS (DADSS Program): System and method for controlling operation of a vehicle using an alcohol detection apparatus, U.S. 2020/0101982 A1 (Bowers et al., 2020)	Alcohol impairment					X		X		A system for controlling operation of a vehicle, the system comprising: • a voice synthesizer unit for providing voice communication to a driver; • a speech recognition unit for receiving speech from a driver; • a breath alcohol sensor unit for detecting a presence of alcohol on the breath of a driver and providing a signal representative of the same; • a vehicle operation interface for controlling operation of the vehicle; and • a controller for (i) selectively causing the voice synthesizer unit to speak to the driver, (ii) operating the speech recognition unit to detect speech by the driver, (iii) receiving the signal from the breath alcohol sensor unit, and (iv) depending on the signal received from the breath alcohol sensor unit, providing a command to the vehicle operation interface to control operation of the vehicle.
Amazon: Vehicle voice user interface, U.S. 11,404,075 B1 (Lakhani et al., 2022)	Drowsiness							X		Techniques for confirming an operator of a vehicle is drowsy are described. A vehicle computing system sends data (e.g., raw sensor data and/or alert data corresponding to an indication that a driver is impaired determined based on the raw sensor data) to a remote server(s). The remote server(s) confirms the driver is impaired based on the raw sensor data and/or other contextual data. The remote server(s) then receives output data from a speechlet and causes the vehicle computing system to present output audio corresponding to output data.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Heart Rate	Blood Pressure/ low	Brain Activity	BAC	BrAC	Respiratory Rate	Speech	Temperature, Skin Conductance, Sweat	Abstract *The following material in this column has been copied directly from the patent.*
American Vehicular Sciences: Driver health and fatigue monitoring system and method, U.S. 8,725,311 B1 (Breed, 2014)	Drowsiness, general impairment	X					X			Vehicle including a seat in which an occupant sits during use of the vehicle and a monitoring system for monitoring the occupant in the seat. The monitoring system includes sets of electric field antennas, each including at least one antenna, a control unit connected to the antenna sets and including selectors coupled to the antennas. The selectors are controlled by the control unit to obtain signals from one or more antennas serving as receiving antennas and one or more antennas serving as sending antennas. The control unit determines which combination of sending antenna(s) and receiving antenna(s) provides a strongest signal in an expected heartbeat range and/or expected respiration range of the occupant and then monitors this combination for changes and/or deviations from a normal range of heartbeats and/or respiration.
Apple: Augmented safety restraint, U.S. 10,189,434 B1 (Casaburo et al., 2019	Inattention, general health, alcohol impairment	X					X		X	An augmented safety restraint system includes a first restraint operable to secure a first passenger. The first restraint has an exposed surface facing away from a body of the first passenger. A gesture-sensing device is disposed on the exposed surface of the first restraint and is operable to receive an input from the first passenger.
Delta Tooling Co.: Alcohol-drinking detecting system and computer program, U.S. 9,149,231 B2 (Fujita et al., 2015)	Alcohol impairment		X							Determination about presence/absence of alcohol in the body is made accurately. A frequency dynamic information processing means 610 which obtains a tendency of time-series fluctuation regarding a frequency of a pulse wave of a back portion of a person detected by an air pack and an alcohol-drinking determining means 650 which determines an alcohol-drinking state when a tendency of a time-series fluctuation regarding the frequency obtained by the frequency dynamic information processing means 610 is separated from a tendency of time-series fluctuation regarding the frequency at a non-drinking state are provided. Since determination about whether or not a person is in an alcohol-drinking state is made according to comparison with time-series fluctuation regarding the frequency at a non-drinking time, where the determination is made using not only frequency analysis of the frequency of a pulse wave changing according to the physical condition of the person but also the time-series fluctuation thereof, determination about presence/absence of alcohol drinking can be made more accurately as compared with the conventional method.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	**Intended State**	**Heart Rate**	**Blood Pressure/ low**	**Brain Activity**	**BAC**	**BrAC**	**Respiratory Rate**	**Speech**	**Temperature, Skin Conductance, Sweat**	**Abstract** *The following material in this column has been copied directly from the patent.*
DENSO: Alcohol detection system and method for vehicle, U.S. 8,201,437 B2 (Takata, 2012)	Alcohol impairment					X				An alcohol detection system for a vehicle has an alcohol sensor, for which alcohol measurement preparation processing such as heating the alcohol sensor to a predetermined temperature is performed, so that the alcohol sensor operates under the stable operation state. The alcohol measurement preparation processing is started, before a driver actually gets in the vehicle. For example, the preparation processing is started, when a predetermined manipulation of a driver on the vehicle before entering the vehicle is detected. The manipulation may be unlocking or opening of a vehicle door.
DENSO: Alcohol concentration detecting device, U.S. 8,441,357 B2 (Ohya, 2013)	Alcohol impairment					X				An alcohol concentration detecting device for a vehicle includes an alcohol sensor to detect alcohol component contained in an expiration of an occupant of the vehicle, a gas sensor to detect gas components other than the alcohol component contained in the expiration, and a controller to calculate alcohol concentration based on detection value of the alcohol sensor. The controller corrects the calculated alcohol concentration based on detection value of the gas sensor. The alcohol sensor and the gas sensor are configured to further detect a state of air in a passenger compartment of the vehicle.
DENSO: Onboard system, vehicle control device, and program product for vehicle control device, U.S. 10,398,368 B2 (Yoshida & Sawada, 2019)	Inattention, emotion, general health	X	X	X					X	An onboard system equipped to a vehicle includes a vehicle control device controlling a switching of a driving mode of the vehicle between a manual driving and a self-driving, and a brain activity sensor capable of detecting an activated portion of a brain of a driver of the vehicle. The vehicle control device determines whether a degree of uneasiness felt by the driver exceeds a threshold or not based on a detection result detected by the brain activity sensor before the switching of the driving mode. When determining that the degree of uneasiness felt by the driver does not exceed the threshold, the vehicle control device switches the driving mode. When determining that the degree of uneasiness felt by the driver exceeds the threshold, the vehicle control device performs a vehicle control corresponding to the degree of uneasiness felt by the driver.
Driving Management Systems: Apparatus, system, and method for detecting the presence of an intoxicated driver and controlling the operation of a vehicle, U.S. 9,758,039 B2 (Hannon, 2017)	Alcohol impairment					X				A system is disclosed to control operation of a vehicle based on a blood alcohol content of a driver. A detector includes a sensor configured to measure an alcohol content of air in a predetermined three-dimensional zone within a vehicle. The three-dimensional zone is proximal to a driver seat side of the vehicle. The sensor is configured to measure the alcohol content of the air independent of interaction of a driver with the detector. The sensor is configured to produce an electrical signal representative of a blood alcohol content of the driver. A controller is electrically coupled to the detector. The controller is configured to determine a tamper event. Optionally, the controller is configured to detect a presence of the driver within the vehicle. A method for preventing operation of a vehicle by an intoxicated person also is disclosed.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Heart Rate	Blood Pressure/ low	Brain Activity	BAC	BrAC	Respiratory Rate	Speech	Temperature, Skin Conductance, Sweat	Abstract *The following material in this column has been copied directly from the patent.*
Faurecia Automotive Seating: Vehicle seat with integrated sensors, U.S. 9,848,814 B2 (Benson et al., 2017)	Inattention, drowsiness, alcohol impairment, drug impairment	X	X				X			An occupant support system includes a vehicle seat and an electronics system for the vehicle seat. The electronics system includes a sensor system configured to obtain sensor data and a computer coupled to the sensor system to process the sensor data and perform a predetermined action using the sensor data.
Ford: System and method for selective engine start in a vehicle depending on driving ability (EP 1 849 644 B1 (Soininen & Richardsson, 2009)	Alcohol impairment, drug impairment				X				X	The present invention relates to a system (1) and method for selectively allowing engine start in a vehicle. A start button (1) is arranged to be touched by a driver for engine start. Sensing means (2) are arranged at the start button (1) in an area which the driver will need to touch for starting. The sensing means (2) are arranged for sensing of substance related parameters associated with a body part (3) of the driver employed for the touching action. Determination means (4) are arranged for determining from any sensed substance related parameters the presence and concentration of one or more specific substances likely to negatively affect the driver's suitability to drive. Selective starting means (5) are provided for either preventing (6) starting of the vehicle engine, should it be determined that the presence of the one or more substances has a concentration that exceeds a predetermined threshold value, or otherwise allowing (7) starting of the vehicle engine.
Ford: System and method for implementing active safety counter measures for an impaired driver, U.S. 7,777,619 B2 (Yopp & Rupp, 2010)	Impairment									Various methods and systems are disclosed for implementing active safety countermeasures in vehicles when it is determined that the driver is impaired.
Ford: System and method for establishing acoustic metrics to detect driver impairment, U.S. 9,963,033 B2 (Miller et al., 2018)	Alcohol impairment							X		An apparatus for detecting an impairment state of a driver in a vehicle is provided. The apparatus comprises a vehicle interface device configured to receive a first audible signal from a driver indicative of at least one word while the driver is in a non-impaired state and to determine a first total time to recite the at least the word based on the first audible signal. The vehicle interface device is further configured to command the driver to recite the at least one word to determine the impairment state of the driver and to receive a second audible signal from the driver indicative of the at least one word. The vehicle interface device is further configured to determine a second total time to recite the at least one word based on the second audible signal and to compare the first total time to the second total time.
Ford: Vehicle occupant impairment detection, U.S. 2020/0148231 A1 (Hassani et al., 2020)	Alcohol impairment	X	X						X	A computer is programmed to receive biometric data, from a transdermal patch in a vehicle during operation of a vehicle, wherein the biometric data include a measurement of a chemical. The computer is programmed to actuate a vehicle component, upon determining from a combination of the measurement of the chemical and vehicle operating data that a risk threshold is exceeded.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Heart Rate	Blood Pressure/ low	Brain Activity	BAC	BrAC	Respiratory Rate	Speech	Temperature, Skin Conductance, Sweat	Abstract *The following material in this column has been copied directly from the patent.*
GM: Vehicle immobilizer methods and apparatus based on driver impairment, U.S. 8,196,694 B2 (Biondo et al., 2012)	Alcohol impairment					X				Embodiments include systems and methods for immobilizing a motor vehicle. A system comprises an impairment sensor system and a control subsystem. The impairment sensor system is adapted to perform an analysis of a sample provided by an operator of a motor vehicle, where the analysis includes determining an impairment-related metric based on the sample. The control subsystem is adapted to control at least one mobility-related apparatus and at least one non-mobility-related apparatus of the motor vehicle. When the result of the analysis indicates that the impairment-related metric does not meet a criteria, the control subsystem is adapted to control the at least one mobility-related apparatus in a manner that disables the motor vehicle from moving and to control the at least one non-mobility-related apparatus in a manner that allows the at least one non-mobility-related apparatus to operate.
Hitachi: Ion detecting device, U.S. 8,921,776 B2 (Sakairi, 2014)	Alcohol impairment					X				The present invention provides a small-sized ion detecting device that quickly and simply performs mass analysis under atmospheric pressure. Accordingly, electrodes are arranged and held in the ion detecting device so as to be able to detect water clusters in ambient air with a high sensitivity. Thereby, ions can be detected even in a spatially-restricted place.
Honda: Management of autonomous vehicle driving features based on driver state, U.S. 10,789,973 B2 (Kane et al., 2020)	Alcohol impairment							X		According to one aspect, driver management is provided. One or more speech segments of a driver of an autonomous vehicle may be recorded. A position, a destination, or a previous destination of a driver or an autonomous vehicle may be tracked. An estimated state of the driver may be determined based on one or more of the speech segments, the position, the destination, or the previous destination, and a calendar event associated with the driver or a passenger of the autonomous vehicle. Autonomous driving features may be automatically enabled, disabled, or operation of the autonomous vehicle may be enabled or disabled in different modes based on the estimated state of the driver. Additionally, notifications may be displayed, rideshare applications may be launched, or warnings may be sent based on the estimated state of the driver.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Heart Rate	Blood Pressure/low	Brain Activity	BAC	BrAC	Respiratory Rate	Speech	Temperature, Skin Conductance, Sweat	Abstract *The following material in this column has been copied directly from the patent.*
Honda: System and method for capturing and decontaminating photoplethysmopgraphy (PPG) signals in a vehicle, U.S. 10,153,796 B2 (Fung et al., 2018)	Alcohol impairment	X	X	X	X		X			A system and method for processing photoplethysmography (PPG) signals in a vehicle. The system and method include receiving a PPG waveform signal from an optical sensor. The system and method also include processing a PPG measurement signal based on the PPG waveform signal. The system and method additionally include receiving a noise waveform signal from at least one of: a seat assembly sensor, a vehicle sensor, and a vehicle system. Additionally, the system and method include processing a motion artifacts measurement signal based on the noise waveform signal. The system and method further include processing a refined PPG signal to suppress the motion artifacts measurement signal from the PPG measurement signal.
Honda: Vehicle control system, U.S. 9,073,431 B2 (Takahashi, 2015)	Alcohol impairment					X			X	A vehicle control system includes an alcohol detector which detects an alcohol intake level of a driver of a vehicle; and a controller which determines whether the driver is a drunk person based on a detection result obtained from the alcohol detector, and which stops the vehicle when a determination result that the driver is the drunk person is obtained. After a door of the vehicle is switched from a closed state to an open state, and before an operation of a start-up of the vehicle is performed, the controller controls the alcohol detector so that a detection of the alcohol intake level is started, and allows a travelling of the vehicle before the detection result is output from the alcohol detector.
Honda: System and method for determining changes in a body state, U.S. 10,238,304 B2 (Fung et al., 2010)	General health, driver state change	X								A method and a system for determining changes in a body state of an individual including receiving a signal from a monitoring system, where the signal indicates a measurement of cardiac activity of the individual over a period of time and determining at least one signal feature, where the signal feature is a reoccurring event of the signal over the period of time. The method also includes determining a first interval between two successive signal features and determining a second interval between two successive first intervals. A derivative is calculated based on the second interval. Changes in the body state are identified based on the derivative.
Hyundai: Non-invasive optical detector for internal substances, DE 10 2019 208 430 A1 (Yang & Kim, 2020)	Alcohol impairment				X					A non-invasive inner substance optical detector includes: a diode array having a plurality of light emitting diodes (LEDs) for emitting light to a target on which an inner substance is detected and a plurality of photodiodes (PDs) for receiving light reflected from the target after being emitted from the plurality of light emitting diodes; and a controller for controlling the plurality of light emitting diodes to be turned on or off and for processing a signal obtained from the photodiodes. The large number of light-emitting diodes and the large number of photodiodes each have a size from several micrometers to several tens of micrometers and are arranged at a distance from several micrometers to several ten micrometers from one another.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Heart Rate	Blood Pressure/ low	Brain Activity	BAC	BrAC	Respiratory Rate	Speech	Temperature, Skin Conductance, Sweat	Abstract *The following material in this column has been copied directly from the patent.*
Hyundai: Health measurement system for vehicle's driver and warning method, U.S. 10,532,658 B2 (Kim & Park, 2020)	General health	X							X	A health measurement system for a vehicle driver and a warning method using the same are disclosed. The health measurement system includes an Internet of Things (IoT) device and a controller. The controller performs health scanning of a driver through the IoT device, and informs the driver of a result of the health scanning. The controller determines a necessary condition of the health scanning of the driver by analyzing traveling environment information, and performs the health scanning only when the necessary condition of the health scanning is satisfied.
Hyundai: Vehicle and method for supporting driver safety thereof, U.S. 2019/0161091 A1 (An, 2019)	General impairment	X		X						A method for adjusting a driving control authority of a vehicle includes: generating stimulation for a driver using a stimulation generator; measuring a driver reaction signal in response to the generated stimulation using a measurement device; processing the measured driver reaction signal using a signal processor; determining a driver state based on the processed driver reaction signal using a determiner; and adjusting the driving control authority of the vehicle according to the determined driver state using a vehicle controller
ACTS (DADSS Program): System and method for disabling a vehicle, U.S. 2012/0228047 A1 (White & Stanley, 2012)	Alcohol impairment					X				A system for disabling the operation of a vehicle when a driver of a vehicle is seated in a vehicle seat. The system includes an alcohol detection sensor configured to be contacted by the driver and to generate a detection signal based on contact between the driver and the detection sensor. The system also includes a sensing electrode located proximate to the occupant and a sensing circuit configured to provide a sensing signal to the sensing electrode. A controller is provided to detect a change in the detection signal resulting from contact between the driver and the detection sensor. The controller is configured to disable the vehicle when either the blood alcohol concentration of the driver of the vehicle exceeds a threshold or the controller does not detect a change in the detection signal resulting from contact of the driver with the detection sensor.
LG Electronics: Driver assistance apparatus, U.S. 10,435,027 B2 (Bahn, 2019)	Alcohol impairment				X	X			X	A driver assistance apparatus, in which a sensor is configured to measure an alcohol concentration from a driver, and output the measured alcohol concentration. The apparatus includes a processor configured to perform a first drunk-driving test based on a first alcohol concentration received from the sensor before starting the vehicle, and perform a second drunk-driving test based on a second alcohol concentration received from the sensor while the vehicle is operating.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Heart Rate	Blood Pressure/ low	Brain Activity	BAC	BrAC	Respiratory Rate	Speech	Temperature, Skin Conductance, Sweat	Abstract *The following material in this column has been copied directly from the patent.*
Magna: Vehicular driver monitoring System using Breath Sensor, U.S. 2020/0283001 A1 (Kulkarni, 2020)	General health						X			A vehicular driver monitoring system includes a pneumographic sensor disposed in a cabin of a vehicle and operable to capture sensor data indicative of breathing of a driver of the vehicle. The pneumographic sensor measures an aspect associated with breathing of the driver. A control includes electronic circuitry and associated software, with the electronic circuitry including a data processor operable to process sensor data captured by the pneumographic sensor. The control, responsive to processing of sensor data captured by the pneumographic sensor, monitors the driver based on the measured aspect associated with the breathing of the driver.
Panasonic: Alcohol detection system, U.S. 7,911,350 B2 (Shoji et al., 2011)	Alcohol impairment				X	X			X	A drunk driving detection system to be incorporated in a vehicle includes a steering wheel, a film, a pair of contact detection electrodes, an alcohol sensor, and a control circuit. The steering wheel is provided with an opening in a portion to be grasped by a driver. The film is liquid-impermeable and air-permeable, and covers the first opening. The contact detection electrodes are provided on the film. The alcohol sensor is provided in a space in communication with the opening. The control circuit is connected to the contact detection electrodes and the alcohol sensor, and measures the resistance between the contact detection electrodes. When the resistance is within a predetermined range, the control circuit determines that the driver is in contact with the film and detects an alcohol drinking condition of the driver based on the output from the alcohol sensor.
Senseair: Combined vehicle mounted breath analyzing and HVAC system and method (WO 2021/002796 A1 (Ljungblad, 2021)	Alcohol impairment					X				The present invention relates to a breath analyzing system and method. In particular the invention relates to a breath analyzing system combined with a heat, ventilation and air conditioning system (HVAC-system) of the vehicle, wherein the settings of the HVAC system are controlled to optimize the performance of the breath analyzing system. In particular the HVAC system may be set to a closed position fascilitating [*sic*] a concentration buil [*sic*] up of breath gases in the compartment. Alternatively the HVAC system may shift between open and closed positions.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Heart Rate	Blood Pressure/ low	Brain Activity	BAC	BrAC	Respiratory Rate	Speech	Temperature, Skin Conductance, Sweat	Abstract *The following material in this column has been copied directly from the patent.*
Sober Steering Sensors Canada: System and method for detecting and measuring ethyl alcohol in the blood of a motorized vehicle driver transdermally and non-invasively in the presence of interferents, U.S. 9,326,713 B2 (Carroll et al., 2016)	Alcohol impairment				X				X	This invention relates to a system and method that can quickly and accurately detect and measure ethyl alcohol in the blood of a motorized vehicle driver transdermally and non-invasively within minutes of ethanol consumption and in the presence of interferents. The system includes an array of sensors embedded into the steering mechanism of a motorized vehicle, a data base of patterns produced through empirical testing of various analytes in various combinations and concentrations, neural net based pattern recognition algorithms to ascertain the driver's transdermal alcohol concentration and a database derived from human testing, correlating the driver's transdermal alcohol concentration with the driver's blood alcohol concentration. The detection system is integrated with a motor vehicle decision module which can prevent the operation of a motorized vehicle by a driver whose BAC exceeds a preset limit.
Stephanie Sofer: Car alcohol monitoring system U.S. 8,089,364 B2 (Sofer, 2012)	Alcohol impairment					X				An alcohol monitoring system for monitoring a driver of a car includes a vapor analyzer system for detecting the amount of alcohol in a driver operating the car. A speed controller is provided for setting the maximum speed of the car to a predetermined level in the event that the amount of alcohol detected in the driver is above a predetermined threshold. A cell phone is configured to automatically call a remote call center, in the event that the amount of the alcohol detected in the driver is above the predetermined threshold. Furthermore, a location system is configured to provide the location of the car to said remote call center. A mapping database in said remote call center is configured to provide nearest resting locations to said car so as to guide the driver to drive the car to any one of said locations.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	**Intended State**	**Heart Rate**	**Blood Pressure/ low**	**Brain Activity**	**BAC**	**BrAC**	**Respiratory Rate**	**Speech**	**Temperature, Skin Conductance, Sweat**	**Abstract** *The following material in this column has been copied directly from the patent.*
Tammy Berg-Neuman & James L. Gowan: Device and system for monitoring operator biometric condition and blood alcohol presence to prevent driving of a vehicle by an alcohol or otherwise impaired operator, U.S. 9,775,565 B1 (Berg-Neuman & Gowan, 2017)	Alcohol impairment	X				X			X	A new system monitors ethanol alcohol levels of a vehicle operator by collecting sweat from the operator's hands, and detecting the presence, if any, of ethanol in the sweat. The system can then be used, if ethanol is present, to take action, such as immobile vehicle disablement, in the event of intoxication caused by an impermissibly high levels of ethanol of the operator. The system includes devices, referred to as pods in the description, which are sweat-collecting devices that are attached to the steering wheel of the vehicle. If the measurable ethanol in collected moisture from the operator's hands exceeds a preset threshold, the system could be configured to warn the operator to park the vehicle thereafter to disable operation of the vehicle, but if the operator does not so discontinue operation of the vehicle hazard warning lights and audible warnings within and without the vehicle will be activated alerting near vehicles of a dangerous vehicle being operated in close proximity. Likewise the new system monitors for pulse rate and oxygen levels of the operator can be used to recommend operator action when the pulse rate and/or oxygen levels are outside of the normal range for an operator. When the pulse rate and or oxygen levels of the system are outside of the normal parameters for an operator, the system will warn the operator to park the vehicle and thereafter to disable operation of the immobile vehicle, but if the operator does not so discontinue operation of the vehicle the hazard warning lights, on board video, and audible warnings within and without the vehicle will be activated alerting near vehicles of a dangerous vehicle being operated in close proximity, and alarms will be sent to real time recording and monitoring devices.
Toyota: Vehicle control device, vehicle control method, and non-transitory computer readable medium storing vehicle control program, U.S. 2019/0210607 A1 (Kobayashi et al., 2019)	Alcohol impairment							X		A vehicle control device includes: a speech acquiring section that acquires speech data related to a speech of a speaker; a state acquiring section that acquires information indicating whether or not a driver attempting to start driving a vehicle is in an intoxicated state based on the speech data; and a control section configured to limit a start operation of the vehicle in a case in which the information indicates that the driver is in the intoxicated state, the start operation being an operation performed by the driver with respect to the vehicle to start driving the vehicle.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Heart Rate	Blood Pressure/ low	Brain Activity	BAC	BrAC	Respiratory Rate	Speech	Temperature, Skin Conductance, Sweat	**Abstract** *The following material in this column has been copied directly from the patent.*
Valeo Comfort and Driving Assistance: Method and apparatus for in-vehicle impairment detection with driver verification, U.S. 2020/0122731 A1 (Vanhelle & Menon, 2020)	Alcohol impairment				X				X	A method for enabling driver operation of a motor vehicle includes receiving an electrical signal representing a property sensed by touching a region of skin of an occupant in the motor vehicle, and determining whether the occupant's ability to drive the motor vehicle is impaired based on the electrical signal. The method further includes performing an image based verification to determine whether the occupant from whom the property was sensed is in a driving position of the motor vehicle, and providing a control signal to enable operation of the motor vehicle based on a result of the determining and a result of the image based verification.

Table 10. Tissue spectroscopy-based system patents

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Infrared	Touch	**Abstract** *The following material in this column has been copied directly from the patent.*
ACTS: System for non-invasive measurement of an analyte in a vehicle driver (DADSS Program), U.S. 2019/0275886 A1 (Steeg et al., 2019)	Alcohol impairment		X	A system for non-invasively measuring an analyte in a vehicle driver and controlling a vehicle based on a measurement of the analyte. At least one solid-state light source is configured to emit different wavelengths of light. A sample device is configured to introduce the light emitted by the at least one solid-state light source into tissue of the vehicle driver. One or more optical detectors are configured to detect a portion of the light that is not absorbed by the tissue of the vehicle driver. A controller is configured to calculate a measurement of the analyte in the tissue of the vehicle driver based on the light detected by the one or more optical detectors, determine whether the measurement of the analyte in the tissue of the vehicle driver exceeds a pre-determined value, and provide a signal to a device configured to control the vehicle.
Betty Brown & Annie Minter: Alcohol ignition interlock system and method, U.S. 2005/0230175 A1 (Brown & Minter, 2005)	Alcohol impairment		X	The alcohol ignition interlock system and method has a transdermal blood alcohol concentration blood alcohol concentration reader in combination with a vehicle ignition interlock circuit that prevents an intoxicated person from operating a vehicle. The blood alcohol concentration reader utilizes a sensor that continuously measures very low levels of transdermal alcohol mounted on the steering wheel of the vehicle beneath a porous cover. The readings are communicated to a microprocessor-controlled control unit and ignition interlock circuitry that either enables or disables start-up of the vehicle, as well as continued operation thereof. Not only does the system prevent an intoxicated person from starting the vehicle, but should the system detect the driver's subsequent intoxicated state while in operation of the vehicle, the driver is given a period of time and distance in which to pull off the road prior to the ignition system being disabled.
Continental: Method and device for checking the blood alcohol level of a driver of a vehicle (WO 2011 038 803 A1 (Jansseune, 2011)	Alcohol impairment	X		The invention relates to a method and device for checking the blood alcohol level of a driver of a vehicle (V). According to the method of the invention, the driver is provided with an accessory (1) on which an electronic module comprising means for measuring the blood alcohol level by infrared spectrometry and arranged so as to extend while contacting the skin of the driver provided with said accessory, and the vehicle (V) is provided with a central processing unit (9). Further, upon a starting control, the central processing unit (9) transmits a signal requesting the transmission of the measured blood alcohol level, and, when receiving same, the electronic module of the accessory (1) supported on the driver transmits, in return, a signal comprising data representative of the measured blood alcohol level. The central processing unit (9) then triggers a safety procedure when the measured blood alcohol level exceeds a predetermined value.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	**Intended State**	**Infrared**	**Touch**	**Abstract** *The following material in this column has been copied directly from the patent.*
DENSO, Soken: Engine starting controller, U.S. 8,469,134 B2 (Osaki et al., 2013)	Alcohol impairment		X	When a driver of a vehicle brings his/her detection part close to a case, a sensor detects a pulse of the driver at the detection part with an optical method, and takes an image of the detection part. An individual certification means determines whether the driver of the vehicle is an authorized person or not based on the image of the detection part taken by the sensor. An alcohol concentration determiner calculates an index value of a blood alcohol concentration of the driver based on the pulse detected at the detection part by the sensor, and determines whether the index value exceeds a criterial value of a drinking assessment. When it is determined that the driver of the vehicle is an authorized person and the index value does not exceed the criterial value of the drinking assessment, a permission means permits the driver to start an engine of the vehicle.
HID Global: Multispectral biometric sensor, U.S. 7,819,311 B2 (Rowe et al., 2010)	Alcohol impairment	X	X	Methods and systems are provided for biometric sensing. An illumination subsystem provides light at discrete wavelengths to a skin site of an individual. A detection subsystem receives light scattered from the skin site. A computational unit is interfaced with the detection system. The computational unit has instructions for deriving a spatially distributed multispectral image from the received light at the discrete wavelengths. The computational unit also has instructions for comparing the derived multispectral image with a database of multispectral images to identify the individual.
HID Global: White-light spectral biometric sensors, U.S. 8,184,873 B2 (Rowe et al., 2012)	Alcohol impairment	X	X	Methods and systems are provided for performing a biometric function. A purported skin site of an individual is illuminated with white light. Light scattered from the purported skin site is received with a color imager on which the received light is incident. Spatially distributed images of the purported skin site are derived and correspond to different volumes of illuminated tissue of the individual. The images are analyzed to perform the biometric function.
LG Innotek: Vehicle safe starting device, U.S. 2018/0037113 A1 (Kim, 2018)	Alcohol impairment	X	X	The present invention relates to a vehicle safe starting device which controls the starting of a vehicle according to a driver's state. One embodiment analyzes blood alcohol concentration by projecting infrared rays into the driver's skin and receiving a reflected signal, and thereafter controls so that the vehicle is not stared *[sic]* if the blood alcohol concentration is larger than a reference value. Since a general breathalyzer using a driver's exhalation is not used, but infrared rays and a method of skin contact touch using a finger, etc. are used, it is possible to accurately measure the blood alcohol level without giving a driver inconvenience, and it is possible to preempt vehicle accidents by blocking driving in an inappropriate state.
Sadeq Albakri: Blood alcohol level sensing system for a vehicle, U.S. 10,850,614 B2 (Albakri, 2020)	Alcohol impairment	X	X	A blood alcohol level sensing system for a vehicle is steering wheel with infrared sensors that are able to detect variations in body chemistry from contact with the palms of the hands to determine if a driver is either alcohol impaired or impaired from certain medical conditions that might affect driving. The system has a digital readout that may be located on the dashboard of the vehicle, and the readout may also be transmitted to a cell phone. In the event of an exceedance of a predetermined set point, an interlock will interrupt the start circuit of the vehicle to prevent it from starting.
Valeo: Method and apparatus for in-vehicle impairment detection with driver verification, U.S. 2020/0122731 A1 (Vanhelle & Menon, 2020)	Alcohol impairment	X	X	A method for enabling driver operation of a motor vehicle includes receiving an electrical signal representing a property sensed by touching a region of skin of an occupant in the motor vehicle, and determining whether the occupant's ability to drive the motor vehicle is impaired based on the electrical signal. The method further includes performing an image based verification to determine whether the occupant from whom the property was sensed is in a driving position of the motor vehicle, and providing a control signal to enable operation of the motor vehicle based on a result of the determining and a result of the image based verification.

Table 11. Camera-based system patents

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Eye/Gaze	Eyelid/ Eye Closure	Pupil	Neck/ Head	Posture	Facial/ Emotion	Abstract *The following material in this column has been copied directly from the patent.*
Bosch: Method and Device for Determining a Reaction Time of a Vehicle Driver, U.S. 2016/0046295 A1 (Wacker, 2016)	Inattention, drowsiness	X						A method and a device for determining a reaction time of a vehicle driver of a vehicle includes a display device displaying at least one visual stimulus; and processing circuitry using a view recognition device to observe the direction of view of the vehicle driver, and determining the reaction time starting from the displaying of the visual stimulus, the reaction time corresponding to a specified time span if the direction of view of the vehicle driver is not recognized within the specified time span as running in the direction of the visual stimulus, or the reaction time corresponding to a time span in which the direction of view of the vehicle driver is recognized within the specified time span as running in the direction of the visual stimulus.
Ananya Sridhar: Distracted driver detection device, U.S. 2021/0350121 A1 (Sridhard, 2021)	Inattention		X				X	A distracted driver detection device for use in a vehicle includes a processor, a video camera, and an accelerometer. The processor is configured to compute an eye open ratio (EOR) and a mouth open ratio (MOR). The processor is configured to provide an audio alert signal to an audio alert component and provide a visual alert signal to a visual alert component when the EOR is less than an EOR threshold for a prescribed EOR assessment time, when the MOR is greater than the MOR threshold for a prescribed MOR assessment time, or when the estimate of the acceleration is greater than an acceleration threshold. The EOR and MOR are calculated from facial landmarks that are generated by a Histogram of Oriented Gradients (HOG) algorithm implemented by the processor.
Mazda: Driver state estimation device, method and computer program therefor, U.S. 2021/0253111 A1 (Iwase, 2021).	Inattention	X						A device, method and computer program product provide driver state estimation. A first index value correlated with an amount of an attention source allocated to top-down attention of a driver and a second index value correlated with an amount of the attention source allocated to bottom-up attention of the driver are determined. The driver state including an attention function degraded state of the driver is estimated based on the first index value and the second index value. A vehicle being operated by the driver may be controlled in accordance with the estimated driver state.
K.S. Niraja: Car driver alcohol level and sleeping status detection and notification system U.S. 2021/0362594 A1 (Madana et al., 2021)	Alcohol impairment, drowsiness		X					The present invention “car driver alcohol level and sleeping status detection and notification system using machine learning programming and IOT-based technology “is a vehicle driver sleepiness monitor, configured as a auto-contained Unit for dashboard unit. The invention is also providing for individual driver interrogation and notification response integrated with defined and fixed unit sensory inputs on vehicle condition and driver control action and translates these inputs into weighing factors to adjust a previous history and biological activity circadian rhythm reference Unit. The invention is also including an in turn to provide a vibration, water spray and audio-visual sleepiness warning alert and an automatic dialog system capable of keeping a drive awake while driving during a long trip or one that extends into the late evening. The invented system also warns the driver or changes the topic of conversation if the system determines that the driver is about to fall asleep and the system

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Eye/Gaze	Eyelid/ Eye Closure	Pupil	Neck/ Head	Posture	Facial/ Emotion	Abstract *The following material in this column has been copied directly from the patent.*
								may also detect whether a driver is effected by alcohol or drugs or any other activity. The invented technology also includes a for drowsiness detection and accident prevention using Raspberry Pi. This system is an auto rune a real-time system which captures high resolution image continuously and measures the state of the eye movement according to the specified algorithm and gives a warning if required.
Ford: Vehicle control handoff, U.S. 10,838,416 B1 (Awad Alla et al., 2020)	Presence							A computer includes a processor and a memory storing instructions executable by the processor to, upon determining that a vehicle entered a geofenced area, start a timer; upon determining that a handoff of the vehicle from an operator to a remote server has not occurred since starting the timer and that the timer has exceeded a time threshold, determine whether the operator is absent based on data from sensors; and then, upon determining that the operator is absent, instruct the vehicle to follow a command received from the remote server.
Ford: Vehicle interior and exterior monitoring, U.S. 2020/0406902 A1 (McBride, 2020)	Presence, inattention				X	X		A LIDAR sensor is mountable to a vehicle exterior with a field of view including a vehicle interior view first portion and a vehicle exterior view first portion. Data can be received from the LIDAR sensor. A state of a vehicle occupant can be determined based at least in part on data from the LIDAR sensor.
FutureWei Technologies: Integrated system for detection of driver condition, U.S. 10,592,785 B2 (Zhu et al., 2020)	Inattention				X	X	X	Methods, apparatus, and systems are provided for integrated driver expression recognition and vehicle interior environment classification to detect driver condition for safety. A method includes obtaining an image of a driver of a vehicle and an image of an interior environment of the vehicle. Using a machine learning method, the images are processed to classify a condition of the driver and of the interior environment of the vehicle. The machine learning method includes general convolutional neural network (CNN) and CNN with adaptive filters. The adaptive filters are determined based on influence of filters. The classification results are combined and compared with predetermined thresholds to determine if a decision can be made based on existing information. Additional information is requested by self-motivated learning if a decision cannot be made, and safety is determined based on the combined classification results. A warning is provided to the driver based on the safety determination.
Hyundai: System and method for determining state of driver U.S. 10,558,875 B2 (Ryu et al., 2020)	Inattention						X	A system for determining a state of a driver includes a face tracking device configured to detect coordinates and a direction vector of a face at intervals of a sampling time from a face image of the driver, an event detecting device configured to detect valid behavior of a vehicle as an event, and a determination device configured to determine an impaired state of the driver based on a reflex response time of the driver when the event is detected by the event detecting device.
Mercedes Benz: Method for Determining the Driving Ability of a Driver in a Vehicle (DE 10 2018 009 100 A1 (Smuda & Lvancevic, 2020)	Drug impairment			X				The invention relates to a method for determining the driving ability of a driver in a vehicle. The driver is identified by means of a driver camera. By means of the driver camera, an eye area comprising at least one pupil (3) of the driver is recorded without additional illumination in the visible

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Eye/Gaze	Eyelid/ Eye Closure	Pupil	Neck/ Head	Posture	Facial/ Emotion	Abstract *The following material in this column has been copied directly from the patent.*
								wavelength range. The illuminance acting on the driver's eye is determined and compared with a standard pupil value determined from a driver profile assigned to the driver. From a deviation of the pupil diameter (D) from the standard pupil diameter, a restriction of the driving ability is determined.
Shandong Agricultural University: In-vehicle safety detection system based on drunk driving and fatigue driving monitoring, CN 214954602 U (Zhang et al., 2021)	Alcohol impairment, drowsiness		X					The utility model discloses an interior safety inspection system of car based on wine drives and driver fatigue monitoring, include: the drunk driving detection module and the fatigue driving detection module are electrically connected with the control module; drunk driving monitoring module includes: pressure sensors and alcohol sensors; the pressure sensor and the alcohol sensor are both electrically connected with the control module; the fatigue driving detection module comprises a camera, the camera is electrically connected with the control module, the control module comprises a single chip microcomputer and an image processor, the pressure sensor and the alcohol sensor are both electrically connected with the single chip microcomputer, and the image processor is electrically connected with the camera; the response module comprises a control ignition relay and an alarm, the ignition relay is electrically connected with the single chip microcomputer, and the alarm is electrically connected with the image processor. The utility model discloses can drive wine and detect with driver fatigue to further carry out the early warning and to the control of vehicle, thereby effectively reduce the emergence of traffic accident.
Volvo: Method and system for perceptual suitability test of a driver, U.S. 7,455,405 B2 (Victor & Larrson, 2008)	Inattention, alcohol impairment, drowsiness	X			X			The invention relates to methods and systems for conducting Perceptual Suitability Tests (PST) for a driver and/or any other person who operates equipment, and/or devices such as a vehicle, a train, an aircraft, a ship, a nuclear reactor, a plant, a chemical process, etc. The invention is especially provided for enabling and disabling Perceptual Impairment Ignition Interlock Devices (PERCEPTIIID) for such vehicles, equipment, and/or devices, the operation of which could especially pose a general and/or potential risk for the environment and/or other people. This invention is also relevant for situations other than driving, but the examples here will be given for driving.[11]
Yazaki: Driver Monitoring Device (Nakajma et al., 1998, Japanese Patent JP H10960 A, also published as U.S. Patent 6,049,747, in 2000)	Inattention, drowsiness				X			PROBLEM TO BE SOLVED: To provide a driver monitoring device that is simple in structure with no hindrance to the steering of a driver in addition to the secureness of performance, reliability, and safety in due consideration of installing it in a vehicle. SOLUTION: A pattern light projecting means Z with two fiber gratings 2 orthogonally superposed on each other picked up a luminescent spot pattern projected on the face of a driver and thereby an image pick-up means 4 photographs it. This photographed image is processed by a data processing means 61, sampling the driver's face, and three-dimensional positional data of each sampling point are found out, then these three-dimensional positional data are processed, finding those of vertical, horizontal, and oblique inclination of

[11] This text is taken from the "Field" section of the patent because the abstract for this patent is incorrect; it belongs to a different patent.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended State	Eye/Gaze	Eyelid/ Eye Closure	Pupil	Neck/ Head	Posture	Facial/ Emotion	**Abstract** *The following material in this column has been copied directly from the patent.*
								the driver's face. Whether the driver is in a dangerous state due to inclination of the face or not is judged by a judging means 62. In addition, when two warning means 8 and 9 have come to a critical state, a warning is given to the driver. The pattern light projecting means Z and the image pick-up means 4 unified in one are set up on a steering column.

Table 12. Vehicle kinematics-based system patents

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended Detection	Acceleration/ Brake Pedal	Steering Input	Lane Position	**Abstract** *The following material in this column has been copied directly from the patent.*
Nauto: System and method for analysis of driver behavior, U.S. 2020/0198645 A1 (Boer, 2020)	Inattention	X	X		The disclosed embodiments include a onboard driver distraction determination system. The determination system includes a onboard sensing and computing system(s), which includes inertial sensor(s), internal sensor(s), and external sensor(s). The onboard system samples data from the sensor(s) during a driving session to determine steering activity metrics and driver behavior. A steering activity metric is a representation of the steering inputs by the driver during the driving session. Driver behavior is a representation of how distracted the driver is during the driving session. By performing the above mentioned steps, the system can provide an analysis of driver distraction and optionally, take control of the vehicle to avoid aberrant behavior.
Dongfeng Liuzhou Motor Co: Safe driving reminding method, device, equipment, and storage medium, CN 113071512 A (Yang et al., 2021)	Drowsiness			X	The invention relates to the technical field of automobiles and discloses a safe driving reminding method, a safe driving reminding device, safe driving reminding equipment and a storage medium, wherein the method comprises the steps of acquiring the current driving information of a vehicle in real time under a preset road condition and detecting whether a driving state monitoring system of the vehicle is in a driver state monitoring mode or not; when the driving state monitoring system is in a driver state monitoring mode, calculating a driver fatigue index in real time according to current driving information through a preset state judgment mechanism so as to obtain the current driver fatigue index; comparing the current driver fatigue index with a preset threshold; when the current driver fatigue index exceeds the preset threshold value, judging the fatigue driving of the driver and giving an alarm prompt, and intelligently updating the fatigue value according to the action of the driver in the driving process and the vehicle driving information, thereby solving the technical problem of effectively reminding the driver of safe driving.
Volkswagen: Method for estimating the attentiveness of the driver of a vehicle (WO/2020/064160 A1 (Büthorn & Mehne. 2020).	Inattention	X	X		In the method according to the invention for estimating the attentiveness of the driver of a vehicle, a first attentiveness value is determined (4) with a long-term estimation of the attentiveness of the driver, wherein the first attentiveness value decreases over the time for which the vehicle is driven. The activation of operator control elements of the vehicle by the driver is detected (7). On the basis of the detected activation, a second attentiveness value is determined (9) with a short-term estimation of the attentiveness of the driver. A signal can be output to the driver (6) or a vehicle function can be triggered in accordance with the first and/or second attentiveness value.
American Vehicular Sciences: Driver fatigue monitoring system and method, U.S. 9,129,505 B2 (Breed et al., 2015)	Drowsiness, general impairment	X	X	X	Method and system for monitoring a driver during movement of the vehicle includes an information obtaining system that obtains information about a driver who traveled the same road at a previous time, and a processor that analyzes the obtained information and vehicle movement to determine whether the driver has lost the ability to continue to control the vehicle. The loss of ability to continue to control the vehicle arises from the driver falling asleep or otherwise being incapable of controlling the vehicle after initially having been awake or otherwise capable of controlling the vehicle. A reactive component is affected by the processor's determination that the driver has lost the ability to continue to control the vehicle, and preferably requires action by the driver to indicate regaining of the ability to operate the vehicle or exerting control over the vehicle to slow the vehicle and bring it to a stop.

Table 13. Camera- and vehicle kinematic-based system patents

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended Detection	Camera-Based Measures				Vehicle Kinematics Measures		Abstract *The following material in this column has been copied directly from the patent.*
		Eye/Gaze	Eyelid/Eye Closure	Neck/Head	Facial/Emotion	Lane Position	Steering Input	
GM: Method and system for mitigating the effects of an impaired driver, U.S. 9,290,174 B1 (Zagorski, 2016)	Inattention, alcohol impairment	X	X		X	X	X	A system and method that, in response to the detection of an impaired driver, develops a scenario-dependent response with an escalating sequence of awakening actions and/or automated driving actions that are designed to mitigate the effects of impaired driving for that particular driving scenario. Some examples of awakening actions include visual, audible, haptic and/or miscellaneous warnings intended to awaken or reengage the impaired driver. If the awakening actions are ineffective, one or more automated driving actions may be used to control certain aspects of vehicle braking, steering, accelerating, etc. The scenario-dependent response is at least partially based on the state, conditions and/or environment in and around the host vehicle (i.e., the current driving scenario) and may take into account factors such as: vehicle dynamics, road characteristics, pedestrian and vehicle traffic conditions, weather conditions and more.

Table 14. Camera- and physiology-based system patents

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended Detection	Camera Based Measures				Physiological Measures						Abstract *The following material in this column has been copied directly from the patent.*
		Eye/Gaze	Eyelid/Eye Closure	Neck/Head, Posture	Facial/ Emotion	Heart Rate, Blood Pressure	Speech	BrAC	Respiratory Rate, Skin Conductance, Temperature	Sweat	Brain Activity	
Toyota: Cognitive tunneling mitigation device for driving, U.S. 11,447,140 B2 (Austin et al., 2022)	Drowsiness	X	X	X		X						A driver monitor method and system for mitigating cognitive tunneling in a vehicle includes in-cabin video cameras, a heart rate monitor, an audio-visual device, and processing circuitry that detects eye gaze direction, eye lid position, and head position using images from the in-cabin video cameras, and measures heart rate variability using the heart rate monitor. A machine learning device uses the eye gaze direction, eye lid position, head position, and heart rate variability to predict whether a driver is transitioning into a cognitive tunneling state or a fatigue state. The audio-visual device outputs one audio-visual cue to mitigate the cognitive tunneling state and outputs a different cue to mitigate the fatigue state. The machine learning device learns by performing a reinforcement learning algorithm in which the audio-video device outputs a verification request and receives a response to the verification request that is fed back to the machine learning device.
DENSO: Dozing alert apparatus, U.S. 2020/0286358 A1 (Doi & Nagata, 2020)	Drowsiness						X					A drowsiness level of a driver in a vehicle is determined. A preliminary alert is performed in response to that the drowsiness level is higher than an alert threshold value. A main alert is performed to

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended Detection	Camera Based Measures				Physiological Measures						Abstract *The following material in this column has been copied directly from the patent.*
		Eye/Gaze	Eyelid/Eye Closure	Neck/Head, Posture	Facial/ Emotion	Heart Rate, Blood Pressure	Speech	BrAC	Respiratory Rate, Skin Conductance, Temperature	Sweat	Brain Activity	
												prompt the driver to wake up from drowsiness as necessary after the preliminary alert. In response to that a predetermined response operation by the driver is detected within a predetermined time after the preliminary alert, the alert threshold value is changed to be higher.
DENSO: Driving assist device, U.S. 9,855,956 B2 (Omi, 2018)	General health, inattention	X	X	X		X						A driving assist device includes a driver state detection unit for detecting an inattentive state as a driver state, an alerting unit for altering the driver upon detection of the inattentive state of the driver, a driving operation unit for being operated by the driver for driving operations; and a driving state switching unit that switches at least one of the driving operations in an automated driving state to a manual driving state when the driver's operation of the driving operation unit is detected during the automated driving state of the vehicle. When at least one of the driving operations in the automated driving state is switched to the manual driving state by the driving state switching unit, the driver state detection unit detects whether the state of the driver is an excited state. When the excited state of the driver is detected, the alerting unit alerts the driver.
Fudan University: Driver state monitoring device, CN 112998710 A, Feng et al., 2021)	Alcohol impairment, inattention, drowsiness				X						X	The invention relates to a driver state monitoring device, which comprises a monitoring box and a lead electroencephalogram cap, wherein the monitoring box comprises a shell, a camera, a signal lamp, a display screen and an integrated circuit board, the display screen and the camera are positioned on the front side of the shell, the integrated circuit board is positioned in the shell and connected with the camera, the signal lamp and the display screen, and the integrated circuit board integrates a wireless receiving module and a main chip; the lead brain electricity cap includes waterproof fabric area, monitoring electrode and monitoring unit, and the both ends of waterproof fabric area are equipped with the linkage unit, and the monitoring electrode distributes in waterproof fabric area middle one side, and the monitoring unit is located the opposite side in the middle of the waterproof fabric area and connects the monitoring electrode, and monitoring unit integration wireless sending module, digital analog converter and signal amplifier. Compared with the prior art, the brain wave monitoring system can synchronously monitor the brain wave signals of the driver, and can accurately predict the psychological

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended Detection	Camera Based Measures				Physiological Measures						Abstract *The following material in this column has been copied directly from the patent.*
		Eye/Gaze	**Eyelid/Eye Closure**	**Neck/Head, Posture**	**Facial/ Emotion**	**Heart Rate, Blood Pressure**	**Speech**	**BrAC**	**Respiratory Rate, Skin Conductance, Temperature**	**Sweat**	**Brain Activity**	
												activities by combining the face recognition technology, so that the driver is reminded in time, and the monitoring effect is better.
Fulscience Automotive Electronics Co: Drunk driving state detection method and device, electronic equipment and storage medium, CN 114801731 A (Xiao, 2022)	Alcohol impairment				X			X				The application provides a drunk driving state detection method and device, electronic equipment and a storage medium, wherein the detection method comprises the following steps: acquiring a face image of a target object located at a driving position and an alcohol concentration in exhaled air of the target object; determining whether a drunk driving face feature exists on the face of the target object based on the face image; based on whether the alcohol concentration is greater than a preset alcohol concentration; when the drunk driving facial features exist on the face of the target object and the alcohol concentration is larger than the preset alcohol concentration, the target object is determined to be in a drunk driving state. By adopting the technical scheme provided by the application, the drunk driving face characteristic can be obtained on the face of the driver, and when the detected alcohol concentration in the exhaled air of the driver is greater than the preset alcohol concentration, the driver is determined to be in the drunk driving state, so that the drunk driving state of the driver can be determined by double detection, and the accuracy of detecting the drunk driving state of the driver is improved.
Honda: System and method for dynamic vehicle control affecting sleep states of vehicle occupants, U.S. 9,463,805 B2 (Kirsch et al., 2016)	Drowsi-ness	X	X	X	X	X			X	X		A computer-implemented method for dynamic vehicle control affecting sleep states of vehicle occupants includes connecting a wearable computing device associated with a vehicle occupant to a vehicle, and determining a state of the vehicle occupant based on physiological data received from at least one of the wearable computing device and the vehicle. The method includes determining a target sleep state of the vehicle occupant based on at least one of the state of the vehicle occupant, the physiological data and vehicle system data, and controlling a vehicle system of the vehicle based on the state of the vehicle occupant in relation to the target sleep state. The method includes monitoring the state of the vehicle occupant including monitoring the physiological data of the vehicle occupant in response to controlling the vehicle system and controlling the vehicle system according to the monitoring in relation to the target sleep state.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended Detection	Camera Based Measures				Physiological Measures						Abstract *The following material in this column has been copied directly from the patent.*
		Eye/Gaze	**Eyelid/Eye Closure**	**Neck/Head, Posture**	**Facial/ Emotion**	**Heart Rate, Blood Pressure**	**Speech**	**BrAC**	**Respiratory Rate, Skin Conductance, Temperature**	**Sweat**	**Brain Activity**	
Honda: System and method for responding to driver behavior, U.S. 2018/0072310 A1 (Fung & Dick, 2018)	Inattention, drowsiness		X	X		X			X			Methods of assessing driver behavior include monitoring vehicle systems and driver monitoring systems to accommodate for a driver's slow reaction time, attention lapse and/or alertness. When it is determined that a driver is drowsy, for example, the response system may modify the operation of one or more vehicle systems. The systems that may be modified include: visual devices, audio devices, tactile devices, antilock brake systems, automatic brake prefill systems, brake assist systems, auto cruise control systems, electronic stability control systems, collision warning systems, lane keep assist systems, blind spot indicator systems, electronic pretensioning systems and climate control systems.
Honda: System and method for responding to driver state, U.S. 10,759,437 B2 ((Fung & Dick, 2020)	General health, alcohol impairment	X				X			X			A method for controlling vehicle systems includes receiving monitoring information from one or more monitoring systems and determining a plurality of driver states based on the monitoring information from the one or more monitoring systems. The method includes determining a combined driver state based on the plurality of driver states and modifying control of one or more vehicle systems based on the combined driver state.
Lear: Distractedness sensing system, U.S. 2021/0009149 A1 (Migneco et al., 2021)	Inattention	X	X	X	X	X			X			A distraction detection system includes using a first signal, e.g., EDP signals or vehicle speed, and an additional signal to determine whether a person is distracted. The distraction system can be part of a vehicle seating system, A vehicle seating system is described and includes a seat configured to support an occupant and to be mounted in a vehicle and occupant sensing system at least partially integrated into the seat to sense an occupant. The sensing system senses a first criterion with respect to the occupant. A controller is configured to receive the first criterion signal from the sensing system and a second criterion to determine a distraction state of the driver. The controller can also determine a false distraction state using the distraction state and other criterion in a vehicle. The controller outputs a control signal when the distraction state exceeds a distraction threshold and when distraction is confirmed.
STMicroelectronics: Method of processing signals indicative of a level of attention of a	Inattention				X						X	A time series of face images of a human during a human activity are captured. A first artificial neural network (ANN) processing pipeline processes the captured time series of face images to provide a first

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended Detection	Camera Based Measures				Physiological Measures						Abstract *The following material in this column has been copied directly from the patent.*
		Eye/Gaze	Eyelid/Eye Closure	Neck/Head, Posture	Facial/ Emotion	Heart Rate, Blood Pressure	Speech	BrAC	Respiratory Rate, Skin Conductance, Temperature	Sweat	Brain Activity	
human individual, corresponding system, vehicle and computer program product, U.S. 2022/0327845 A1 (Rundo et al., 2022)												attention level indicator signal. An electrophysiological signal indicative of the level of attention of the human during the activity is also captured. A second ANN processing pipeline processes the sensed electrophysiological signal to providing a second attention level indicator signal. A risk indicator signal is then generated based on at least one of the first attention level indicator and second attention level indicator. A user circuit is then triggered as a result of the risk indicator reaching or failing to reach at least one attention level threshold.
Thunder Power: Method for recognizing vehicle driver and determining whether driver can start vehicle, U.S. 10,173,687 B2 (Sham, 2019)	Inattention, drowsiness, alcohol impairment					X			X			Provided are systems and methods for increasing vehicle safety by determining whether a driver can operate a vehicle based on whether the physical status of the driver and the identity of the driver are acceptable. A first set of sensors may determine the physical status of the driver. The first set of sensors may include an electrocardiogram detection component, an alcohol detection component, a body temperature detection component, and a photography component, among others. A second set of sensors may determine the identity of the driver. The second set of sensors may a fingerprint detection component, an electrocardiogram detection component, and a photography component, among others. When it is determined that the physical status of the driver is unacceptable, the method may include activating an automatic driving system.
Toyota: Driving consciousness estimation device, U.S. 10,640,122 B2 (Kishi et al., 2020)	Inattention, drowsiness	X		X								A driving consciousness estimation device includes a driving readiness estimation unit configured to estimate a driving readiness relating to a driving consciousness of the driver from a driver's reaction to the travelling environment, a driving task demand estimation unit configured to estimate a driving task demand which is an index required for the driver with respect to the driving readiness from the travelling environment, and an attention awakening unit configured to execute awakening of attention for the driver relating to the driving of the vehicle based on the result of comparison between the driving readiness and the driving task demand.
Toyota: Impairment evaluation system, U.S. 10,166,992 B2 (Schmidt, 2019)	Alcohol impairment	X					X	X				A system configured to administer an impairment evaluation when a driver has been identified as attending an impairment event is provided. The system includes a driver profile unit configured to determine a sober driver profile. A sensor unit detects the location

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended Detection	Camera Based Measures				Physiological Measures						Abstract *The following material in this column has been copied directly from the patent.*
		Eye/Gaze	**Eyelid/Eye Closure**	**Neck/Head, Posture**	**Facial/ Emotion**	**Heart Rate, Blood Pressure**	**Speech**	**BrAC**	**Respiratory Rate, Skin Conductance, Temperature**	**Sweat**	**Brain Activity**	
												and operation of the motor vehicle after a motor vehicle stop. An impairment event unit receives the information regarding the operation of the vehicle from the sensor unit and compares the operation of the vehicle with the sober driver profile after the motor vehicle stop. The drinking unit identifying the motor vehicle stop as an impairment event when the operation of the vehicle deviates from the sober driver profile a predetermined amount. A challenge is administered to the driver after the impairment event so as to determine if the driver is impaired. The vehicle is rendered inoperable when the driver fails the challenge.
Toyota: Vehicle occupant information acquisition device and vehicle control system, U.S. 9,783,202 B2 (Yamada, 2017)	Alcohol impairment					X	X	X				A vehicle occupant information acquisition device includes a microcomputer, an acquisition unit and an alert unit. The microcomputer controls the vehicle to switch between an autonomous driving mode and a manual driving mode. The acquisition unit acquires, from vehicle occupants riding in the vehicle, information relating to driving suitability of the vehicle occupants. In a case in which the microcomputer is switching the vehicle from the autonomous driving mode to the manual driving mode, the microcomputer causes the alert unit to alert one of the vehicle occupants who is determined to be suitable to drive the vehicle based on the information acquired by the acquisition unit that he/she has been selected as the driver of the vehicle.

Table 15. Camera-, physiology-, and vehicle kinematics-based system patents

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended Detection	Camera-Based Measures			Physiological Measures			Vehicle Kinematics Measures		Abstract *The following material in this column has been copied directly from the patent.*
		Eye	Eyelid/Eye Closure	Facial/ Emotion	Heart Rate, Blood Pressure	Speech	Respiratory Rate, Skin Conductance, Temperature	Steering Input	Pedal Activity	
Continental: Driver assistance system, vehicle, method for operating the driver assistance system, computer program and computer-readable storage medium (DE 10 2018 210 367 A1 (Anton, 2020)	Inattention	X	X	X	X				X	The invention relates to a driver assistance system (2) for a vehicle (1), in particular a motor vehicle, with a plurality of parameters for operating the driver assistance system, at least one first parameter characterizing a state of a driver, with at least one first operating mode for operating the vehicle and at least a second one Operating mode for operating the vehicle, and with at least one setpoint in relation to the first parameter, wherein in the first operating mode the vehicle (1) can be operated as a tracking vehicle in the lane of a leading vehicle and in the second operating mode the vehicle (1) as an autonomous one or semi-autonomous single vehicle can be operated, the at least one setpoint being adjustable on the basis of the operating mode. The invention further relates to a vehicle, a method for operating the driver assistance system, a computer program and a computer-readable storage medium.
DENSO: Vehicular user hospitality system, U.S. 7,821,382 B2 (Kameyama, 2010)	Driver comfort	X		X	X	X	X	X		A vehicular user hospitality system recognizes a situation concerning vehicle use according to a combination of a disturbance stimulation type and hospitality intention category. With an intention estimation table, the system determines a reference intention parameter value for providing an intensity reference of a hospitality intention for each of safety, convenience, and comfort categories. The system settles an intention intensity reference using a reference intention parameter value specific to each situation. The system supplements the reference intention parameter value with the current disturbance stimulation value to determine an intention intensity parameter value to be appropriately used as a function selection reference value while considering a disturbance stimulation magnitude. Using a function specification table, function specification information for specifying a function of a hospitality operating portion is extracted according to a combination of the disturbance stimulation type and the hospitality intention category to thereby determine a control content.
Hyundai Mobis: Apparatus and method for detecting driver status, U.S. 9,682,711 B2 (Lee, 2017)	Inattention	X	X	X	X	X	X	X	X	An apparatus for detecting a driver status may include an information acquisition unit acquiring driver's vehicle driving information, driver's vehicle operation information, and driver status information, a calculation unit calculating a driving load indicated by converting a factor obstructing safe driving into a numerical value, based on the information acquired by the information acquisition unit, a comparison unit between the driving load calculated by the calculation unit and a preset load margin, and a warning unit warning the driver when the comparison unit determines that the calculated driving load exceeds the preset load margin.

Organization, Patent Title, Patent Number, Citation (Inventors and Year)	Intended Detection	Camera-Based Measures			Physiological Measures			Vehicle Kinematics Measures		Abstract *The following material in this column has been copied directly from the patent.*
		Eye	Eyelid/Eye Closure	Facial/ Emotion	Heart Rate, Blood Pressure	Speech	Respiratory Rate, Skin Conductance, Temperature	Steering Input	Pedal Activity	
Hyundai Mobis: Apparatus and method of safety support for vehicle, U.S. 2020/0098265 A1 (Agnew et al., 2020)	Inattention	X	X		X	X	X	X	X	A vehicle safety support apparatus includes: a driver monitoring sensor configured to monitor a driver; an external environment monitoring sensor configured to monitor an external environment of a vehicle; and at least one processor configured to: determine whether the vehicle is in an immediate hazard situation based on data acquired from the driver monitoring sensor and the external environment monitoring sensor; determine, in response to determining that the vehicle is in the immediate hazard situation, whether to perform a recovery maneuver or a rescue maneuver based on the data acquired from the driver monitoring sensor and the external environment monitoring sensor to get out of the immediate hazard situation; and perform, in response to determining to perform the rescue maneuver, autonomous driving to move the vehicle to a safe area by taking over a driving control from the driver.
Toyota: Vehicle emergency evacuation device, U.S. 8,954,238 B2 (Kobana et al., 2015)	General health, alcohol impairment, inattention, drowsiness	X		X	X			X	X	An emergency evacuation device of a vehicle that executes an automatic vehicle stop control based on a command of a driver is disclosed. The emergency evacuation device comprises a driver's physiological condition estimation portion that estimates a driver's physiological condition; a driver's command input portion, operated by the driver, that receives a driver's command input and outputs a command of an execution of an automatic vehicle stop control in accordance with the command input; and an automatic vehicle stop control portion that executes the automatic vehicle stop control in response to the command from the driver's command input portion, wherein based on the driver's physiological condition estimated in the driver's physiological condition estimation portion, the structure of the driver's command input portion, for example, the arrangement of receptor(s) of the driver's command input portion receiving the command from the driver is changed.

Discussion

The above sections of the report provide a focused review of DMS and other technologies that could potentially be applied or adapted to detect indicators of alcohol intoxication in a driver. Since all information provided above was gathered from publicly available sources, this should not be considered an exhaustive discussion. Some manufacturers did not explicitly indicate which driver states they were attempting to assess. In these cases, state was inferred based on the measures collected. The goals were to:

1. Perform a thorough search and scan of DMS, compiling their system or brand names and market-readiness into a tabular format;
2. Categorize technologies based on the primary method by which the systems collect data and estimate driver state;
3. Gather publicly available information on measures of driver behaviors, physical (e.g., posture) and affective states, and physiological states (e.g., heart rate, sweat) that are used by the reviewed systems in estimating driver state;
4. Document systems developed to detect alcohol-based driver impairment; as well as systems that are currently used to determine inattention or drowsiness that could be transferrable to alcohol impairment detection; and
5. Draw inferences about systems' current development status and potential in the domain of driver monitoring as related to impairment.

While the strengths and limitations of different technological approaches to the detection of alcohol or alcohol intoxication in a driver were discussed throughout this report, evaluating the efficacy of specific systems was not a goal of the review. Additionally, manufacturers did not disclose sufficient information to understand exactly how systems assessed driver state. For this report, 331 technologies were reviewed. However, 44 were excluded for reasons such as expired patents or insufficient information available to conduct a review. The remaining technologies are classified using the primary method of determining driver state:

1. ***Physiology-based systems:*** Physiology-based systems use biometric measures from the driver to determine driver state. Two reviewed systems are in the research and development stages for alcohol impairment detection. One system (.08 sensitive passive breath-based vapor detection system by the DADSS program) is expected to be licensed for widespread use within the next few years. A zero-tolerance (.02 sensitive) directed-breath-based system was released for open licensing for use in fleet and commercial vehicles in December 2021.
2. ***Tissue spectroscopy-based systems:*** Tissue spectroscopy is an emerging method of estimating alcohol in the bloodstream. The alcohol concentration is determined from the interstitial fluid present under the dermal tissue layer (Ridder et al., 2009). One reviewed system – the DADSS Touch Sensor – is in the prototype stage of research and development for in-vehicle use and is planned to be licensed for widespread use within the next few years. Currently, it is unclear if the TruTouch 2500 model is commercially available; at this time, it is not being implemented in such a way that it can be used in dynamic driving environments.

3. ***Camera-based systems:*** Certain camera-based measures such as eye closure over time, pupil diameter, saccades, and fixations are known to be impaired due to alcohol, but there is a lack of clinical and psychophysiological research that aid in determining driver alcohol impairment from camera-based measures. None of the reviewed systems that claimed alcohol impairment detection as the objective are known to be available for driver monitoring.
4. ***Vehicle kinematics-based systems:*** Vehicle kinematics-based systems estimate driver state by monitoring the driver's inputs to the steering wheel, or the overall vehicle motion (speed and steering inputs). Vehicle kinematics-based systems are widely available for detection of changes in the ability to drive (e.g., lane drifts due to potential distraction or drowsiness), but not yet documented to be specifically used for identifying alcohol impairment. While vehicle kinematic measures can indicate changes in driving ability, their use in specifying the cause (e.g., drowsiness, distraction, or alcohol-impairment) is unlikely without the use of other measures.
5. ***Hybrid systems (combination of cameras with physiological and/or vehicle kinematics sensors):*** Hybrid systems take a multi-method approach to driver state detection. Descriptions of three prototype hybrid systems (Nissan, Samsung, Toyota) indicate the use of physiological measures along with camera-based measures to determine impairment. The effectiveness of these systems for alcohol impairment detection is unknown, as these systems are prototypes and not in-market.
6. Patent-stage systems (systems that are at an active patent stage, grouped together irrespective of the reported primary method of sensing): While patents exist, the details do not support this study's determination of the suitability or availability of the systems for detecting alcohol impairment.

Driver state monitoring systems that can reliably detect specific BACs are still in research and development. Consequently, these technologies continue to evolve, and any findings in this report risk being inaccurate later. With that caveat, key findings from the review of the known measures used in each system, the potential for the systems to detect alcohol effects on the driver, and the commercial availability of the systems are stated below.

Among the DMS included in this review, many focused on driver inattention or drowsiness detection. Further, no DMS technologies currently available for production could determine alcohol level in the blood (i.e., BAC) or alcohol impairment of driving skills. Additionally, the study found no market-ready technologies that effectively determine alcohol impairment of dynamic driving skills (irrespective of BAC).

Furthermore, although camera-based technologies have been used in hybrid systems to detect visible signs of impairment or inattention in combination with other potential measures of impairment, camera-based technologies alone have not been demonstrated to detect the presence of alcohol specifically and accurately in a driver or alcohol-related impairment. To develop the appropriate driver warnings or interventions, the measures used by camera-based systems to assess impairment may require more research to determine if the driver is impaired specifically by alcohol, as opposed to being impaired due to distraction, other drugs, or drowsiness. Camera-based and most physiology-based DMS are still in the stages of prototype research and design for alcohol impairment detection. Vehicle kinematic measures are attributed to a range of driver states, including impairment and are unlikely to isolate alcohol impairment without other measures. Determination of the driver's state may be useful, not only for applying effective intervention strategies but for preventing false positives and minimizing user annoyance, distrust, and misuse of the system.

Some physiology-based systems offer potential measurements of alcohol. Though still in the research and development stages, the DADSS program, for example, has begun to release its systems' design specifications in stages (first a directed-breath system for commercial fleets, then as passive systems for widespread licenses for use in all vehicles). This release began in 2021 and will continue over the next few years. The DADSS technologies provide a means of establishing the presence of alcohol in the driver's breath (through breath vapor measurement) or blood stream (through tissue spectroscopy). Research is being conducted to use these technologies to determine the estimated amount of alcohol in the driver's bloodstream, which would then allow comparisons with per se BAC laws. In addition, a sweat-based sensor is being researched by Hyundai and the Cintalapa Technology Institute. Note that the potential for sweat-based systems to provide robust estimates of alcohol impairment from short-duration samples is yet to be assessed.

In the future, hybrid systems (i.e., those that use a variety of sensors and measures in combination) may be able to identify and discern between driver states due to the number of different indicators/measures considered in making determinations. It is expected that the efficacy and effectiveness of hybrid systems will become clearer with the ongoing research on these measure combinations by DMS manufacturers and technology developers.

This page is intentionally left blank.

DMS for Level 2 Automation

Background

Driving automation is commonly discussed in terms of driving automation levels using SAE's taxonomy that ranges from 0 (no driving automation) to 5 (full driving automation) (SAE International, 2021). Level 0 (L0), no driving automation, may still include safety features that alert the driver to possible hazards (e.g., forward collision warning, lane departure warning) or perform momentary actions in specific situations (e.g., automatic emergency braking, lane departure prevention). Level 2 (L2), partial driving automation, provides sustained lateral and longitudinal control support of the vehicle.

L2 systems are currently available on production vehicles from many vehicle manufacturers. While driving automation systems can provide benefits, they can also have unintended consequences (Bainbridge, 1983; Sheridan, 2002). L2 features are designed to *support* drivers, not *supplant* their role entirely. While the vehicle can control acceleration, braking, and lane keeping under certain conditions, the driver is still expected to maintain attention to the roadway, perform object and event detection and response (OEDR), monitor the automation, and intervene when necessary to maintain safe vehicle operation. With reduced involvement in the DDT, drivers may exhibit lower attention, become distracted, or become involved in non-driving related secondary tasks (Llaneras et al., 2013). These consequences can result in a reduced ability to effectively assume manual control when necessary.

To better understand or infer driver state while L2 systems are engaged, DMSs have been introduced in many commercially available vehicles. DMSs can estimate driver state through a variety of possible metrics including blink rate, pupil size, head position, heart rate, and steering and braking behavior (Halin et al., 2021). In many cases, if the DMS detects that the driver may not be appropriately engaged in the DDT, the vehicle HMI will provide an alert to the driver. Depending on system capabilities, re-engagement may require the driver to perform certain behaviors, such as looking straight ahead at the road or applying slight pressure to the steering wheel.

The two primary DMS approaches currently used in production vehicles with L2 systems can be categorized as hands-on-wheel or eyes-on-road. Hands-on-wheel systems typically use torque or capacitance sensing to determine whether the driver has at least one hand on the wheel. Eyes-on-road systems typically use the driver's gaze direction to determine where the driver is looking. Both approaches rely on imperfect proxy metrics to infer driver state and readiness to resume full manual control. For example, hands-on-wheel DMS do not directly assess whether the driver is paying attention to the driving task, and eyes-on-road systems – despite assessing whether the driver's gaze is in the general direction of the forward roadway – do not directly assess whether the driver is cognitively attending to the driving task and performing OEDR. Driver distraction has been shown to have negative effects on takeover performance in L2 driving, including longer time to take over following an urgent takeover request (Yang et al., 2021). Therefore, it is critical to fully understand the current capabilities, limitations, and future directions of DMSs.

The purpose of this task was to identify DMS strategies and understand the technological landscape in the context of partial driving automation. These research questions were addressed through three separate but complementary activities: a literature review, a technology review, and interviews with SMEs.

Literature Review

DMSs can be used to monitor driver attentiveness (Dong et al., 2010). L2 systems are typically equipped with some form of DMS to confirm driver engagement in the driving task. Some of these systems specifically also target driver distraction and drowsiness.

The functional goal of a DMS is to determine if the driver is in a state where they could safely maintain or take over vehicle control (Wörle et al., 2019). Quantifying a driver's state is challenging since it can be affected by mental processes that may not be easily observable (Strayer et al., 2013). Current DMSs use visual attention and physical readiness metrics to estimate driver state. When considering the human factors and physiology of potential driver states in view of DMS monitoring and mitigation strategies, the problem of accurately differentiating driver state (i.e., DMS specificity) and designing appropriate mitigation based on the state becomes more complex.

Designing mitigation strategies specific to driver state requires understanding how the proximal indicators relate to the physiological state. Therefore, the neurophysiological literature on distraction and drowsiness, in conjunction with the human factors and psychology literature on driver behavior, were reviewed. In comparison to overt attentional indicators, relatively few peer-reviewed papers to date have explored neurophysiological measures related to driving performance. Thus, the research team only summarized implications for DMS-based monitoring for which higher quality and higher corroborating evidence were indicated. Key human factors and physiological findings on attention, distraction, and drowsiness are presented.

Driver Monitoring Methods

As previously noted, most commercially available DMSs in vehicles with L2 systems operate using one of two general approaches: eyes-on-road or hands-on-wheel systems. Eyes-on-road DMSs typically operate by examining a driver's face through a small camera to classify a range of behaviors such as eye gaze, head and face orientation, facial expressions, hand and foot positions, and body posture (Rangesh & Trivedi, 2019). Hands-on-wheel systems typically capture driver behaviors through vehicle sensors that provide measurements such as drivers' hand placement and grip on the steering wheel (Dong et al., 2010; Doudou et al., 2019) or torque input.

Physiological measures, while considered robust indicators of driver state (Begum et al., 2013), are less practical to implement in commercially available vehicles. They can directly measure the variations in neural activity and related biological factors and are often used in research settings (see Chowdhury et al., 2018, for a review). Electroencephalogram (EEG), functional magnetic resonance imaging (fMRI), electrooculography (EOG), electromyography (EMG), cardiac activity, and skin conductance are commonly used to measure neural electrical activity, eye/facial muscle activation, muscle fatigue, heart rate, and other indicators of alertness and attentiveness (Dong et al., 2010; Doudou et al., 2019; Gonçalves & Bengler, 2015). While physiological measurements can be impractical to implement in production vehicles, certain measures, such as skin conductance, can be collected using steering wheel sensors.

Driver Posture and Body Position

When driving vehicles with L2 driving automation, drivers must be physically ready at any time to assume manual control safely and effectively. Physical (or motor) readiness is described as the driver being able to engage the vehicle control interfaces with minimal delay (Zeeb et al., 2015). Some market-ready, hands-off DMSs estimate physical readiness by requiring drivers to intermittently place their hands over, or grip, the steering wheel. Driver posture, seat position and recline status, as well as foot position can also be used in estimating a driver's physical readiness to regain control (Mioch et al., 2017). Similarly, Lenné et al. (2020) found that observation of facial relaxation may be indicative of driver attention and inattention.

Visual Attention and Distraction

Driver visual attention is primarily described by its visual indicators, including gaze location, saccades and fixations, blink frequency and eye closure rates, and gaze-proxy indicators, such as head orientation (Smith et al., 2003; Louw et al., 2019). Visual attention is critical for monitoring and navigation, as visual cues are the primary signals that the driver uses for hazard anticipation and mitigation (Crundall & Underwood, 2011; Mourant & Rockwell, 1970, 1972).

Distracted driving is "any activity that diverts attention from driving, including talking or texting on your phone, eating and drinking, talking to people in your vehicle, fiddling with the stereo, entertainment or navigation system — anything that takes your attention away from the task of safe driving" (NHTSA, n.d.). In contrast, inattention is the full absence of or insufficient allocation of attention to activities critical to driving (Regan et al., 2011). Since this definition does not include a competing activity, it makes inattention a construct that applies to other states, such as drowsiness (discussed later).

Studies of driver behaviors generally point to reduced monitoring, hazard detection, and vehicle control performance in conditions of visual distraction, and certain reductions in performance with cognitive distraction (Lee, 2014; Liang & Lee, 2010). Research suggests partial driving automation may increase the likelihood of distracted driving. Carsten and colleagues (2012) found that when drivers were supported by automation (e.g., lateral control) they tended to disengage from the driving task by shifting their visual and cognitive attention to engage in other activities. This disengagement and shift in attention became more prevalent with increasing automation capabilities.

When drivers perform secondary tasks and the vehicle automation is in control, these task interactions slow driver reaction and takeover times, and increase post-takeover lane excursions (Payre et al., 2017; Shen & Neyens, 2017). Interestingly, Zeeb and colleagues (2016) found minimal decrements in takeover time from participants responding to non-critical events after completion of a task (writing an email, reading news, watching a video). However, the takeover quality measured using lateral positioning was significantly affected. Drivers deviated on average 8 to 9 cm more in the "news" and "video" conditions than in a "no-task" condition. The authors concluded that this indicated reduced processing and situation awareness of the scene, even though automatic motor readiness was established with ease. This body of work demonstrates the negative and consequential effects associated with distracted driving.

External Indicators of Distraction

Many of the effects of distraction—irrespective of the source of the distraction—are reflected in visual behaviors and sometimes body movements. Liang and Lee (2010) found that visual, cognitive, and combined distractions all resulted in slow saccades and reduced gaze concentration. However, visual distraction generally interfered with steering and hazard detection performance more severely than cognitive distraction. While distracted driving can involve tasks that take drivers' eyes off the road, many tasks increase risk of a crash by occupying attentional resources (Patten et al., 2004; Strayer et al., 2015). In a driving simulator study where participants performed a difficult cognitive task (n-back task; see Mehler et al., 2011 for a common version of the task), changes in pupil size were the most sensitive to workload imposed by secondary tasks while fixation duration and driving performance metrics were not sensitive to changes in cognitive demand (Niezgoda et al., 2015). Eye blink rate has also been shown to be an indicator of workload, with research demonstrating blink inhibition when drivers are under higher visual demand but increased under higher mental workload (Recarte et al., 2008; Marquart et al., 2015). Changes in blinking and pupil dilation together can also indicate changes in workload (Siegle et al., 2008).

Additionally, head position may be coupled with gaze detection to provide an indication of what a driver is attending to (Fridman et al., 2016; Land & Horwood, 1996; Muñoz et al., 2015). Head position may be a proxy for distraction when measures of gaze are unavailable, but the external situation and road geometry should be considered when making inferences. For example, eye movements of a driver monitoring the near/far and tangent points during approach and exit of curves tend to be less associated with head position (Muñoz et al., 2015; Murata et al., 2012). Additionally, aggregate measures such as the mean and total fixation time, spatial spread of glance location, and mean saccade length have been shown to be indicators of distracted driving (Crundall & Underwood, 2011) while temporal and spatio-contextual patterns of glances can help discriminate one form of inattention from another. Many of these measures are dependent on advancements in sensing technology and on-board processing units.

Neurophysiological Indicators of Distraction

A body of work has shown patterns of neurological signals related to driver distraction. Various brain regions are involved in the planning and execution of manual driving tasks (Navarro et al., 2018; Spiers & Maguire, 2007), three of which are primary to operational vehicle control—the right extrastriate cortex, the right anterior cerebellum, and the right mediodorsal thalamus. These three regions support complex visuomotor planning and coordination, and are related to the execution of highly practiced actions (Navarro et al., 2018). Other regions are key to tasks that span the strategic and tactical levels of driving, and involve sensory, cognitive, and motor implications that are central to hazard identification and response, visuospatial processing and memory, and adaptation of motor responses based on new goals (Chung et al., 2014; Navarro et al., 2018). These skills are key for safe and effective vehicle takeover.

There is evidence that dual task performance of an auditory sentence comprehension task and a visual image pseudo-driving task can lead to decreased activation in the cognitive processing regions active in processing the driving task (right parietal and bilateral occipital regions of the cortex) compared to single task performance (Uchiyama et al., 2012). A simulator study found similar results in that cognitive processing of auditory information can lead to reduced activation of the regions of the brain that are important for visual alertness and attention (Schweizer et al., 2013). Regions that support sensory processing are also detrimentally affected when dual tasks are performed compared to a single task, even when the tasks' stimuli are presented in different sensory modalities (Just et al., 2001).

Neurophysiological evidence suggests that engagement in a secondary activity, such as listening to the radio when the drivers' eyes are on the road, can impede both intake and comprehension of information and reduce takeover performance (Han et al., 2023). Various regions of the brain are recruited together as a network for multitask performance; and an increase in workload can result in a cognitive bottleneck that impedes performance in one or more tasks (Navarro et al., 2018; Schweizer et al., 2013). This finding is key to the design of DMS-based mitigation strategies. Warning modalities are sometimes determined by leveraging an available sensory channel to prevent overload on a single channel. For example, a driver who is texting may be alerted by auditory tones and verbal messages to prevent visual overload. However, it is possible that disengaged drivers may need to be alerted with sensory channels, and in an increasingly urgent way, to reorient attention.

Challenges With Measuring Distraction

While gaze metrics have value, visual behaviors may not be indicative of full cognitive attentiveness—drivers may look, but not process the information relevant to the stimuli (Shinar, 2008; Crundall & Underwood, 2011). For example, a driver engaged in mind wandering may have their eyes on the road but fail to comprehend passing signs or scan for hazards due to distraction. A simulator study demonstrated that even though drivers who reported "mind wandering" were looking at the road, their gaze patterns were narrowly focused on a region of the forward roadway (He et al., 2011). Thus, simple eyes on/off road measurements are unlikely to be sensitive to cognitive distraction. Even when drivers' eyes remain on the road, their cognitive resources can still be taxed, potentially impacting performance. Harbluk and colleagues (2007) reported that the engagement of drivers in cognitive tasks led to a reduction in the time spent monitoring peripheral scene locations; and a temporal concentration of gaze in the forward roadway (also see Lee & Boyle, 2015; Lee et al., 2009; Liang & Lee, 2010). Monitoring of mirrors and instruments, traffic signals, and intersections was reduced in the task condition (Harbluk et al., 2007), and participants in this study also had slower reactions to events that incited hard braking responses. An approach to DMS that considers the temporal and spatio-contextual variations in visual measures can help investigate features such as gaze concentration to improve specificity of the type of distraction (e.g., scanpath analysis [Crundall & Underwood, 2011]; task analytic eye glance analysis [Hoekstra-Atwood et al., 2019]). Together, these studies demonstrate that driver gaze metrics should be carefully evaluated when drawing conclusions about attentiveness, especially under high-workload conditions.

Drowsiness

Fatigue is related to task-induced alertness decrements, whereas drowsiness is often used as a general term that incorporates the effects of the task and task environment, as well as the biological and circadian cycles (but there is no commonly accepted definition or distinction, see Hecht et al., 2019 for a brief discussion). For this review, drowsiness was used as a general construct of the gradual decline in alertness as compared to a normal energy state (Wang et al., 2006). Alertness denotes an energetic state, in contrast to attention, which is viewed as the channelization of that available energy towards one or more activities.

Steering input has been demonstrated as an indicator of drowsiness. In a longitudinal simulator study of driver drowsiness during manual driving, 87 metrics of drowsiness were reduced into two principal components, which primarily reflected steering variability and variability of lateral lane position (Forsman et al., 2013). Steering variability was found to reliably predict even moderate levels of drowsiness. Such detection of drowsiness in manual control largely relies on vehicle control and handling parameters (McDonald et al., 2018).

While useful under manual control, steering wheel measures are uninformative with active partial and higher levels of driving automation where lateral and longitudinal vehicle control is managed by the vehicle. Drowsiness can set in quickly when the driver is removed from the vehicle control loop, and driver behavioral measures should be used to determine state changes. Jarosch and colleagues (2019) reported that the onset of drowsiness was rapid in an on-road, Wizard-of-Oz automated driving study. Participants were asked to perform one of two tasks—a monotonous monitoring task and a free-choice activity that included watching videos of the participant's choice. Drowsiness onset, as measured by percent of eyelid closure over the pupil over time (PERCLOS) and the Karolinska Sleepiness Scale, occurred more rapidly in the monotonous task condition than in the free-choice condition. In a simulator study, the authors also found that takeover performance was reduced as a result of drowsiness induced by a monotonous monitoring task (Jarosch et al., 2017).

Indicators of Drowsiness

Eye closure is a measure commonly used as an indicator of drowsiness. PERCLOS is a reliable measure of drowsiness (Wang et al., 2006). In addition, mean closure over a duration (MEANCLOS) and average eye closure speed (AECS) are also used in drowsiness estimation (Gonçalves & Bengler, 2015). Eye blinks are also used in drowsiness detection (as well as workload measurement, wherein the blink behaviors are different). The number of blinks as well as blink duration increase as task time increases (Benedetto et al., 2011; Fukuda et al., 2005; Martins & Carvalho, 2015).

As discussed above, changes in blinking behavior can be indicative of driver experiences (e.g., increased cognitive workload). The direction of gaze, head/neck orientation (specifically, head pitch angle), seating and foot pressure, measure of relaxation of grip on the steering wheel, and facial features (such as mouth open/sag) are secondary measures that may be used to improve predictability of drowsiness (Heitmann et al., 2001; Murata et al., 2012, 2013). Measuring variables over time such as PERCLOS, blink duration, and AECS can be used to indicate progression of drowsiness. In more extreme instances of drowsiness, drivers may experiences microsleeps, which are brief periods of loss of attention and closed eyes or "blank" stares during which the driver may "look at, but not see" hazards and objects (Boyle et al., 2008). These episodes are typified by detrimental vehicle performance, particularly lane excursions and steering reversals. Microsleep episodes can happen any time of the day but are typically found in the daytime in drivers with sleep problems (Boyle et al., 2008). Blink duration is associated with microsleeps and is generally considered an indicator of the onset of drowsiness (Mulhall et al., 2020; Rodriguez et al., 2018; Schleicher et al., 2008).

In the realm of neurophysiology, the onset of drowsiness has been found to result in reduced activation in the parietal regions of the brain that inhibit sensory processing and comprehension, which poses challenges in selecting appropriate mitigation strategies (Chen et al., 2018; Forsman et al., 2013). Research into the neurophysiology of drowsiness is still emerging with nonconvergent evidence on the nature of drowsiness-induced decreases in activation in different brain regions.

Technology Review

The objective of the technology review was to summarize a sample of common DMSs that are used in current passenger vehicles.

Method

The considerations listed below helped to focus the scope of the technology review; these elements were used to guide all article searches and the selection of relevant sources to review.

The review of OEM DMSs focused on OEM material, consumer reviews, and websites, and followed a three-step process:

1. Researchers conducted preliminary searches to identify a sample of OEMs that are currently equipping their vehicles with DMSs or planning to equip them soon.
2. The team investigated the DMS information available to the public and used by these OEMs (e.g., via OEM websites, owner's manuals, press releases, automotive and dealership blogs).
3. Key details were documented, such as DMS strategy, re-engagement strategies, and how the system presents messages to the driver.

Key Findings

- The reviewed vehicles' L2 features varied in capabilities.
- The predominant DMS strategy for many of the reviewed systems was hand placement on the steering wheel. Camera systems are used as the primary detection method for other reviewed systems.
- Driver engagement using hands-on-wheel systems can be estimated through torque or capacitance sensors. The reviewed camera systems monitor the driver's eyes and gaze patterns to determine engagement with the driving task.
- Operating requirements of the L2 capabilities reviewed are generally at or above 20 mph, and the presence of lane markings is a key requirement for most of these systems. A range of weather, lighting, and road geometry conditions influence operation.
- For the alerting strategies of the reviewed systems, the most common sensory modalities of presentation were visual and auditory. Many systems used a graded alerting strategy that often-engaged multi-modal features.

Stakeholder Interviews

The purpose of the stakeholder interviews was to gather information about industry trends, design policies, philosophies, use case scenarios, and functional requirements associated with DMSs from knowledgeable stakeholders and industry representatives. Individual or group interviews with SMEs were conducted with researchers or representatives from eight OEMs and a non-OEM, nonprofit scientific and educational organization.

Method

Representatives from each organization were contacted via email and were scheduled for an online Webex interview. All interviews occurred in 2021. The following questions were used to guide each interview.

- What is your driver monitoring system? Please provide a brief description.
- Provide an overview of the approaches used in the system (eyes-on-road, hands-on-wheel) – are there others?
- What are the current sensor, design, and implementation challenges? What challenges were overcome and how?
    - What are key sensor, roadway, or data challenges that you face?
    - What measures and metrics do you use to determine driver engagement/distraction, impairment, or fatigue?
    - What specific data about the driver's behavior do you use to make state determinations?
- What factors influence you to include (or not) DMSs in an L2?
- What, in your opinion, is the level of maturity of DMS technologies- where and how can they improve?
- What ADAS applications are the best use of DMSs (summary of use cases and scenarios)?
- What are the key ways that DMSs are less effective than hoped for?
    - What are the types of system failures anticipated within design?
- What are future advances in methods?

Key Findings

The interviews gathered information about various DMSs either being produced or researched by the organizations interviewed. Broadly, current DMSs can be grouped into two categories: hands-on-wheel or eyes-on-road.

Hands-on-Wheel DMS in L2 and Manual Steering

Steering torque input is an example of one DMS technology that is typically used to infer if the driver is drowsy or inattentive. After detection, an alert can be given to the driver. A challenge in this system is making sure the algorithm can differentiate whether changes in the steering pattern reflect changes in the driver's state (i.e., less attention/increased drowsiness) or changes in the environment (e.g., side winds, roadway type, traffic levels, weather).

A hands-on-wheel method in an L2 system can be used as an indirect indicator of whether a driver is engaged in the driving task. The general approach of such a method is to detect the driver's hands touching the steering wheel using capacitive and/or steering inputs from the driver. If sufficient feedback from the driver is not received, manufacturers tend to present escalating warnings. Importantly, hands-on-wheel DMS, in the absence of other measures, do not indicate whether the driver is visually attending to the roadway. Furthermore, some hands-on-wheel DMSs have shown to be vulnerable to spoofing with weights or other devices (Siddiqui, 2023).

Eyes-on-Road DMS in L2

In typical eyes-on-road DMSs, a near-infrared (IR) camera monitors drivers' eyes, gaze, and/or head position to determine whether visual attention is towards or away from the road. While the driver's direction of gaze is a more direct measure of attentiveness than hands-on-wheel, it is not a perfect measure. Drivers may be cognitively distracted (e.g., mind wandering) or otherwise failing to scan the environment adequately visually, and identification of drivers who are "looking but not seeing" requires a thorough understanding of gaze behavior. Nonetheless, eyes-off-the-road time is correlated with distraction, despite the limitation that drivers may "look but not see."

Discussion

The purpose of this task was to identify DMS strategies and understand the technological landscape. These questions were addressed through three separate but complementary activities: a human factors-focused literature review, technology review, and interviews with OEMs and other SMEs. The key findings and implications are discussed next.

Many vehicles currently on the road include L2 systems that simultaneously support both lateral and longitudinal vehicle control. Because L2 systems are not able to perform the entire dynamic driving task, driver attentiveness is especially important to both recognize the need to resume control or respond to take over requests.

Maintaining the driver's visual and cognitive engagement in the driving task is critical for safe and effective use of L2 systems. However, there are challenges associated with assessing driver engagement. Additionally, it is important to consider that assessing whether drivers' eyes are on the road may be insufficient for fully estimating driver engagement. This consideration is of particular importance when drivers are at higher risk for task disengagement (e.g., driving long distances). While takeover requests are an important component of L2 systems, it is important to note that drivers may need to intervene to maintain safety in the absence of any alert from the vehicle (e.g., if a hazard emerges that is outside the L2 system's detection or response capabilities).

The current work also sought to understand the impacts of distraction and drowsiness on driver performance. Literature revealed that distracted driving was found to negatively affect the quality of transfer of control from automation to the driver, particularly impacting lateral positioning post transfer. This is a particular concern in complex environments such as narrow roadways or dense traffic, in which slight lane deviations could have severe consequences, such as the vehicle running off the road or colliding with another vehicle. Drowsiness can lead to a reduction in sensory processing, meaning drivers may be delayed in or unable to comprehend important environmental information.

While DMS technologies are in the market, they are unable to fully capture all forms of driver inattention.

Limitations

This investigation of DMS for L2 systems had some notable limitations. The information-gathering efforts of this line of research were limited to information publicly available at the time. DMS is a rapidly evolving field and much of the most advanced research and development is proprietary and not available to the public. Therefore, the findings of this research do not necessarily reflect the most recent advancements in DMS technology. This research also involved a review of a sample of production vehicle DMS and interviews with only 9 SMEs, so not all vehicle manufacturers' approaches and expert opinions were represented. Finally, this research involved a broad review of L2 DMS approaches and did not provide a detailed assessment of specific features of DMS, such as the algorithms used as a basis to provide alerts and interventions, or the detailed characteristics of those alerts and interventions.

References

Amodio, A., Ermidoro, M., Maggi, D., Formentin, S., & Savaresi, S. M. (2018). Automatic detection of driver impairment based on pupillary light reflex. *IEEE Transactions on Intelligent Transportation Systems, 20*(8), 3038-3048.

Arnedt, J. T., Wilde, G. J., Munt, P. W., & MacLean, A. W. (2001). How do prolonged wakefulness and alcohol compare in the decrements they produce on a simulated driving task? *Accident Analysis & Prevention*, *33*(3), 337-344.

Arora, S. S., Vatsa, M., Singh, R., & Jain, A. (2012, March 29-April 1). *Iris recognition under alcohol influence: A preliminary study*. 5th IAPR International Conference on Biometrics (pp. 336-341), New Delhi, India. Institute of Electrical and Electronics Engineers.

Bainbridge, L. (1983). Ironies of automation. In G. Johannsen & J.E. Rijnsdorp, (Eds.), *Analysis, Design and Evaluation of Man–Machine Systems* (pp. 129-135) [Proceedings of the IFAC/IFIP/IFORS/IEA Conference, Baden-Baden, Federal Republic of Germany, 27–29 September 1982]. Pergamon.

Begum, S. (2013, October 6-9). *Intelligent driver monitoring systems based on physiological sensor signals: A review*. 16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013), (pp. 282-289). Kurhaus, The Hague, The Netherlands.

Beideman, L. R., & Stern, J. A. (1977). Aspects of the eyeblink during simulated driving as a function of alcohol. *Human Factors*, *19*(1), 73-77.

Benedetto, S., Pedrotti, M., Minin, L., Baccino, T., Re, A., & Montanari, R. (2011). Driver workload and eye blink duration. *Transportation Research Part F: Traffic Psychology and Behaviour*, *14*(3), 199–208. https:/doi.org/10.1016/j.trf.2010.12.001

Boyle, L. N., Tippin, J., Paul, A., & Rizzo, M. (2008). Driver performance in the moments surrounding a microsleep. *Transportation Research Part F: Traffic Psychology and Behaviour*, *11*(2), 126–136. https:/doi.org/10.1016/j.trf.2007.08.001

Burian, S. E., Hensberry, R., & Liguori, A. (2003). Differential effects of alcohol and alcohol expectancy on risk-taking during simulated driving. *Human Psychopharmacology: Clinical and Experimental*, *18*(3), 175-184.

Calhoun, V. D., & Pearlson, G. D. (2012). A selective review of simulated driving studies: combining naturalistic and hybrid paradigms, analysis approaches, and future directions. *Neuroimage*, *59*(1), 25-35.

Campbell, H., Doughty, M. J., Heron, G., & Ackerley, R. G. (2001). Influence of chronic alcohol abuse and ensuing forced abstinence on static subjective accommodation function in humans. *Ophthalmic and Physiological Optics*, *21*(3), 197-205.

Carsten, O., Lai, F. C., Barnard, Y., Jamson, A. H., & Merat, N. (2012). Control task substitution in semiautomated driving: Does it matter what aspects are automated? *Human Factors*, *54*(5), 747–761.

Castro, J. J., Pozo, A. M., Rubiño, M., Anera, R. G., & Jimenez del Barco, L. (2014). Retinal-image quality and night-vision performance after alcohol consumption. *Journal of Ophthalmology*, *2014*.

Chen, J., Wang, H., & Hua, C. (2018). Assessment of driver drowsiness using electroencephalogram signals based on multiple functional brain networks. *International Journal of Psychophysiology*, *133*, 120–130. https:/doi.org/10.1016/j.ijpsycho.2018.07.476

Chowdhury, A., Shankaran, R., Kavakli, M., & Haque, M. M. (2018). Sensor applications and physiological features in drivers' drowsiness detection: A review. *IEEE Sensors Journal*, *18*(8), 3055-3067.

Crundall, D., & Underwood, G. (2011). Chapter 11 - Visual attention while driving: measures of eye movements used in driving research. In B. E. Porter (Ed.), *Handbook of Traffic Psychology* (pp. 137–148). Academic Press. https:/doi.org/10.1016/B978-0-12-381984-0.10011-6

Driver Alcohol Detection System for Safety. (n.d.). *Touch technology*. https:/www.dadss.org/touch-technology

Das, D., Zhou, S., & Lee, J. D. (2012). Differentiating alcohol-induced driving behavior using steering wheel signals. *IEEE Transactions on Intelligent Transportation Systems*, *13*(3), 1355-1368.

Dong, Y., Hu, Z., Uchimura, K., & Murayama, N. (2010). Driver inattention monitoring system for intelligent vehicles: A review. *IEEE Transactions on Intelligent Transportation Systems*, *12*(2), 596–614.

Doudou, M., Bouabdallah, A., & Berge-Cherfaoui, V. (2019). Driver drowsiness measurement technologies: Current research, market solutions, and challenges. *International Journal of Intelligent Transportation Systems Research*, 1–23.

Fillmore, M. T., & Vogel-Sprott, M. J. A. C. (1998). Behavioral impairment under alcohol: cognitive and pharmacokinetic factors. *Alcoholism: Clinical and Experimental Research*, *22*(7), 1476-1482.

Forsman, P. M., Vila, B. J., Short, R. A., Mott, C. G., & Van Dongen, H. P. (2013). Efficient driver drowsiness detection at moderate levels of drowsiness. *Accident Analysis & Prevention*, *50*, 341–350.

Fridman, L., Lee, J., Reimer, B., & Victor, T. (2016). "Owl" and "Lizard': Patterns of head pose and eye pose in driver gaze classification. *IET Computer Vision*, *10*(4), 308–314.

Fukuda, K., Stern, J. A., Brown, T. B., & Russo, M. B. (2005). Cognition, blinks, eye-movements, and pupillary movements during performance of a running memory task. *Aviation, Space, and Environmental Medicine*, *76*(7), C75–C85.

Gonçalves, J., & Bengler, K. (2015). Driver state monitoring systems–transferable knowledge manual driving to HAD. *Procedia Manufacturing*, *3*, 3011–3016.

Guo, K., Zhai, T., Purushothama, M. H., Dobre, A., Meah, S., Pashollari, E., Vaish, A., DeWilde, C., & Islam, M. N. (2022). Contactless vital sign monitoring system for in-vehicle driver monitoring using a near-infrared time-of-flight camera. *Applied Sciences, 12*(9), 4416.

Halin, A., Verly, J. G., & Van Droogenbroeck, M. (2021). Survey and Synthesis of State of the Art in Driver Monitoring. *Sensors,* 21(16). https:/doi.org/10.3390/s21165558

Han, Y., Wang, T., Shi, D., Ye, X., & Yuan, Q. (2023). The effect of multifactor interaction on the quality of human-machine co-driving vehicle take-over. *Sustainability*, *15*(6), 5131.

Hancock, P. A. (2013). Driven to distraction and back again. In M. A. Regan, J. D. Lee, & T.W. Victor (Eds.) *Driver Distraction and Inattention: Advances in Research and Countermeasures, Volume 1,* 9–26. Ashgate.

Harbluk, J. L., Noy, Y. I., Trbovich, P. L., & Eizenman, M. (2007). An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance. *Accident Analysis & Prevention*, *39*(2), 372–379. https:/doi.org/10.1016/j.aap.2006.08.013

Harford, M., Villarroel, M., Jorge, J., Redfern, O., Finnegan, E., Davidson, S., Young, J. D., Tarassenko, L., & Watkinson, P. (2022). Contactless skin perfusion monitoring with video cameras: tracking pharmacological vasoconstriction and vasodilation using photoplethysmographic changes. *Physiological Measurement*, *43*(11), 115001.

Harrison, E. L., & Fillmore, M. T. (2005). Are bad drivers more impaired by alcohol?: Sober driving precision predicts impairment from alcohol in a simulated driving task. *Accident Analysis & Prevention*, *37*(5), 882-889.

Hawthorne, J. S., & Wojcik, M. H. (2006). Transdermal alcohol measurement: A review of the literature. *Canadian Society of Forensic Science Journal*, *39*(2), 65-71.

He, J., Becic, E., Lee, Y. C., & McCarley, J. S. (2011). Mind wandering behind the wheel: Performance and oculomotor correlates. *Human Factors*, *53*(1), 13-21.

Hecht, T., Feldhütter, A., Radlmayr, J., Nakano, Y., Miki, Y., Henle, C., & Bengler, K. (2019). A review of driver state monitoring systems in the context of automated driving. In S. Bagnara, R.Tartaglia, S. Albolino, T. Alexander, & Y. Fujita, (Eds.). *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018). IEA 2018. Advances in Intelligent Systems and Computing*, vol 823. Springer, Cham. https:/doi.org/10.1007/978-3-319-96074-6_43.

Heitmann, A., Guttkuhn, R., Aguirre, A., Trutschel, U., & Moore-Ede, M. (2001). Technologies for the monitoring and prevention of driver fatigue. *Proceedings of the First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, 81–86. https:/doi.org/10.17077/drivingassessment.1013

Helland, A., Jenssen, G. D., Lervåg, L. E., Westin, A. A., Moen, T., Sakshaug, K., Lydersen, S., Mørland, J., & Slørdal, L. (2013). Comparison of driving simulator performance with real driving after alcohol intake: A randomised, single blind, placebo-controlled, cross-over trial. *Accident Analysis & Prevention*, *53*, 9-16.

Hoekstra-Atwood, L., Prendez, D., Campbell, J. L., & Richard, C. M. (2019). Some on-road glances are more equal than others: Measuring engagement in the driving task. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 63*(1), 1986–1990.

Irwin, C., Iudakhina, E., Desbrow, B., & McCartney, D. (2017). Effects of acute alcohol consumption on measures of simulated driving: a systematic review and meta-analysis. *Accident Analysis & Prevention*, *102*, 248-266.

Jackson, M. L., Kennedy, G. A., Clarke, C., Gullo, M., Swann, P., Downey, L. A., Hayley, A. C., Pierce, R. J., & Howard, M. E. (2016). The utility of automated measures of ocular metrics for detecting driver drowsiness during extended wakefulness. *Accident Analysis & Prevention*, *87*, 127-133.

Jarosch, O., Kuhnt, M., Paradies, S., & Bengler, K. (2017). It's out of our hands now! Effects of non-driving related tasks during highly automated driving on drivers' fatigue. *Proceedings of the Ninth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*.

Jarosch, O., Paradies, S., Feiner, D., & Bengler, K. (2019). Effects of non-driving related tasks in prolonged conditional automated driving–A Wizard of Oz on-road approach in real traffic environment. *Transportation Research Part F: Traffic Psychology and Behaviour*, *65*, 292–305.

Jones, A. W., & Andersson, L. (2003). Comparison of ethanol concentrations in venous blood and end-expired breath during a controlled drinking study. *Forensic Science International*, *132*(1), 18-25.

Just, M. A., Carpenter, P. A., Keller, T. A., Emery, L., Zajac, H., & Thulborn, K. R. (2001). Interdependence of nonoverlapping cortical systems in dual cognitive tasks. *NeuroImage*, *14*(2), 417–426. https:/doi.org/10.1006/nimg.2001.0826

Kersloot, T., Flint, A., & Parkes, A. (2003, December 16-18). *Steering entropy as a measure of impairment.* Young Researchers Seminar, Lyon-Bron, France.

Klingholz, F., Penning, R., & Liebhardt, E. (1988). Recognition of low-level alcohol intoxication from speech signal. *Journal of the Acoustical Society of America*, *84*(3), 929-935.

Land, M., & Horwood, J. (1996). The relations between head and eye movements during driving. *Vision in Vehicles*, *5*, 153–160.

Lawson, B., Aguir, K., Fiorido, T., Martini-Laithier, V., Bouchakour, R., Burtey, S., Reynard-Carette, C. H., & Bendahan, M. (2019). Skin alcohol perspiration measurements using MOX sensors. *Sensors and Actuators B: Chemical*, *280*, 306-312.

Lee, J. D. (2014). Dynamics of driver distraction: The process of engaging and disengaging. *Annals of Advances in Automotive Medicine*, *58*, 24.

Lee, J. D., & Boyle, L. N. (2015). Is talking to your car dangerous? It depends: Prologue to the special section. *Human Factors*, *57*(8), 1297–1299.

Lee, J. D., Fiorentino, D., Reyes, M. L., Brown, T. L., Ahmad, O., Fell, J., Ward, N., & Dufour, R. (2010, August). *Assessing the feasibility of vehicle-based sensors to detect alcohol impairment* (Report No. DOT HS 811 358). National Highway Traffic Safety Administration. https://westerntransportationinstitute.org/wp-content/uploads/2016/08/4W2004_Final_Report.pdf

Lee, K., Hyun, S. A., & Oah, S. (2016). Detecting driver fatigue by steering wheel grip force. *International Journal of Contents*, *12*(1), 44-48.

Lee, Y.-C., Lee, J. D., & Boyle, L. N. (2009). The interaction of cognitive load and attention-directing cues in driving. *Human Factors*, *51*(3), 271–280.

Lenné, M. G., Roady, T., & Kuo, J. (2020). Driver state monitoring for decreased fitness to drive. In D. L. Fisher, W. J. Horrey, J. D. Lee, & M. A. Regan (Eds.), *Handbook of Human Factors for Automated, Connected and Intelligent Vehicles* (Chapter 11). CRC Press.

Liang, Y., & Lee, J. D. (2010). Combining cognitive and visual distraction: Less than the sum of its parts. *Assessing Safety With Driving Simulators*, *42*(3), 881–890. https:/doi.org/10.1016/j.aap.2009.05.001

Llaneras, R. E., Salinger, J., & Green, C. A. (2013). Human factors issues associated with limited ability autonomous driving systems: Drivers' allocation of visual attention to the forward roadway. *Proceedings of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*.

Louw, T., Kuo, J., Romano, R., Radhakrishnan, V., Lenné, M. G., & Merat, N. (2019). Engaging in NDRTs affects drivers' responses and glance patterns after silent automation failures. *Transportation Research Part F: Traffic Psychology and Behaviour*, *62*, 870-882.

Marczinski, C. A., Harrison, E. L., & Fillmore, M. T. (2008). Effects of alcohol on simulated driving and perceived driving impairment in binge drinkers. *Alcoholism: Clinical and Experimental Research*, *32*(7), 1329-1337.

Marinkovic, K., Halgren, E., Klopp, J., & Maltzman, I. (2000). Alcohol effects on movement-related potentials: a measure of impulsivity? *Journal of Studies on Alcohol, 61*(1), 24-31.

Marmot, M. G., Elliott, P., Shipley, M. J., Dyer, A. R., Ueshima, H. U., Beevers, D. G., Stamler, R., Kesteloot, H., Rose, G., & Stamler, J. (1994). Alcohol and blood pressure: the INTERSALT study. *BMJ*, *308*(6939), 1263-1267.

Marple-Horvat, D. E., Cooper, H. L., Gilbey, S. L., Watson, J. C., Mehta, N., Kaur-Mann, D., Wilson, M., & Keil, D. (2008). Alcohol badly affects eye movements linked to steering, providing for automatic in-car detection of drink driving. *Neuropsychopharma-cology*, *33*(4), 849-858.

Marquart, G., Cabrall, C., & de Winter, J. (2015). Review of eye-related measures of drivers' mental workload. *Procedia Manufacturing*, *3*, 2854-2861.

Martins, R., & Carvalho, J. (2015). Eye blinking as an indicator of fatigue and mental load-a systematic review. *Occupational Safety and Hygiene III*, *10*.

Maurage, P., Masson, N., Bollen, Z., & D'Hondt, F. (2020). Eye tracking correlates of acute alcohol consumption: A systematic and critical review. *Neuroscience & Biobehavioral Reviews*, *108*, 400-422.

McDonald, A. D., Lee, J. D., Schwarz, C., & Brown, T. L. (2018). A contextual and temporal algorithm for driver drowsiness detection. *Accident Analysis & Prevention*, *113*, 25–37. https:/doi.org/10.1016/j.aap.2018.01.005

Mehler, B., Reimer, B., & Dusek, J. A. (2011). MIT AgeLab delayed digit recall task (n-back) (Working paper 2011-3B). *Massachusetts Institute of Technology*.

Mets, M. A., Kuipers, E., de Senerpont Domis, L. M., Leenders, M., Olivier, B., & Verster, J. C. (2011). Effects of alcohol on highway driving in the STISIM driving simulator. *Human Psychopharmacology: Clinical and Experimental*, *26*(6), 434-439.

Mioch, T., Kroon, L., & Neerincx, M. A. (2017). Driver readiness model for regulating the transfer from automation to human control. *Proceedings of the 22nd International Conference on Intelligent User Interfaces*.

Moser, A., Heide, W. & Kömpf, D. (1998). The effect of oral ethanol consumption on eye movements in healthy volunteers. *Journal of Neurology, 245*, 542–550. https:/doi.org/10.1007/s004150050240

Moskowitz, H., & Burns, M. (1990). Effects of alcohol on driving performance. *Alcohol Health & Research World*, *14*(1), 12-15.

Mothers Against Drunk Driving (2021, May 12). Updated report: Advanced drunk driving prevention technologies (Edition Two). [Docket submission, Document ID NHTSA-2020-0102 in Regulations.gov]. https:/downloads.regulations.gov/NHTSA-2020-0102-0013/attachment_1.pdf

Mourant, R. R., & Rockwell, T. H. (1970). Mapping eye-movement patterns to the visual scene in driving: An exploratory study. *Human Factors*, *12*(1), 81–87.

Mourant, R. R., & Rockwell, T. H. (1972). Strategies of visual search by novice and experienced drivers. *Human Factors*, *14*(4), 325–335.

Mulhall, M. D., Cori, J., Sletten, T. L., Kuo, J., Lenné, M. G., Magee, M., Spina, M.-A., Collins, A., Anderson, C., Rajaratnam, S. M. W., & Howard, M. E. (2020). A pre-drive ocular assessment predicts alertness and driving impairment: A naturalistic driving study in shift workers. *Accident Analysis & Prevention*, *135*, 105386. https:/doi.org/10.1016/j.aap.2019.105386

Muñoz, M., Lee, J., Reimer, B., Mehler, B., & Victor, T. (2015). Analysis of drivers' head and eye movement correspondence: predicting drivers' glance location using head rotation data. *Proceedings of the Eighth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*.

Murata, A., Koriyama, T., & Hayami, T. (2012). A basic study on the prevention of drowsy driving using the change of neck bending angle and the sitting pressure distribution. In *Proceedings of the 51st Annual Conference of the Society of Instrument and Control Engineers of Japan,* 274–279.

Murata, A., Nakatsuka, A., & Moriwaka, M. (2013). Effectiveness of back and foot pressures for assessing drowsiness of drivers. *Proceedings of the 52nd Annual Conference of the Society of Instrument and Control Engineers of Japan,* 1754-1759.

National Highway Traffic Safety Administration. (2016). *The ABCs of BAC: A guide to understanding blood alcohol concentration and alcohol impairment* (Flyer. Report No. DOT HS 809 844). National Highway Traffic Safety Administration.

NHTSA. (2020). *Request for information: impaired driving technologies*. Federal Register, Vol. 85, No. 219. [Docket submission, Document ID NHTSA-2020-0102, 71987-71989 in Regulations.gov].

NHTSA. (n.d.) *Distracted driving.* [Web page]. www.nhtsa.gov/risky-driving/distracted-driving

Navarro, J., Reynaud, E., & Osiurak, F. (2018). Neuroergonomics of car driving: A critical meta-analysis of neuroimaging data on the human brain behind the wheel. *Neuroscience & Biobehavioral Reviews*, *95*, 464–479. https:/doi.org/10.1016/j.neubiorev.2018.10.016

Nicholson, M. E., Wang, M., Airhihenbuwa, C. O., Mahoney, B. S., Christina, R., & Maney, D. W. (1992). Variability in behavioral impairment involved in the rising and falling BAC curve. *Journal of Studies on Alcohol*, *53*(4), 349-356.

Niezgoda, M., Tarnowski, A., Kruszewski, M., & Kamiński, T. (2015). Towards testing auditory–vocal interfaces and detecting distraction while driving: A comparison of eye-movement measures in the assessment of cognitive workload. *Transportation Research Part F: Traffic Psychology and Behaviour*, *32*, 23–34. https:/doi.org/10.1016/j.trf.2015.04.012

Oscar-Berman, M., & Marinković, K. (2007). Alcohol: effects on neurobehavioral functions and the brain. *Neuropsychology Review*, *17*(3), 239-257.

Paton, A. (2005). Alcohol in the body. *BMJ, 330*(7482), 85-87.

Patten, C. J., Kircher, A., Östlund, J., & Nilsson, L. (2004). Using mobile telephones: cognitive workload and attention resource allocation. *Accident Analysis & Prevention*, *36*(3), 341-350.

Payre, W., Cestac, J., Dang, N.-T., Vienne, F., & Delhomme, P. (2017). Impact of training and in-vehicle task performance on manual control recovery in an automated car. *Transportation Research Part F: Traffic Psychology and Behaviour*, *46*, 216–227.

Pisoni, D. B., & Martin, C. S. (1989). Effects of alcohol on the acoustic-phonetic properties of speech: perceptual and acoustic analyses. *Alcoholism: Clinical and Experimental Research*, *13*(4), 577-587.

Rangesh, A., & Trivedi, M. M. (2019). Forced spatial attention for driver foot activity classification. *Proceedings of the IEEE/CVF International Conference on Computer Vision Workshops*.

Recarte, M. Á., Pérez, E., Conchillo, Á., & Nunes, L. M. (2008). Mental workload and visual impairment: Differences between pupil, blink, and subjective rating. *The Spanish Journal of Psychology*, *11*(2), 374-385.

Regan, M. A., Hallett, C., & Gordon, C. P. (2011). Driver distraction and driver inattention: Definition, relationship and taxonomy. *Accident Analysis & Prevention*, *43*(5), 1771–1781. https:/doi.org/10.1016/j.aap.2011.04.008

Rezaee-Zavareh, M. S., Salamati, P., Ramezani-Binabaj, M., Saeidnejad, M., Rousta, M., Shokraneh, F., & Rahimi-Movaghar, V. (2017). Alcohol consumption for simulated driving performance: A systematic review. *Chinese Journal of Traumatology*, *20*(3), 166-172.

Ridder, T., Ver Steeg, B., & Laaksonen, B. D. (2009). Comparison of spectroscopically measured tissue alcohol concentration to blood and breath alcohol measurements. *Journal of Biomedical Optics*, *14*(5), 054039.

Romanowicz, M., Schmidt, J. E., Bostwick, J. M., Mrazek, D. A., & Karpyak, V. M. (2011). Changes in heart rate variability associated with acute alcohol consumption: current knowledge and implications for practice and research. *Alcoholism: Clinical and Experimental Research*, *35*(6), 1092-1105.

SAE International. (2021). *Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles* (J3016_202104). www.sae.org/standards/content/j3016_202104/

Schiel, F., & Heinrich, C. (2009). Laying the foundation for in-car alcohol detection by speech. In *Tenth Annual Conference of the International Speech Communication Association*.

Schleicher, R., Galley, N., Briest, S., & Galley, L. (2008). Blinks and saccades as indicators of fatigue in sleepiness warnings: Looking tired? *Ergonomics*, *51*(7), 982–1010.

Schweizer, T., Kan, K., Hung, Y., Tam, F., Naglie, G., & Graham, S. (2013). Brain activity during driving with distraction: An immersive fMRI study. *Frontiers in Human Neuroscience*, *7*, 53. https:/doi.org/10.3389/fnhum.2013.00053

Shen, S., & Neyens, D. M. (2017). Assessing drivers' response during automated driver support system failures with non-driving tasks. *Journal of Safety Research*, *61*, 149–155.

Sheridan, T. B. (2002). *Humans and automation: system design and research issues*. John Wiley & Sons Inc.; Human Factors and Ergonomics Society.

Shinar, D. (2008). Looks are (almost) everything: Where drivers look to get information. *Human Factors*, *50*(3), 380–384.

Siddiqui, F. (2023, July 7). Tesla owners are using steering-wheel weights to drive hands-free. *The Washington Post*. / www.washingtonpost.com/technology/2023/07/07/tesla-fsd-autopilot-wheel-weights/

Siegle, G. J., Ichikawa, N., & Steinhauer, S. (2008). Blink before and after you think: Blinks occur prior to and following cognitive load indexed by pupillary responses. *Psychophysiology*, *45*(5), 679–687.

Silva, J. B. S., Cristino, E. D., Almeida, N. L. D., Medeiros, P. C. B. D., & Santos, N. A. D. (2017). Effects of acute alcohol ingestion on eye movements and cognition: a double-blind, placebo-*controlled* study. *PLOS One*, *12*(10), e0186061.

Smith, P., Shah, M., & da Vitoria Lobo, N. (2003). Determining driver visual attention with one camera. *IEEE Transactions on Intelligent Transportation Systems*, *4*(4), 205-218.

Spiers, H. J., & Maguire, E. A. (2007). Neural substrates of driving behaviour. *NeuroImage*, *36*(1), 245–255. https:/doi.org/10.1016/j.neuroimage.2007.02.032

Strayer, D. L., Cooper, J. M., Turrill, J., Coleman, J., Medeiros-Ward, N., & Biondi, F. (2013). *Measuring cognitive distraction in the automobile.* AAA Foundation for Traffic Safety.

Strayer, D. L., Turrill, J., Cooper, J. M., Coleman, J. R., Medeiros-Ward, N., & Biondi, F. (2015). Assessing cognitive distraction in the automobile. *Human Factors*, *57*(8), 1300-1324.

Tuchin, V. V. (2008). *Handbook of optical sensing of glucose in biological fluids and tissues*. CRC press.

Uchiyama, Y., Toyoda, H., Sakai, H., Shin, D., Ebe, K., & Sadato, N. (2012). Suppression of brain activity related to a car-following task with an auditory task: An fMRI study. *Transportation Research Part F: Traffic Psychology and Behaviour*, *15*(1), 25–37. https:/doi.org/10.1016/j.trf.2011.11.002

Valeo. (n.d.) *Driver Monitoring*. https:/www.valeo.com/en/driver-monitoring

Veldstra, J. L., Brookhuis, K. A., De Waard, D., Molmans, B. H., Verstraete, A. G., Skopp, G., & Jantos, R. (2012). Effects of alcohol (BAC 0.5‰) and ecstasy (MDMA 100 mg) on simulated driving performance and traffic safety. *Psychopharmacology*, *222*(3), 377-390.

Victor, T. W., Tivesten, E., Gustavsson, P., Johansson, J., Sangberg, F., & Ljung Aust, M. (2018). Automation expectation mismatch: Incorrect prediction despite eyes on threat and hands on wheel. *Human Factors, 60(8),* 1095-1116.

Vogel-Sprott, M. (1997). Is behavioral tolerance learned? *Alcohol Health and Research World*, *21*(2), 161-168.

Wang, Q., Yang, J., Ren, M., & Zheng, Y. (2006, June 21-23). Driver Fatigue Detection: A Survey. *2006 6th World Congress on Intelligent Control and Automation*, *2*, 8587–8591. Dalian, China. https:/doi.org/10.1109/WCICA.2006.1713656

West, R., Wilding, J., French, D., Kemp, R., & Irving, A. (1993). Effect of low and moderate doses of alcohol on driving hazard perception latency and driving speed. *Addiction*, *88*(4), 527-532.

Wörle, J., Metz, B., Thiele, C., & Weller, G. (2019). Detecting sleep in drivers during highly automated driving: The potential of physiological parameters. *IET Intelligent Transport Systems*, *13*(8), 1241–1248.

Yadav, A. K., & Velaga, N. R. (2020). Alcohol-impaired driving in rural and urban road environments: Effect on speeding behaviour and crash probabilities. *Accident Analysis & Prevention*, *140*, 105512.

Yang, S., Kuo, J., & Lenné, M. G. (2021). Effects of distraction in on-road level 2 automated driving: impacts on glance behavior and takeover performance. *Human Factors*, *63*(8), 1485-1497.

Zakhari, S. (2006). Overview: how is alcohol metabolized by the body? *Alcohol Research & Health*, *29*(4), 245.

Zeeb, K., Buchner, A., & Schrauf, M. (2015). What determines the take-over time? An integrated model approach of driver take-over after automated driving. *Accident Analysis & Prevention*, *78*, 212-221.

Zeeb, K., Buchner, A., & Schrauf, M. (2016). Is take-over time all that matters? The impact of visual-cognitive load on driver take-over quality after conditionally automated driving. *Accident Analysis & Prevention*, *92*, 230–239. https:/doi.org/10.1016/j.aap.2016.04.002

This page is intentionally left blank.

Table 9 Patent Citations

An, D. Y. (2019, May 30). *Vehicle and method for supporting driver safety thereof* (U.S. Patent No. 2019/0161091 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20190161091

Bahn, J. (2019, October 8). *Driver assistance apparatus* (U.S. Patent No. 10,435,027 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10435027

Benson, M. K., Lowell, D. R., Montgomery, S. M., Dexter, B. R., Bonk, J. T., Cummings, D. L., Haase, A. S., Baudu, S., Boussetta, R., Drubetskoy, P., Dacosta-Mallet, A.-I., & Mitchell, C. (2017, December 26). *Vehicle seat with integrated sensors* (U.S. Patent No. 9,848,814 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9848814

Berg-Neuman, T., & Gowan, J. L. (2017, October 3). *Device and system for monitoring operator biometric condition and blood alcohol presence to prevent driving of a vehicle by an alcohol or otherwise impaired operator* (U.S. Patent No. 9,775,565 B1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9775565

Biondo, W. A., McCall, C. E., & Proefka, D. T. (2012, June 12). *Vehicle immobilizer methods and apparatus based on driver impairment* (U.S. Patent No. 8,196,694 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/8196694

Bowers, K., Zaouk, A., Strassburger, R., Willis, M., & Dalal, N. (2020, April 2). *System and method for controlling operation of a vehicle using an alcohol detection apparatus* (U.S. Patent No. 2020/0101982 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20200101982

Breed, D. S. (2014, May 13). *Driver health and fatigue monitoring system and method* (U.S. Patent No. 8,725,311 B1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/8725311

Carroll, J., Bellehumeur, D., & Carroll, C. (2016, May 3). *System and method for detecting and measuring ethyl alcohol in the blood of a motorized vehicle driver transdermally and non-invasively in the presence of interferents* (U.S. Patent No. 9,326,713 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9326713

Casaburo, D., Kurz, D., & Knorr, S. (2019, January 29). *Augmented safety restraint* (U.S. Patent No. 10,189,434 B1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10189434

Fujita, E., Ogura, Y., Maeda, S., & Kojima, S.(2015, October 6). *Alcohol-drinking detecting system and computer program* (U.S. Patent No. 9,149,231 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9149231

Fung, K. C., Dick, T. J., & Hall, C. W. (2010, March 26). *System and method for determining changes in a body state* (U.S. Patent No. 10,238,304 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10238304

Fung, K. C., Dick, T. J., & Palande, D. (2018, December 11). *System and method for capturing and decontaminating photoplethysmopgraphy (PPG) signals in a vehicle* (U.S. Patent No. 10,153,796 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10153796

Hannon, M. (2017, September 12). *Apparatus, system, and method for detecting the presence of an intoxicated driver and controlling the operation of a vehicle* (U.S. Patent No. 9,758,039 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9758039

Hassani, A., Prakah-Asante, K. O., Melcher, D., Greenberg, J. A., Kochhar, D. S., Yeung, J. B., & Mayer, K. M. (2020, May 14). *Vehicle occupant impairment detection* (U.S. Patent No. 2020/0148231 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20200148231

Hök, B., Gester, R., Ljungblad, J., & Pettersson, H. (2017, September 28). *Sensor system for passive in-vehicle breath alcohol estimation* (U.S. Patent No. 20,170,274,768 A1). U.S. Patent and Trademark Office. https://patentimages.storage.googleapis.com/f4/58/e4/-f50d7c73b88cbb/US20170274768A1.pdf

Kane, A. P., Murrish, R. W., Kinoshita, S., & Chavalit, W. (2020, September 29). *Management of autonomous vehicle driving features based on driver state* (U.S. Patent No. 10,789,973 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10789973

Kim, K. Y., & Park, J. M. (2020, January 14). *Health measurement system for vehicle's driver and warning method* (U.S. Patent No. 10,532,658 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10532658

Kobayashi, H., Muguruma, A., Sugiyama, Y., Higashihara, S., Matsuo, R., & Yamamuro, N. (2019, July 11). *Vehicle control device, vehicle control method, and non-transitory computer readable medium storing vehicle control program* (U.S. Patent No. 2019/0210607 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20190210607

Kulkarni, G. (2020, September 10). *Vehicular driver monitoring system using breath sensor* (U.S. Patent No. 2020/0283001 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20200283001

Lakhani, H., Schaaf, T., Nicolich-Henkin, L. R., DeMatos, R., & Yu, M. (2022, August 2). *Vehicle voice user interface* (U.S. Patent No. 11,404,075 B1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/11404075

Ljungblad, J. (2021, July 1). *Combined vehicle mounted breath analyzing and HVAC system and method* (Patent No. WO 2021/002796). World Intellectual Property Organization. https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2021002796

Miller, T. L., Watkins, S. A., Bennie, B., Porter, M. E., & Richardson, B. F. M. (2018, May 8). S*ystem and method for establishing acoustic metrics to detect driver impairment* (U.S. Patent No. 9,963,033 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9963033

Ohya, N. (2013, May 14). *Alcohol concentration detecting device* (U.S. Patent No. 8,441,357 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/-downloadPdf/8441357

Sakairi, M. (2014, December 30). *Ion detecting device* (U.S. Patent No. 8,921,776 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/8921776

Shoji, R., Yukawa, J., Konno, F., & Ishizaki, T. (2011, March 22). *Alcohol detection system* (U.S. Patent No. 7,911,350 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/7911350

Sofer, S. (2012, January 3). *Car alcohol monitoring system* (U.S. Patent No. 8089364 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/8089364

Soininen, M., & Richardsson, C. (2009, September 30). *System and method for selective engine start in a vehicle depending on driving ability* (EP 1 849 644 B1). European Patent Office. https://data.epo.org/publication-server/rest/v1.0/publication-dates/20090930/patents/EP1849644NWB1/document.pdf

Takahashi, A. (2015, July 7). *Vehicle control system* (U.S. Patent No. 9,073,431 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9073431

Takata, T. (2012, June 19). *Alcohol detection system and method for vehicle* (U.S. Patent No. 8,201,437 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/8201437

Vanhelle, S., & Menon, M. (2020, April 23). *Method and apparatus for in-vehicle impairment detection with driver verification* (U.S. Patent No. 2020/0122731 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20200122731

White, C. W., & Stanley, J. G. (2012, September 13). *System and method for disabling a vehicle* (U.S. Patent No. 2012/0228047 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20120228047

Yang, S. H., & Kim, D. G. (2020, August 6). *Nicht-invasiver optischer detektor für innere substanzen* [*Non-invasive optical detector for internal substances]* (Patent No. DE 10 2019 208 430 A1). Deutsches Patent- und Markenamt [German Patent and Trademark Office]. https://patentimages.storage.googleapis.com/c1/3a/e5/8c994b7b7edc30/DE102019208430A1.pdf

Yopp, W. T., & Rupp, J. D. (2010, August 17). *System and method for implementing active safety counter measures for an impaired driver* (U.S. Patent No. 7,777,619 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/7777619

Yoshida, I., & Sawada, K. (2019, September 3). *Onboard system, vehicle control device, and program product for vehicle control device* (U.S. Patent No. 10,398,368 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10398368

Table 10 Patent Citations

Albakri, S. (2020, December 1). *Blood alcohol level sensing system for a vehicle* (U.S. Patent No. 10,850,614 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10850614

Brown, B. J., & Minter, A. D. (2005, October 20). *Alcohol ignition interlock system and method* (U.S. Patent No. 2005/0230175 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20050230175

Jansseune, L. (2011, July 4). *Method and device for checking the blood alcohol level of a driver of a vehicle* (WO 2011/038803). World Intellectual Property Organization. https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2011038803

Kim, D. H. (2018, February 8). *Vehicle safe starting device* (U.S. Patent No. 2018/0037113 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20180037113

Osaki, R., Osaki, S., Komura, T., Nishii, K., & Tatsumoto, H. (2013, June 25). *Engine starting controller* (U.S. Patent No. 8,469,134 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/8469134

Rowe, R. K., Sidlauskas, D. P., & Harbour, R. M. (2010, October 26). *Multispectral biometric sensor* (U.S. Patent No. 7,819,311 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/7819311

Rowe, R. K., Corcoran, S. P., Nixon, K. A., Doucet, T., & Martin, R. (2012, May 22). *White-light spectral biometric sensors* (U.S. Patent No. 8,184,873 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/8184873

Steeg, B. V., Ridder, T., Cech, L., & Krause, J. K. (2019, September 12). *System for non-invasive measurement of an analyte in a vehicle driver* (U.S. Patent No. 2019/0275886 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20190275886

Vanhelle, S., & Menon, M. (2020, April 23). *Method and apparatus for in-vehicle impairment detection with driver verification* (U.S. Patent No. 2020/0122731 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20200122731

This page is intentionally left blank.

Table 11 Patent Citations

Awad Alla, M. A., Nemec, B. J., Tsai, T.-H., & Krishnamurthy, V. (2020, November 17). *Vehicle control handoff* (U.S. Patent No. 10,838,416 B1). U.S. Patent and Trademark Office. B1). U.S. Patent and Trademark Office. B1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10838416

Iwase, K. (2021, August 19). *Driver state estimation device, method and computer program therefor* (U.S. Patent No. 2021/0253111 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20210253111

Madana Mohana, R., Chintamadaka, Y., Chandika Babu, M., Niraja, K. S., Thirupal Reddy, K., Churchill Dass Prince, M., Kishore Kumar, N. T., Sunitha, V., Chitrala, V., Kiranmai, P., Kumar Vishwakarma, M., Kishore Kumar,, A., & Dugyala, R. (2021, November 25). *Car driver alcohol level and sleeping status detection and notification system* (U.S. Patent No. 2021/0362594 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20210362594

McBride, J. R. (2020, December 31). *Vehicle interior and exterior monitoring* (U.S. Patent No. 2020/0406902 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20200406902

Nakajima, M., Sasaki, K., & Ishikawa, N. (1998, January 6). *Driver monitoring device* (Patent No. JPH10960A). Japanese Patent Office. https://worldwide.espacenet.com/patent/search/family/015512316/publication/JPH10960A?q=JPH10960A
[Also published as U. S. Patent 6,049,747, April 11, 2000, at https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/6049747 with a different abstract]

Ryu, S. S., Kim, J. K., Lee, B. J., & Kim, S. Y. (2020, February 11). System and method for determining state of driver (U.S. Patent No.10,448,875 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10558875

Smuda, P., & Lvancevic, R. (2019, May 3). *Verfahren zur bestimmung der fahrtüchtigkeit eines fahrers in einem fahrzeug* [*Method for determining the driving ability of a driver in a vehicle]* (Patent No. DE 10 2018 009 100 A1). Deutsches Patent- und Markenamt [German Patent and Trademark Office]. https://www.patentguru.com/DE102018009100A1

Sridhard, A. K. (2021, November 11). *Distracted driver detection device* (U.S. Patent No. 2021/0350121 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20210350121

Victor, T., & Larsson, P. (2008, November 25). *Method and system for perceptual suitability test of a driver* (U.S. Patent No. 7,455,405 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/7455405

Wacker, E.-S. (2016, February 18). *Method and device for determining a reaction time of a vehicle driver* (U.S. Patent No. 2016/0046295 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20160046295

Zhang, P., Yang, S., Chen, H., & Zhang, W. (2021, November 30). *In-vehicle safety detection system based on drunk driving and fatigue driving monitoring* (CN 214954602 U). China National Intellectual Property Administration. https://worldwide.espacenet.com/patent/search/family/079065928/publication/CN214954602U?q=CN214954602U

Zhu, Y., Liu, L., Yin, X., Zhang, J., & Li, J.. (2020, March 17). *Integrated system for detection of driver condition* (U.S. Patent No. 10,592,785 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf

Table 12 Patent Citations

Boer, E. R. (2020, June 25). *System and method for analysis of driver behavior* (U.S. Patent No. 20200198645 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20200198645

Breed, D. S., Johnson, W. C., & DuVall, W. E. (2015, September 8). *Driver fatigue monitoring system and method* (U.S. Patent No. 9,129,505 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9129505

Büthorn, R., & Mehne, F. (2020, February 4). *Method for estimating the attentiveness of the driver of a vehicle* (Patent No. WO/2020/064160). Deutsches Patent- und Markenamt [German Patent and Trademark Office]. https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2020064160

Yang, S., Shi, J. Shi, S., Zhang, N., Gao, F., Ou, K., & Liu, S. (2021, July 6). *Safe driving reminding method, device, equipment and storage medium* (Patent No. CN 113071512 A). China National Intellectual Property Administration. https://worldwide.espacenet.com/patent/search/family/076618711/publication/CN113071512A?q=pn%3DCN113071512A

This page is intentionally left blank.

Table 13 Patent Citations

Zagorski, C. T. (2016, March 22). *Method and system for mitigating the effects of an impaired driver* (U.S. Patent No. 9,290,174 B1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9290174

This page is intentionally left blank.

Table 14 Patent Citations

Austin, B. P., Lenneman, J. K., & Domeyer, J. E. (2022, September 20). *Cognitive tunneling mitigation device for driving* (U.S. Patent No. 11,447,140 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/11447140

Doi, A., & Nagata, M. (2020, September 10). *Dozing alert apparatus* (U.S. Patent No. 2020/0286358 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20200286358

Feng, K., Shang, H., Zeng, X., Song, L., Wu, Y., Li, C, & Liu, J. (2021, June 22). *Driver state monitoring device* (Report No. CN 112998710 A1). China National Intellectual Property Administration. https://worldwide.espacenet.com/patent/search/family/076406316/-publication/CN112998710A?q=112998710

Fung, K. C., & Dick, T. J. (2020, September 1). *System and method for responding to driver state* (U.S. Patent No. 10,759,437 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10759437

Fung, K. C., & Dick, T. J. (2018, March 15). *System and method for responding to driver behavior* (U.S. Patent No. 2018/0072310 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20180072310

Kirsch, D. M., Vashi, H., & Chen, B. (2016, October 11). *System and method for dynamic vehicle control affecting sleep states of vehicle occupants* (U.S. Patent No. 9,463,805 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9463805

Kishi, H., Akutsu, M., Akamatsu, M., & Sato, T. (2020, May 5). *Driving consciousness estimation device* (U.S. Patent No. 10,640,122 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10640122

Migneco, F., Yetukuri, A., Gallagher, D., & Pizana, J. (2021, January 14). *Distractedness sensing system* (U.S. Patent No. 2021/0009149 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20210009149

Omi, T. (2018, January 2). *Driving assist device* (U.S. Patent No. 9,855,956 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9855956

Rundo, F., Asnaghi, G., & Conoci, S. (2022, October 13). *Method of processing signals indicative of a level of attention of a human individual, corresponding system, vehicle and computer program product* (U.S. Patent No. 20220327845 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20220327845

Schmidt, E. R. (2019, January 1). *Impairment evaluation system* (U.S. Patent No. 10,166,992 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print-/downloadPdf/10166992

Sham, W. (2019, January 8). *Method for recognizing vehicle driver and determining whether driver can start vehicle* (U.S. Patent No. 10,173,687 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/10173687

Xiao, X. (2022, July 29). *Drunk driving state detection method and device, electronic equipment and storage medium* (Report No. CN 114801731 A1). China National Intellectual Property Administration. https://worldwide.espacenet.com/patent/search/family/-082518477/publication/CN114801731A?q=114801731

Yamada, Y, (2017, October 10). Vehicle occupant information acquisition device and vehicle control system (U.S. Patent No. 9,783,202 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9783202

Table 15 Patent Citations

Agnew, D., MacKenzie, & Johnson, N. (2020, March 26). *Apparatus and method of safety support for vehicle* (U.S. Patent No. 2020/0098265 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20200098265

Anton, F. G. (2020, February 1). *Fahrerassistenzsystem, fahrzeug, verfahren zum betreiben des fahrerassistenzsystems, computerprogramm und computerlesbares speichermedium* [*Driver assistance system, vehicle, method for operating the driver assistance system, computer program and computer-readable storage medium*] (Patent No. DE 10 2018 210 367 A1). Deutsches Patent- und Markenamt [German Patent and Trademark Office]. https://patentscope.wipo.int/search/en/detail.jsf?docId=DE279813153&_cid=P20-LW6PX5-16566-1

Kameyama, S. (2010, October 2). *Vehicular user hospitality system* (U.S. Patent No. 7,821,382 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/7821382

Kobana, M., Sasaki, K, & Kawamata, S. (2015, Feb. 10). *Vehicle emergency evacuation device* (U.S. Patent No. 8,954,238 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/8954238

Lee, S.-G. (2017, June 20). *Apparatus and method for detecting driver status* (U.S. Patent No. 9,682,711 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/9682711

DOT HS 813 577
September 2024

U.S. Department of Transportation
National Highway Traffic Safety Administration

NHTSA

16170-092524-v4