TECHNICAL REPORT

ISO/TR 23049

First edition
2018-09

Road Vehicles — Ergonomic aspects of external visual communication from automated vehicles to other road users

Véhicules routiers — Aspects ergonomiques de la communication visuelle exterieure du véhicule automatisé aux autres utilisateurs de la route

Reference number
ISO/TR 23049:2018(E)

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Published in Switzerland

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Introduction

The need for external communication was highlighted in the National Highway Traffic Safety Administration's (NHTSA) 2017 automated vehicle policy: "New complexity is introduced to this interaction as ADSs take on driving functions, in part because in some cases the vehicle must be capable of accurately conveying information to the human driver regarding intentions and vehicle performance".

This document focuses on the various ways to enhance traffic scenarios by suggesting communication from Automated Driving Systems (ADS-DV)s [16]. While communication may involve many modalities (visual, speech, audio signals, haptics, etc.) and combinations thereof, this document mainly focuses on the visual modality, since interaction with vehicles is primarily a visual task [13].

As AV systems enter the market, road users need to understand how to safely interact with these vehicles. This is particularly important when situations occur such as uncertainty of right-of-way involving road users of all types including AVs, pedestrians, bicyclists, drivers, and passengers. Although there is still some discussion about the need to provide external communication, it is important to start working on this concept. Within the minimum sound requirements for hybrid and electric vehicles (2016), the NHTSA requires non-internal combustion vehicles add an audible alert so that pedestrians with visual impairment can hear these vehicles at low speeds, full compliance by September 2019. Since any other audible signals would conflict with this regulated signal, visual signalling is recommended. Since the implementation of supplemental visual signalling on ADS-DVs may help other road users navigate traffic scenarios more easily, there is a need to investigate standardizing signals if they are to be used. Consistency across the automotive industry is needed to minimize potential road user confusion and establish societal trust with respect to ADS-DVs. This includes design considerations made for vehicles of different types and sizes.

It is recommended that if ADS-DVs have external visual communication systems, the communication should be standardized across the automotive industry. Learnability of these systems is a main focus, limiting the number of signals and ensuring they are distinct and salient yet not distractive, with the aim of their implementation providing a positive impact on societal acceptance and traffic safety.

Road Vehicles — Ergonomic aspects of external visual communication from automated vehicles to other road users

1 Scope

The purpose of this document is to provide guidance for developers of visual external communication systems for automated vehicles (AV), particularly Automated Driving System – Dedicated Vehicles (ADS-DV), as defined by SAE J3016.

The main objective of this document is to propose how ADS-DVs could communicate with other road users via an external communication system. It discusses the interaction between humans and ADS-DVs within roadway environments. Recommendations for the type of external visual communication messaging are presented along with the supporting methodological rationale.

This document does not address functionality elements of the ADS-DV external visual communication system itself. Rather, it serves to propose how the system communicates to human users such that it can be learned and understood by society at large.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Background

As ADS-DVs enter the market, road users will need to interact with them in an effective manner. In manually-driven vehicles, the effectiveness of interactions are based intrinsically on the rules of the road that define priorities for given situations. Recent studies have also shown that vehicle behaviour also determines the behaviour of other road users [3]. However, at times it is difficult to resolve a specific situation deterministically. Common situations include conflict with another road user, uncertainty as to who has the right-of-way, accommodation of other road users, and acts of fairness on the road. Currently, such situations are sometimes resolved by coordination and negotiation between two or more humans such as interactions between driver-pedestrian, driver-driver, and driver-cyclist.

Since a human driver may not be in an ADS-DV or a person may be in the vehicle but not actively controlling it, effective human-to-human interactions likely will not be feasible and a substitute may be needed. The vehicle's behaviour will be programmed or will be a response to changing circumstances, which may deviate from what people expect in normal human-human interaction. Therefore, a new way of communication may need to replace these traditional human-to-human communications by communicating the ADS-DV's current or planned behaviour with other road users. Such communication could enable other road users to make more judicious decisions and enable better public acceptance

of ADS-DVs. Studies are currently investigating the needs and benefits of visual communication of automated vehicles to surrounding traffic and other road users.

5 Current road user interactions

Currently, vehicular road communication concerns vehicle state, intent and warnings, and several methods of communication are utilized. Vehicles have dedicated signals that have conventional and sometimes regulated meanings; these signals can provide state information (brake light, reverse horn in trucks), intent information (turn signal to indicate intended departure from current lane), and general warnings (honking, hazard light). These signals are not sent directionally to a specific road user, but all recipients are expected to respond by taking a suitable action or, at least, by taking notice. Additional means of communication are informal vehicle signals, such as blinking the headlights or tapping on the brakes, but the meaning of these messages is ambiguous and depends on local and cultural norms.

A driver can also communicate by taking dynamic actions such as moving into a conflict space, cutting into the gap between vehicles, or creeping forward onto a busy crosswalk. Finally, there are explicit communication forms such as hand signals, head movements, torso movements, as well as implicit communication such as eye contact [11]. What is unique about these human-to-human communications is that they are usually directional and intended for specific road users. Currently, such human-to-human communication is used to resolve difficult situations; for example, in Germany, the rules of the road mandate this kind of communication when road signs and traffic rules are not enough. While human-to-human communication is often effective in resolving traffic situations, it can also be misinterpreted or misused, leading to complications.

The most certain means of communication from a driver is vehicle motion as this indicates what the driver is actually doing as well as the driver's intent. For instance, at a stop if a driver takes their foot off the brake in an automatic-transmission vehicle, the car begins to inch forward, communicating both that the vehicle is starting to go as well as the driver expects to go next. There is a strong correlation between vehicle movement and communications, and any new signalling scheme will need to have that in mind. When vehicle motion state is likely to change imminently, secondary cues could be necessary to better anticipate the future vehicle behaviour. Brake lights fulfil these tasks as well as eye contact between pedestrians or side traffic with the driver of the car concerned. ADS-DVs should enable this information exchange.

6 Potential ADS-DV communication

6.1 General

A traditional vehicle and an ADS-DV can communicate in several methods. The following outline describes these, considering conveyable information and relevance to road users.

6.2 Vehicle information

6.2.1 State

Vehicle state encompasses speed, rate of acceleration, deceleration, idle, etc. Vehicle state has traditionally been communicated implicitly through observable behaviours without the requirement of extra displays; however, this information can be signalled explicitly by multiple modalities. One acoustic modality example is the tone and beeps used by trucks when backing up or the additional sounds generated by EVs in lower speed conditions. A visual example involves brake lights indicating deceleration. In their evaluation of vehicle-to-pedestrian communication displays for AVs, Clamann, Aubert, and Cummings [1] utilized a dedicated visual display on a grid which showed vehicle speed as white text on a black background. The benefits and potential consequences of such explicit signal concepts for vehicle state would need further exploration.

6.2.2 Driving mode

While driving mode can be considered a division of vehicle state, there is also a distinction. Outside of common driving behaviours, communicating driving mode is meant to convey different information to other road users and may have a different impact on behaviour. Driving mode communication would indicate whether the vehicle is operated by automation. An ADS-DV can provide information to other road users to alert them to the fact the vehicle is an ADS-operated vehicle. There is much debate as to whether there is a need to indicate this mode information, considering both the concern that certain road users may wish to "game" such a vehicle or take advantage of it as well as the benefit of enhancing its conspicuity.

6.3 Vehicle "understanding" of the environment

6.3.1 Perception

A signalling mechanism that provides information to the "world" about what the vehicle sees can be introduced, though the effectiveness of these mechanisms remains unclear. For example, an ADS-DV that is approaching a crosswalk can display to the car behind it that there are pedestrians crossing the road (something that the vehicle behind cannot "see"). An ADS-DV that quickly avoids an obstacle can indicate the reason for the abrupt manoeuvre to the car behind it.

6.3.2 Recognition and acknowledgment

Another type of information that an ADS-DV can broadcast is its recognition of the scene. For example, it can indicate whether it recognizes the crosswalk and stop line and whether it recognizes other road users (cyclists, pedestrians, other cars, etc.). This information can be broadcasted; however, there is an issue in how this information can be transmitted to a specific road user, and obtaining some kind of an acknowledgment response. This is even a bigger issue in crowded spaces where there would be no guarantee that the intended recipient would see the signal. For example, a pedestrian may receive the recognition as the intended recipient, but a motorcyclist nearby may see the same signal and act upon it when the vehicle has not recognized him or her. Therefore communicating recognition and acknowledgement has additional challenges that would need to be considered.

6.3.3 Belief state

An ADS-DV can communicate its belief state about the world, which is a reflection of how it "understands" the world. Information such as "this pedestrian does not intend to enter the crosswalk and therefore I will not stop" can be broadcasted to road users as well as information concerning the vehicle's operational design domain (as defined in [16]), operational policies such as always yielding to merging traffic, and technical limitations [2]. The vehicle can provide information about its stopping distances with respect to other road users and infrastructure features (braking distance from an encroaching pedestrian). It can also communicate its expectations concerning other road users giving or taking right of way. An example of this is the common use of stickers on German public transport buses indicating that they have the right to enter traffic just after activating the turn indicator.

6.4 Guidance

An ADS-DV can provide guidance information to other road users. Examples include an ADS-DV indicating to pedestrians when it is safe to enter a crosswalk or when it is time to stop and wait. In their assessment of external vehicle-to-pedestrian displays, Fridman, Mehler, Xia, Yang, Facusse, and Reimer (2017)[4], found that designs intended to indicate that it was safe to walk yielded much more varied levels of design communication understanding. Consistency in message understanding is strongly desired. Moreover, providing guidance is not consistent with current OEM approaches, as vehicles currently do not tell road users what to do; they communicate state or intent of the vehicles themselves. This strategy is not in line with existing traffic rules, with regard to vehicle signalling, and it has the potential for creating additional harm if the guidance is incorrect or does not take into account other vehicles in vicinity. For example, in Israel and in Sweden, there have been campaigns to educate drivers to not provide guidance information by means of hand waving to pedestrians, as there

have been several accidents where drivers waved schoolchildren to cross not realizing that other cars were speeding through the adjacent lane. Therefore communicating guidance is not recommended at this point in time.

6.5 Intent

Vehicle intent is an important information element that can be provided. Currently, all vehicles have turn signals to indicate respective departure from current manoeuvre (communication evolving historically from driver hand gestures into standardized vehicle turn indicators). Additional statements such as “intend to yield,” “will give right of way,” “will yield to merging traffic,” or “plan to continue in my current mode” can be communicated visually using a variety of formats and lighting schemes.

The intent of the automated driving system (ADS) is planned and therefore can be communicated. This intent and the communication of it will be more reliable than a human driver communicating intent. Additionally, by conveying these types of vehicle intent, identification of the ADS-DV is achieved. Therefore, communicating intent continues to be investigated.

7 Format of ADS-DV communication

Gap distances and speed perception have been shown to be main determinants of a pedestrian’s decision to cross streets. However, some people have difficulty gauging the speed of oncoming traffic, particularly children, as the U.S. Department of Transportation Federal Highway Administration has shown within the Pedestrian Safer Journey education and outreach programs [14]. Research shows that people believe additional displays will be needed on automated vehicles. Clamann, Aubert, and Cummings (2017) [1] evaluated visual displays on vehicles, primarily investigating response time to cross streets as vehicles approach, with the displays providing guidance (walk / don’t walk) or vehicle information (speed). In their follow-up surveys, half of the participants reported having displays “would be helpful when autonomous vehicles become available”.

Auditory signals generally are advised when the frequency of use is relatively low and the messaging is of a warning or awareness-raising nature (and surrounding sound levels support the use of auditory signals). The visual modality, while very powerful in terms of specificity, may demand additional attention by road users. However, visual signalling is primarily used for communication that is more frequent.

As specific interfaces for ADS-DVs are developed, care should be taken such that consistency or coherency with existing vehicle interfaces is maintained and avoid interference or confusion with other signals from ADS-DVs or otherwise. There are concerns with repurposing existing interfaces or not coordinating with existing interfaces. The interface should be detectable and recognizable yet not overwhelm road users in close proximity.

8 Considerations for ADS-DV communication

As ADS-DVs become introduced to the public, consideration will need to be given to how they will integrate within the current vehicle environments. Given the multiple vehicle communication methods possible, a solution that bridges traditional vehicle communication and enhances the specific ADS-DV communication with other road users is desirable for traffic safety and societal acceptance. It is possible to equip ADS-DVs with the ability to communicate with other road users to improve interaction within road situations as well as indicate manoeuvres intended by the ADS-DV. This involves dedicated vehicle signals which would be frequently used and abide by existing and forthcoming laws, regulations, and policies. Such communication schemes will need to be both unique and distinct, and they will need to co-exist and not interfere with existing communication schemes, considering mixed traffic situations and scenarios with multiple AVs.

Any new communication scheme implemented on ADS-DVs will likely require multiple exposures for people to learn, as an inherently intuitive signal that would be understood by the majority of people in all cultures and for all situations does not currently seem to exist. The signals used should be few, yet perceptible, learnable, and easily understood, similar to existing signals used in vehicles. The format

and style of communication signals should be harmonious across OEM's in order to avoid the use of different messages for different types of vehicles in different countries. Minimally, the kinds of messages should be harmonized amongst manufacturers even if the specific implementation might slightly differ. A known failure mode in developing these signals is that various OEMs introduce different signals, potentially creating confusion among the public, and this could contribute to people not accepting or trusting ADS-DVs. Therefore, consistency across the automotive industry is paramount if signals are to be added.

When introducing new communication signals, it is important that these are equally noticeable by various road users even though they are provided on different types and sizes of vehicles. It is likely that some standard requirements have to be met regarding where signals are positioned to become detectable by the majority of road users. The character of the signals will also be important to secure that they will be noticeable under almost all environmental conditions. For requirement setting, it should be possible to rely on similar approaches as done for existing visual communication signals, such as the evolution of indicator lights.

Vehicle intent is the informational element that can be robustly communicated and consistently interpreted by road users. Habibovic, Andersson, Klingegård, Malmsten-Lundgren, and Larsson (2017) [5] utilized an interface concept consisting of an outward-facing LED light strip that uses distinct patterns of light to inform surrounding road users what the automated vehicle is about to do. They found that three distinct visual signals were understood where the vehicle communicated: "I am driving in automated mode", "I am about to yield", "I am about to start driving". In Lagstrom and Lundgren's research (2015)[6], they also utilized a strip of LED lights and found that pedestrians could understand and confidently interpret the AV's intentions after only a short one-on-one training where they initially experienced the signals with no prior knowledge of the system and then were shown images with the signal meanings. Quoting the researchers, "the pedestrians also reported that the interface replaced the role of the driver in encounters with the automated vehicle, and even excelled today's interaction as the communication was clearer and available earlier". Aligning with this type of communication method would likely not worsen interactions, but where an ADS-DV no longer has the element of human driver communication, it could improve how vehicles communicate with other road users.

9 Acceptance of ADS-DVs by the public

By definition, acceptance includes the action of consenting to receive or undertake something offered and the action or process of being received as adequate or suitable, typically to be admitted into a group. Public acceptance of AVs will involve not only how people will relate to the technology, such as the vehicle itself, but also how they will relate and receive the overall concept of multiple AVs in the public space.

One important prerequisite for achieving acceptance is trust. In sociology and psychology, trust is a measure of belief in the honesty, fairness, and benevolence of another human being. Trust is also achieved when there is reasonable calibration between expectations and actual behaviour [8]. "Trust can be based on in-the-moment information, such as seeing a lack of a human driver in a car. Trust can also be based on conceptual understanding of autonomous vehicles, such as their ability to avoid human error."[12].

Regarding machine behaviour, what can be measured is the confidence people have that it will behave as intended or expected. Those who are unfamiliar with the workings of the machine or its past behaviour may wish to infuse a certain level of trustworthiness onto a given machine or its behaviours [7]. From a product development perspective, the goal is to design a machine that will behave reliably such that people have a reasonably high level of confidence in its behaviour.

Confidence in automated systems may be impacted by whether or not the user and the system share the same goals. To the degree that they share a goal and that goal is not violated, users will continue to trust and utilize the system [15]. An example of existing visual communication where goals are clearly shared is the countdown of seconds until a traffic light turns green, where the provided information helps the efficiency of the transportation system. Clear communication of vehicle behaviour can help to achieve a common shared goal between other road users and ADS-DVs. Based on a mutual understanding of this goal, people's trust in ADS-DVs should be positively impacted.