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Summary

Emergency vehicles face risks when interacting with surrounding traffic. To support civilian drivers' move over-behavior they can be provided with an Emergency Vehicle Approaching (EVA) warning. An EVA warning is an in-car warning that lets the driver know that an emergency vehicle is approaching them about 15 seconds in advance. This allows the driver to notice the emergency vehicle earlier and thereby provides them with more time to move over safely. One previous study found that drivers required one interaction with the EVA system to move over quicker compared to drivers who did not get an EVA warning (Weibull et al., 2023). One purpose of the present study was therefore to examine if an introduction to the EVA system had an impact on the learning effect.

VTI and the University of Gothenburg conducted a simulator experiment during the spring with 73 participants. In the experiment, the participants were approached by an emergency vehicle two times while driving on a highway. To examine driver behavior in the upcoming naturalistic study, eye tracking was considered a valuable method. Eye-tracking, combined with measurements of vehicles' speed and placement, allowed for a thorough examination of the effects of whether an introduction to the EVA system affected driver behavior. In previous studies, only measures of vehicle position and speed had been used as measurements of EVA's effect. Through eye-tracking, it was possible to explore how drivers' glance behavior changed when they received an EVA warning.

The results did not indicate a difference in move-over behavior depending on whether the participants were introduced to the EVA system or not. The eye-tracking analysis showed great potential and will be a central part of a forthcoming publication.

Emergency Vehicle Approaching System

1. Background

To improve the safety of emergency vehicles, civilian drivers must move over in a safe and timely manner. Today, warning lights and sirens are used to warn civilian drivers to move over when an emergency vehicle (EV) is approaching. However, the current warning system is not perfect (De Lorenzo & Eilers, 1991). Sirens can be difficult to localize and the distance to them is often overestimated (Caelli & Porter, 1980). In addition, modern vehicles have a high degree of soundproofing, which can lead to delayed detection of sirens. Delayed detection can result in an insufficient amount of time to plan and execute a safe move-over procedure.

One proposed method to support drivers when interacting with EVs in traffic is to provide the drivers with an Emergency Vehicle Approaching (EVA) warning (Lenné et al., 2008). An EVA warning gives the driver an early in-car notification that an EV is approaching and encourages the driver to move over (Payre & Diels, 2020). Providing an EVA warning gives the driver more time to find a suitable way to move over. This would decrease delays for EVs and lower the risks of accidents between EVs and other road users. A handful of previous studies such as Lenné et al. (2008), Lidestam et al. (2020), Payre and Diels (2020), and Savolainen et al. (2010) have concluded that early warnings for approaching EVs can provide safety benefits.

In Weibull et al. (2023) it was suggested that drivers require one first interaction to benefit from the EVA warnings. In the mentioned study drivers were driving in a simulator in a highway scenario. They were approached by EVs three times. The drivers either received or did not receive EVA warnings (EVA vs. No-EVA). The results of the study showed that there was no difference in move-over behavior between the EVA and No-EVA groups the first time they were approached by the EV. However, the second and third times the EVA group moved over faster compared to the No-EVA group. Therefore, the current pre-study was initiated. Furthermore, it was an opportunity to explore drivers' eye-glance behavior when approached by an emergency vehicle. The project partners were curious to see where the participants would look when an EVA warning was given to them, and if there would be any eye-glance differences between the different experimental groups.

2. Project set up

2.3 Purpose

The current simulator study will function as a preparatory study for a naturalistic study that hopefully will be conducted in a real traffic environment. To be able to examine driver behavior in the upcoming naturalistic study, eye tracking is believed to be a valuable method. Eye-tracking in combination with measurements of vehicles' speed and placement will allow for a thorough examination of the effects of EVA warnings. In previous studies, only measures of vehicle position and speed have been used as measurements of EVA's effect. Through eye-tracking it would be possible to explore how drivers' glance behavior changes when given an EVA warning. Furthermore, it allows for analysis of when the drivers first look at the EV. That point in time can later be used to explore how long time it takes for drivers to move over once they have seen the EV or been given an EVA warning.

Therefore, the purpose of the current study was to evaluate the learning effects and eye glance behavior associated with emergency vehicle interactions, with and without EVA warnings.

2.4 Objectives

The goals of the current study were:

1: Examine the effect of EVA introduction before interaction with the EVA system

Since many civilian drivers do not encounter EVs regularly in traffic, EVA warnings must be effective starting from the first interaction. It would therefore be beneficial if an introduction would lead to faster move-over time when the driver is faced with the EVA warning in a real-life situation. This would increase traffic safety.

2: Explore eye-tracking as a method to measure driver behavior when given an EVA warning

Eye tracking will be used to prepare for the upcoming study. The eye-tracking data is believed to give us more detailed information on driver behavior, specifically concerning how early drivers search the traffic environment behind themselves to identify the EV to move over in a safe and efficient manner.

3: Examine the driver's experience of EVA

User acceptance is crucial for gaining benefits from any system. In the current study, the participants will be asked to rate their attitude towards EVA warnings.

2.5 Project period

The project period was from April until November 2023. A scientific article is still being written and will be submitted December 2023.

2.6 Partners

In this pre-study, VTI and the University of Gothenburg participated. VTI developed the simulation scenario and recruited research participants. GU contributed to the experiment design. During data collection, representatives from VTI and GU acted as experimental leaders. Part of the analysis was included in the master's thesis produced as a result of this pre-study. VTI has since the thesis work ended continued with further analysis.

3. Method and activities

In the pre-study, a simulator study was conducted with VTI's moving base simulator in Gothenburg (SIM-IV).

3.1 Participants

A total of 73 participants were included, ranging from 19 to 54 years old (M = 38.1, SD = 10.1), all possessing a valid driver's license. One driver chose to terminate their participation due to simulator sickness. Therefore, the data from 72 participants is analyzed.

3.2 Design

The study employed a 2 (Introduction) x 2 (EVA) between-subjects design (See Table 1). Half of the participants were briefed about the EVA warning system (See appendix) before driving in the simulator (Groups 1 & 3). They were given information in a brochure designed to resemble one provided by a car manufacturer, which they were encouraged to read. On the other hand, Groups 2 and 4 were instructed to read a brochure about parking assistance (See appendix), serving as an irrelevant condition for the current study (acting as a placebo-control condition). This was to see if an introduction to the EVA system would allow for quicker compliance with the warning system.

Table 1 - Group design

	EVA Introduction	Parking Introduction
EVA	Group 1 (n = 18)	Group 2(n = 18)
No-EVA	Group 3(n = 18)	Group 4(n = 18)

3.3 Materials

The pre-study utilized a simulator study employing a VTI moving base simulator (SIM-IV) and a passenger car cabin (Volvo XC60). The simulator provided eight degrees of freedom and a 210-degree forward field of vision. Within the cabin, five Smart Eye-tracking cameras were installed (Figure 1). Data from these cameras were utilized to analyze the eye-glance behaviors of the different groups, especially when an EVA warning was presented. The study primarily focused on comparing the glance behavior

of the EVA group to the control group's eye-glance behavior at the same simulation point. To be able to track the eye-glance behavior, five predefined areas of interest were created. The front windshield, the infotainment system, the speedometer, the left rear-view mirror, the right rear-view mirror, and the center rear-view mirror. The visual areas were predefined so it in the analysis phase would be easier to estimate where the drivers were looking.

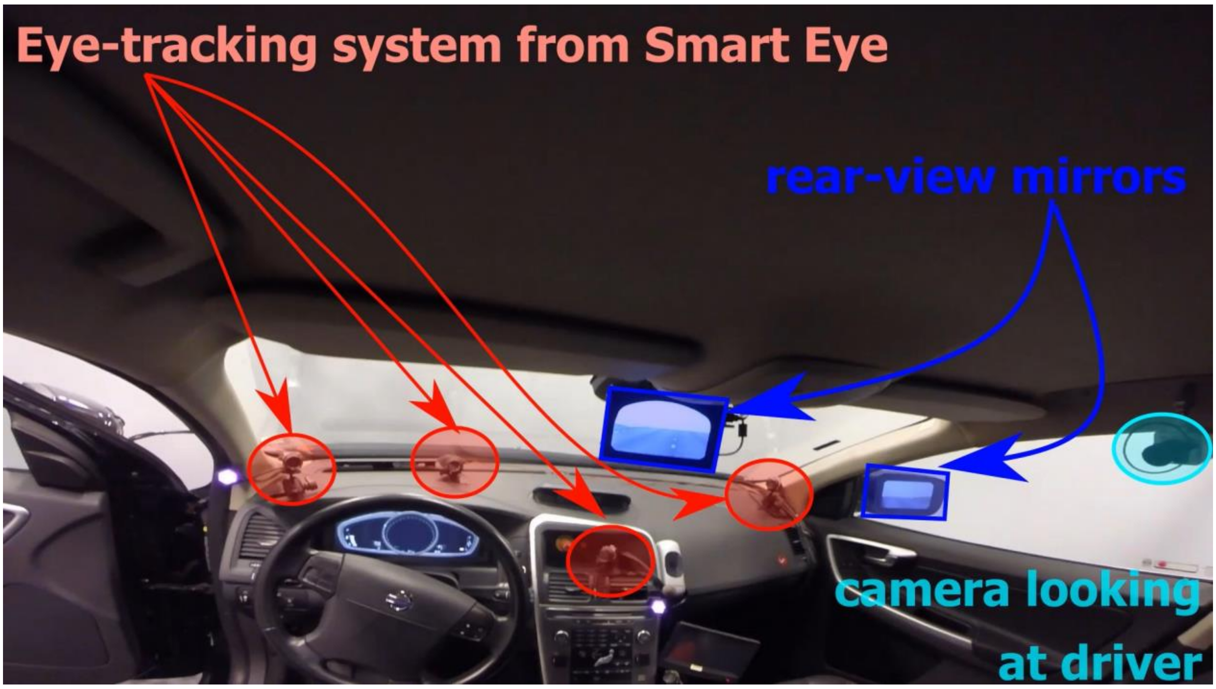

Figure 1 – The inside of the cabin used in the current experiment. Figure by Aramrattana (2021)

To examine the driver's behavior when interacting with the emergency vehicle, a measure of *move-over time* was calculated. The move-over time measured the time between the participant's vehicle being out of the way for the emergency vehicle and the emergency vehicle overtaking the participant's vehicle. The participant's vehicle was considered to have moved over when the participant's vehicle was 2.5 m from the center position of the leftmost lane. This was the smallest lateral difference that allowed the emergency vehicle to overtake the participant's vehicle.

3.4 Procedure

When arriving at VTI, all participants were informed that the purpose of the study was to test novel technical solutions in cars. Furthermore, they were informed about the procedure, their anonymity, and their right to at any time end their participation in the experiment. After that, they provided informed consent and responded to a presurvey.

questionnaire. They were asked about their driving experience and demographics. For instance, age and gender. They were also asked if they had any hearing or visual impairments. Before sitting down in the simulator, they were asked to read an instruction, either about the parking assistance system or the EVA system. The experimental leader did not answer any questions about the system or their relevance to the experiment.

Before they started driving, the eye-tracking system was calibrated for every participant. All drivers were instructed to simulate their normal behavior in real traffic. The driving scenario occurred on a three-lane highway with high traffic density in the right and middle lanes. Surrounding cars maintained a slower speed than the participant’s car, leading the participant to prefer the left-most lane. Approximately nine minutes into driving, Groups 1 and 2 received an EVA warning. About 20 seconds later, an emergency vehicle approached participants from all four groups. The idea was that the emergency vehicle and the participant's vehicle would be positioned in a way that required the participant to change lanes if the emergency vehicle wanted to continue at their desired speed. Another approach by an emergency vehicle occurred after another six minutes. The simulation concluded a few minutes after the second emergency vehicle had passed the participant’s vehicle.

Upon completion, participants were invited to fill out a post-test survey. The survey gathered the participant’s ratings and experiences regarding driving with or without EVA and EVA introduction, respectively.

4. Results and Deliverables

The results section is structured after the expected results stated in the start report:

- *Examine the effect of EVA introduction before interaction with the EVA system*
- *Explore eye-tracking as a method to measure driver behavior when given an EVA warning*
- *Examine the driver's experience of EVA*

4.1 Examine the effect of EVA introduction before interaction with the EVA system

It was possible to see the emergency vehicle 30 seconds before overtaking. Therefore, all participants who moved over earlier than 30 seconds before overtaking were removed from the current analysis. The mean move-over times depending on the introduction are displayed in Table 2.

Table 2 – Mean Move-over time for the EVA and Parking instruction groups

	EVA instruction			Parking instruction		
	n	*M*	*SD*	*n*	*M*	*SD*
Event 1	26	16.16	6.69	23	14.48	5.2
Event 2	23	15.39	6.98	24	17.1	7.35

The difference in move-over time was examined through two independent t-tests, one per event. The EVA introduction did not result in a significant difference in move-over time in Event 1 ($t(47)=0.99$, $p=.33$.) or Event 2 ($t(45)=0.82$, $p=.42$.)

4.2 Explore eye-tracking as a method to measure driver behavior when given an EVA warning

The eye-glance behavior was examined by analyzing in what pre-defined areas the participants looked. The pre-defined areas were the front windshield, the infotainment system, the speedometer, the left rear-view mirror, the right rear-view mirror, and the center rear-view mirror. When analyzing the predefined areas were assembled into different groups. The left-, right- and center rearview mirrors together formed the category *mirrors*, the infotainment system, and speedometer were grouped as *dashboards,* and finally, the front windshield functioned as one category. Below are preliminary figures of the eye-tracking data that will be used in an upcoming publication. A more in-depth analysis will be provided in the publication.

In the figures below, the x-axis displays time, 0 equals when the emergency vehicle surpassed the participant's vehicle. -30 marks 30 seconds before overtaking and 30, 30 seconds post overtaking. The y-axis is the percentage of participants who looked into that predefined area during a given second. As for the lines in the figures, the Yes/No refers to

if they received an EVA warning. EVA/Park refers to if they read an introduction about EVA or parking assistance.

As displayed in Figure 2, a majority of the time was spent looking through the front windshield.

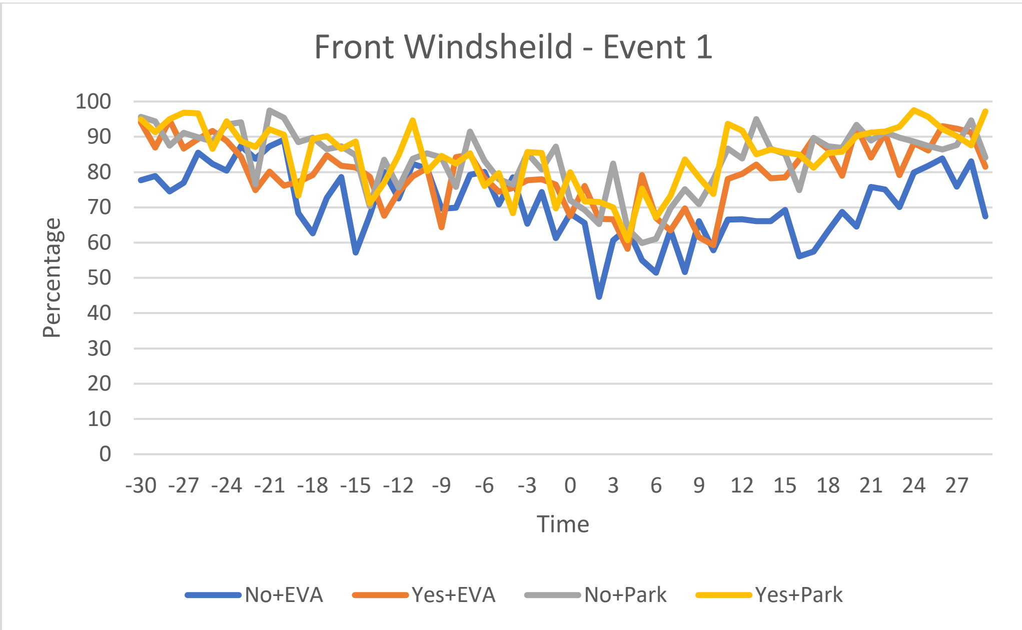

Figure 2 – Percentage of time around emergency vehicle event 1 spent looking through the windshield

As is displayed in Figure 3, it seems like the time spent looking at the dashboards increases around the emergency vehicle interaction. In general, a small percentage of the time was spent looking at the dashboards.

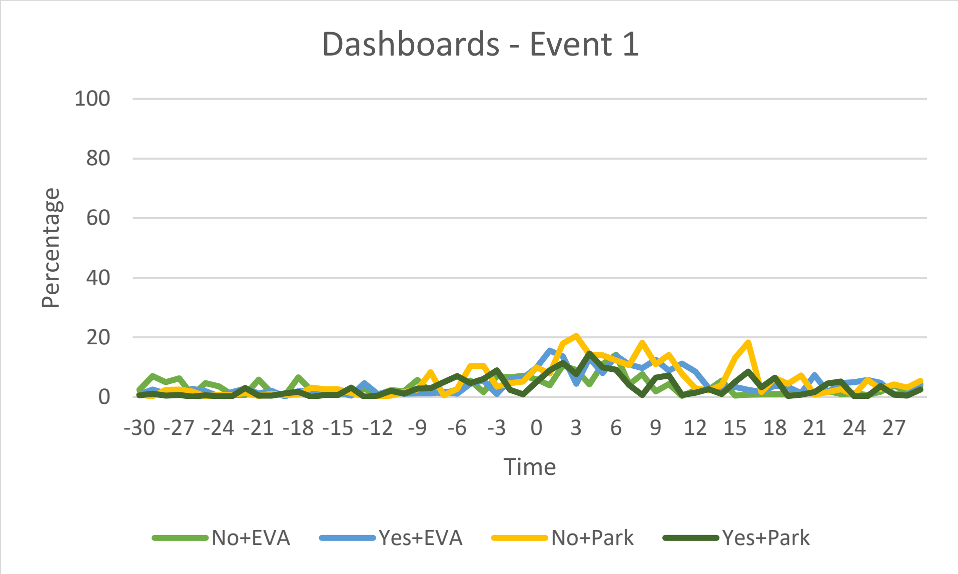

Figure 3 - Percentage of time around emergency vehicle event 1 spent looking at the dashboards

The mirror eyeglance data suggests that the participants who received an EVA warning spent more time looking in the mirrors earlier than the participants who did not receive an EVA warning (Figure 4).

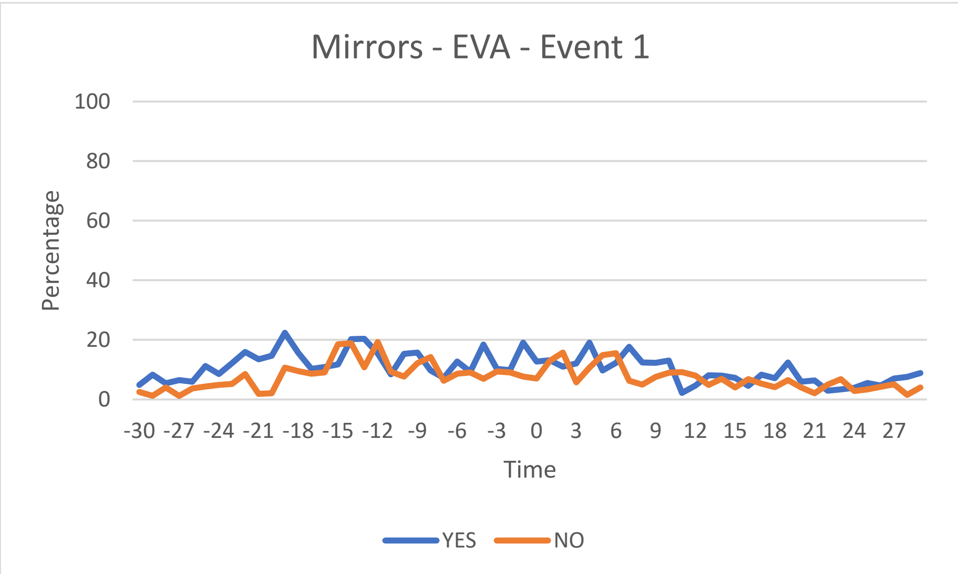

Figure 4 - Percentage of time around emergency vehicle event 1 spent looking at the mirrors

4.3 Examine the driver's experience of EVA

In the post-survey drivers were given statements related to their experience in the simulator. All answers were indicated on a 1–7-degree Likert scale (1= Fully disagree, 7 = Fully agree). A majority of drivers felt like they knew what to do when the emergency

vehicle appeared. The drivers who received EVA warnings were asked about their experience with the EVA system (Table 3). The drivers were in general positive toward EVA warnings. They believed it to be helpful and improve their driving behavior. Furthermore, they stated that they felt like they could trust the warning and would like to get the warnings in their own vehicle. In general, they did not believe that the warning was difficult to hear or made them stressed.

Table 3 - Post survey questions regarding experience in the simulator (Likert scale, 1 = Strongly disagree, 7 = Strongly agree)

	n	*M*	*SD*
It was easy to know what to do when the EV appeared	72	6.23	1.32
The warning voice was difficult to hear	35	1.94	1.66
The warning voice was very helpful	35	5.89	1.66
It was easy to understand the warning voice	35	6.63	0.73
The warning voice improved my driving behavior	35	5.49	1.42
The warning voice made me stressed	35	2,40	1.67
I want to receive warnings for emergency vehicles in my own car (Complement to blue lights and sirens)	35	5,91	1.7
I felt I could trust the warning voice	35	6,23	1.14

5. Conclusions, Lessons Learnt and Next Steps

The introduction did not seem to make a difference in move-over behavior. However, one issue with the simulated scenario was the lack of surrounding traffic. There was not enough traffic to make all the drivers prefer the left-most lane. Therefore, some drivers would switch lanes even though the emergency vehicle was not spotted. However, the possible time of discovery is seen in the eye-tracking data and can thereby support the understanding of the move-over behavior.

In the current pre-study, an appropriate method for eye-tracking analysis was developed. Using the predefined areas of interest was a successful method. Though it may decrease the granularity of data, it saved many hours of eye-tracking analysis. The eye-tracking analysis yielded significant differences between the different experimental groups which will be presented in a forthcoming publication.

The use of eye tracking has great potential as a complement to the driving simulator data. The knowledge gained in this pre-study will be of value in Kajsa Weibull's upcoming dissertation. Unfortunately, due to time restraints, it will not be possible to include the naturalistic study in the dissertation. However, we aim to continue with the work of understanding driver behavior in relation to in-car warnings. Hopefully, with a naturalistic experiment, where the knowledge gained in the pre-study to be applied.

6. Dissemination and Publications

One master's thesis was written during the spring of 2023 (Nazari, 2023). A scientific paper will be published and included in a doctoral dissertation.

7. Acknowledgement

The project partners would like to thank the participants of the driving simulator study. We would also like to thank SAFER for supporting this pre-study.

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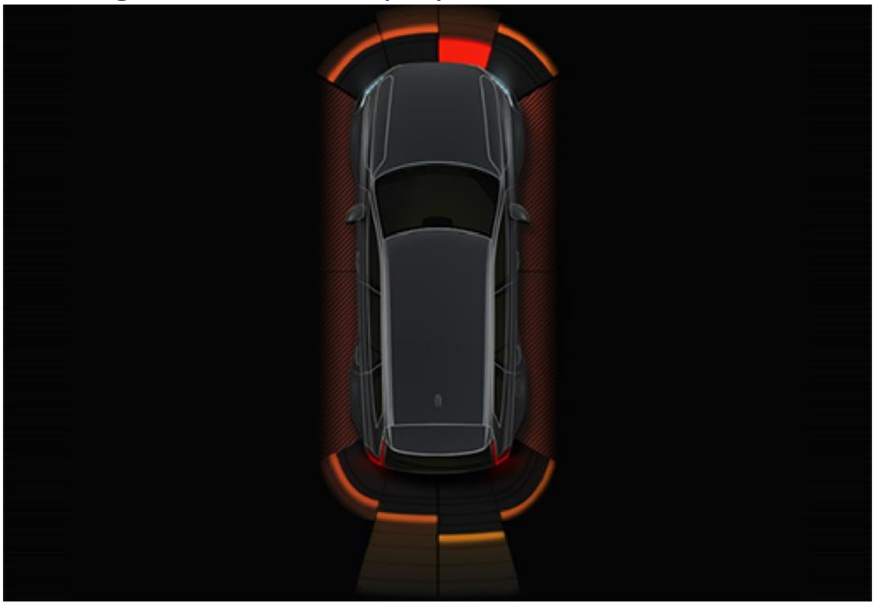
9. Appendix

Parkeringshjälp

Uppdaterad 2023-01-21

Funktionen parkeringshjälp kan hjälpa föraren vid manövrering i trånga utrymmen genom att indikera avstånd till hinder med ljudsignaler kombinerat med grafik i centerdisplayen.



Bildskärmsvy med hinderzoner och sensorsektorer.

Centerdisplayen visar en översiktsbild med förhållandet mellan bilen och upptäckta hinder. En markerad sektor indikerar var hindret befinner sig. Sidosektorerna ändrar färg då avståndet minskar mellan bilen och ett objekt. Ju kortare avstånd till hindret, desto tätare ljuder signalen.

Vid avstånd inom ca 25 cm (0,8 ft) till ett hinder åt sidorna är tonen intensivt pulserande och aktivt sektorfält skiftar färg från ORANGE till RÖD.

OBS

Ljudvarningar ges bara för objekt vilka befinner sig direkt i bilens färdväg.

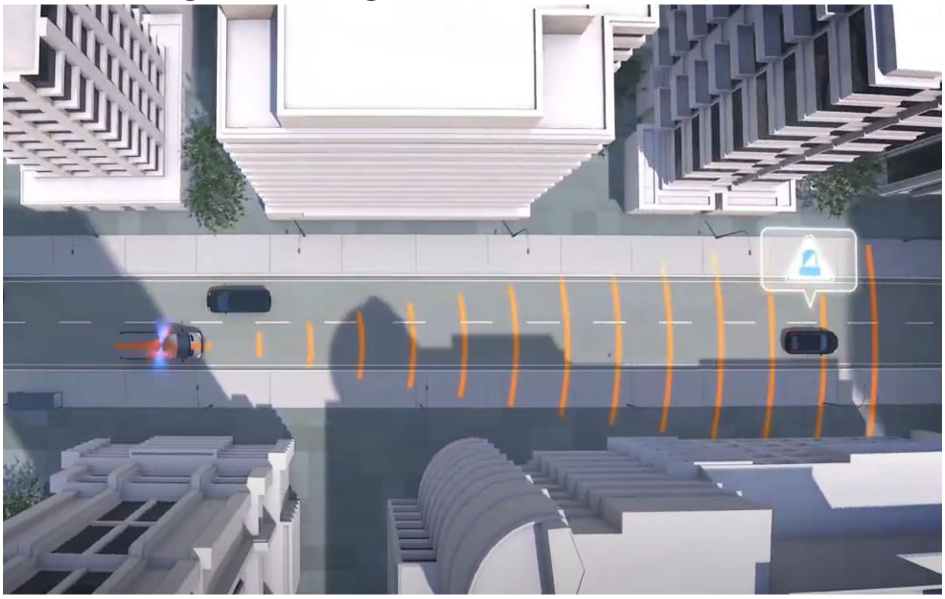
Varning

- Funktionen är ett kompletterande förarstöd med avsikt att underlätta körningen och göra den säkrare – den kan emellertid inte hantera samtliga situationer vid alla trafik-, väder- och vägförhållanden.
- Föraren rekommenderas att läsa ägarmanualens samtliga avsnitt om denna funktion för att ta del av bl.a. dess begränsningar, vilka föraren ska vara medveten om innan funktionen används.
- Förarstödsfunktioner kan inte ersätta förarens uppmärksamhet och omdöme utan denne är alltid ansvarig för att bilen framförs på ett säkert sätt, med lämplig hastighet och med lämpligt avstånd till andra fordon samt i enlighet med gällande trafikregler och bestämmelser.

Tidig varning för utryckningsfordon

Uppdaterad 2023-01-21

Funktionen Tidig varning för utryckningsfordon kan hjälpa föraren att lämna fri väg genom att en ljudvarning avges när ett utryckningsfordon i förarens bils färdväg närmar sig.



Om ett utryckningsfordon närmar sig sänds en tidig varning ut.

Om ett utryckningsfordon som kommer passera bilens färdväg närmar sig sänds en ljudvarning ut ca 20 sekunder innan utryckningsfordonet kör i kapp. Ljudvarningen lyder ”Varning! Utryckande fordon. Var god ge fri väg” och upprepas två gånger.

När varningen ljuder ska föraren uppmärksamma varifrån utryckningsfordonet kommer samt lämna fri väg när tillfälle ges. Den tidiga varningen ger föraren mer tid att lämna fri väg på ett trafiksäkert vis.

OBS

Ljudvarningar ges bara för objekt vilka befinner sig direkt i bilens färdväg.

Varning

- Funktionen är ett kompletterande förarstöd med avsikt att underlätta körningen och göra den säkrare – den kan emellertid inte hantera samtliga situationer vid alla trafik-, väder- och vägförhållanden.
- Föraren rekommenderas att läsa ägarmanualens samtliga avsnitt om denna funktion för att ta del av bl.a. dess begränsningar, vilka föraren ska vara medveten om innan funktionen används.
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