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ORIGINAL ARTICLE

How do drivers merge heavy goods vehicles onto freeways? A semi-structured interview unveiling needs for communication and support

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Abstract
Freeway merging of heavy goods vehicles (HGV) is a safety–critical manoeuvre. However, at present, it is largely unknown how HGV drivers perceive and execute the merging manoeuvre, and how current advanced driver support and automation systems (ADAS) contribute. We performed semi-structured in-depth interviews with 15 HGV drivers to assess their visual and cognitive processes while merging, interactions with other road users, and attitudes towards ADAS as a basis for future support and automation system design. Results show that the reported execution of merging varies substantially between drivers. Drivers reported reliance on courtesy of other traffic but stated that car drivers are often causing conflicts, whereas other HGV drivers are more cooperative. Current ADAS were perceived as useful in general, with remarks about misuse and abundance of systems. We recommend the introduction of driver support and automation systems which facilitate cooperative behaviour and support effective communication.

Keywords Heavy goods vehicles · Merging · ADAS · Automation · Commercial vehicle · Semi-structured interview

1 The challenge of merging a heavy goods vehicle (HGV)

The number of heavy goods vehicle (HGV) on European and American roads is increasing (European Automobile Manufacturers Association 2017; Federal Motor Carrier Safety Administration 2017; The International Council on Clean Transportation 2017), creating a need to study the effects of HGV drivers' behaviour on traffic safety. In the United States, 4761 fatal crashes in 2017 involved large trucks, with 72% of these fatalities being occupants of other vehicles (National Highway Traffic Safety Administration 2017). HGVs spend a large portion of their driving time on freeways, where merging is known to be a safety–critical manoeuvre (McCartt et al. 2004; Sen et al. 2003). In 2017, 4.5%, 26.5%, and 33.6% of the fatal crashes with HGVs occurred on freeways/expressways, interstates, and other principal arterial roads, respectively (Federal Motor Carrier Safety Administration 2017).

A total of 6.9% of fatal crashes involving HGVs are related to driveway access, the entrance ramp, or the acceleration/deceleration lane (Federal Motor Carrier Safety Administration 2017). Merging onto the freeway is a cognitively demanding task (Baumann et al. 2011; De Waard et al. 2009; McCartt et al. 2004): The (HGV) driver has to observe the on-ramp and adjacent freeway lanes, obtain a safe headway, find a gap to merge into, and synchronise speed. Additionally, on-ramps have a fixed length (which varies between sites), creating time pressure to complete the manoeuvre (Kassner et al. 2010; Kondyli 2009).

1.1 Modelling of merging behaviour

There is a considerable amount of research on the microscopic modelling of merging behaviour. Modelling studies have demonstrated the effects of other road users' behaviour on the efficiency of the merging manoeuvre. Hidas (2002) showed improved traffic flow at merging sections by including traffic which showed courtesy behaviour (i.e., making space for the

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vehicle moving into the lane). Kondyli and Elefteriadou (2011) introduced, based on focus groups and real traffic observations of merging sections, a decision-making model in which the decision to change lanes depended on the interaction with other vehicles. However, the microscopic modelling of driver behaviour does not offer insights into drivers' perspectives and factors contributing to merging decisions and execution. The present interview study was designed to investigate in depth the visual, cognitive, and behavioural aspects of the merging manoeuvre from the HGV drivers' perspective.

1.2 Merging cars onto the freeway

By asking regular (i.e., non-truck) drivers, Kassner and Vollrath (2006) and Kondyli (2009) derived a number of behaviours that need to be performed when merging onto the freeway. Common behaviours mentioned were: global traffic analysis, searching for a gap, and the actual lane change (Kassner and Vollrath 2006). Furthermore, speed adaptation was identified as a key subtask, whereas exceeding the length of the acceleration lane and unsafe headways were reported as predominant errors (Kassner and Vollrath 2006). The decision whether or not to change lanes was reported to be affected by the relative speed and distance to the vehicle behind. In a driving simulator study, Baumann et al. (2011) showed that the decision to change lanes is affected by the speed difference and distance to the trailing vehicle, where for a 30 km/h closing speed and 40 m distance to the trailing vehicle on the adjacent freeway lane, drivers were about equally likely to merge in front or behind the trailing vehicle.

The studies above did not study HGV driver behaviour and the types of critical situations between HGVs and other vehicles that may occur while merging. In HGV merging, vehicle length is a crucial factor: 16.5 m long tractor-semi-trailer combinations (EU) are approximately three times longer as cars, whereas tractor-B-train combinations can be up to 25.25 m long, i.e., five times longer as cars. Moridpour et al. (2010) found significantly different merging behaviours between cars and HGVs (e.g. speed increase was lower and distance to the preceding vehicle in target lane was smaller for HGVs). Nilsson et al. (2018) found that HGV drivers of road train combinations adjust their lane change behaviour according to the cooperative behaviour of other road users. Driving an HGV requires the driver to distribute attention to various sources of visual information (Bothe 2014) where situation awareness is challenged by a large number of mirrors and remaining blind spots surrounding the HGV.

1.3 Advanced driver assistance systems (ADAS) for HGV drivers

Merging is a complex driving task, which cannot easily be automated by computers. Flämig (2016) described use cases of future freight transport; herein the author envisioned, among others, a partially automated driving scenario where freeway driving occurs in an automated manner, yet the human still executes the merging manoeuvre. Although the truck driving task cannot be fully automated at the current state of technology, ADAS are a viable option for supporting truck drivers. Ostermann et al. (2016) examined HGV drivers' attitudes toward various visual aids, including a 360 degree top view, blind spot cameras, and reversing views via a camera monitor system (CMS) in urban environments. The subjective ratings showed that the traditional mirrors were still an important source of information and that the CMS reduced perceived stress and were evaluated as positive by the HGV drivers. The results also indicated that ADAS that reduce blind spots (e.g., 360° top view displays) might be of help in non-urban environments where rear traffic needs to be assessed. The positive ratings of the visual aids are consistent with an interview study by Liao, Li, and Chen (2017), in which Chinese HGV drivers reported to appreciate ADAS that would help to merge from service areas onto the freeway.

It is important to gain insight into what kind of support is needed during the merging manoeuvre, and what are the truck drivers' attitudes towards such support. Literature shows that negative attitudes towards technology may reduce the efficacy of an otherwise effective support system (Parasuraman and Riley 1997; Payre et al. 2014; Kyriakidis et al. 2019). The dissemination of ADAS to the HGV market is low because of long development cycles (Gough and Fassam 2014). This slow uptake requires an assessment of HGV drivers' attitudes towards ADAS in their early design stages.

1.4 Why we need to interview HGV drivers

Assuming that actions of drivers are governed by mental processes such as mental scripts and procedural knowledge, it appears valuable to ask drivers about driving situations and their exerted behaviours (Plant and Stanton 2013). Verbal reports of drivers may give insights into visual-cognitive processes and execution strategies of the merging manoeuvre. However, interviews need to be carefully designed to elicit expert knowledge and to avoid that participants merely reconstruct or rationalise how a merging manoeuvre should theoretically be executed.

Interviews with HGV drivers were conducted to obtain a deeper understanding of HGV drivers' mental representation of the traffic situation and the challenges of merging an HGV safely onto the freeway. Herein, it was of particular interest to identify critical interactions of HGV drivers with other road users while merging. The analyses of critical situations can be used to formulate requirements for future ADAS. Summarizing, the present interview study was designed to obtain in-depth

Table 1 Characteristics of each interviewed driver

Driver-ID	Age in years (gender)	Yearly mileage (km)	Experience (years of driving a truck)	Estimated time spent on the freeway (%)	Type of vehicle	Current truck brand
1	48 (male)	110,001–120,000	20 years	70	Truck trailer	DAF XF, Volvo FH
2	42 (male)	120,001–130,000	24 years	70	Truck trailer, tractor semi-trailer	DAF XF
3	58 (male)	110,001–120,000	25 years	80	Tractor semi-trailer	Volvo FH 3
4	61 (male)	110,001–120,000	41 years	70	Tractor semi-trailer	Mercedes Benz 1845 big space
5	60 (male)	120,001–130,000	38 years	70	Tractor semi-trailer	DAF XF 105
6	52 (male)	120,001–130,000	30 years	70	Tractor semi-trailer	MAN TGX
7	30 (male)	140,001–150,000	5 years	80	Tractor semi-trailer	Volvo FH
8	46 (male)	20,001–30,000	20 years	80	Tractor semi-trailer	Mercedes Benz Actros 2017
9	30 (male)	20,001–30,000	10 years	80	Tractor semi-trailer, truck, truck-trailer	Mercedes Benz Actros 2017
10	50 (male)	120,001–130,000	24 years	70	Tractor semi-trailer	Mercedes Benz
11	60 (male)	110,001–120,000	37 years	70	Tractor semi-trailer	Volvo
12	50 (male)	120,001–130,000	28 years	70	Tractor semi-trailer	Scania R450
13	29 (male)	100,001–110,000	9 years	90	Tractor semi-trailer	MAN TGX
14	44 (male)	120,001–130,000	23 years	40	Tractor trailer	Volvo FH12
15	35 (male)	100,001–110,000	19 years	80	Tractor semi-trailer	MAN TGX XXL

Shown are the driver's age, gender, yearly mileage, years of driving, time spent on the freeway, the type of HGV combination, and the brand driven by the drivers

information about three main aspects of merging HGV onto freeways: (1) visual, cognitive, and behavioural processes while merging, (2) interactions with other road users, and (3) attitudes towards current ADAS as well as future assistance systems for the merging manoeuvre.

2 Methods

2.1 Participants

Fifteen HGV drivers were recruited as described in Sect. 2.3. Table 1 provides an overview of the drivers' characteristics. The drivers were on average 46.3 (SD 11.25) years old, all-male, and had 23.5 (SD 10.5) years of truck driving experience. The median yearly mileage was 110,001–120,000 km. Fourteen out of the 15 drivers spent 70% or more of their driving time on the freeway. Volvo FH was indicated 4 times as the current truck brand, Mercedes Benz Actros four times, DAF XF three times, MAN TGX three times, and Scania R 1 time. The drivers' nationality was either Dutch (7 drivers) or German (8 drivers). Three interviews were held in English and 12 in German.

2.2 Materials

2.2.1 Study materials

The interviews were recorded with an aLLreLi CP00341 8 GB sound recorder and transcribed for further analysis. The drivers were sequentially provided with (1) a sketch of a merging section (Fig. 1), (2) a depiction of an HGV cabin (Fig. 2), (3) a questionnaire about driving exposure and (4) a questionnaire about ADAS use. The sketch was provided before the interview. The depiction of the HGV cabin was provided during the interview, and the driving exposure and the ADAS questionnaires were offered after the interview. The sketch was present on the table throughout the interview. The depiction of the HGV cabin was available during the last part of the interview to aid drivers in describing their behaviours in various situations.

2.2.2 Sketch of merging section

We used a sketch of a freeway merging section to assess the mental representation of the HGV drivers (Fig. 1). The sketch depicted a top view of a merging section with the participants' HGV at the on-ramp and two HGVs on the right lane of the freeway. The participants were asked to write down actions performed and tasks of the driver while

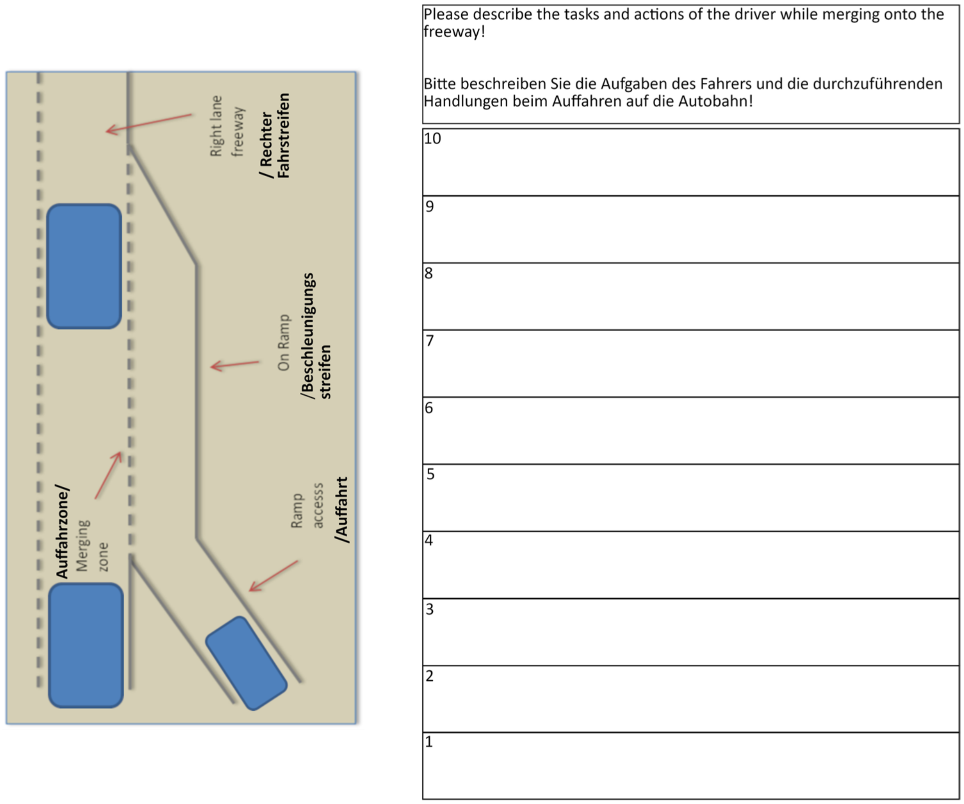

Fig. 1 Merging tasks and action assessment

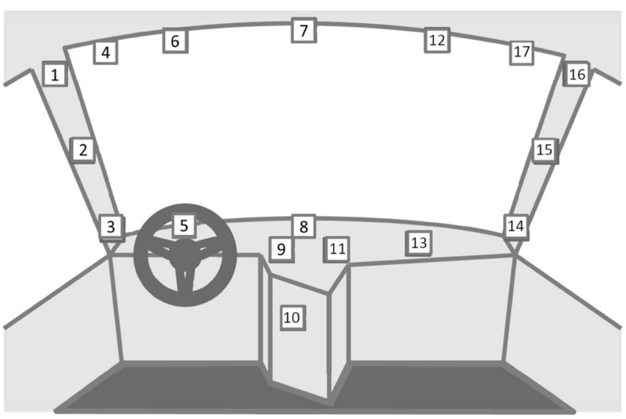

Fig. 2 ADAS location questionnaire depiction used to assess potential locations of new merging ADAS (adapted from Ostermann et al. 2016)

merging (based on Kassner and Vollrath 2006). The form provided ten blanks alongside the sketched road, in which participants could fill in the tasks/actions chronologically. Participants were not required to fill all blanks. Drivers were not required to verbalize while completing the form but were not prevented from doing so.

2.2.3 Interview

The interview covered three main topics. First, the interviewer addressed visual tasks and behaviours while merging onto the freeway in situations with different numbers and types of vehicles. Subsequently, critical driving situations were discussed. Finally, the use of and attitude towards current ADAS was enquired (see Sect. 2.3 for a detailed description).

2.2.4 ADAS location assessment

A depiction of an HGV cabin was used to assess the optimal position of a rectangular screen that displays an ego-centric top-view virtual camera image (Fig. 2). A top-view image was well received by drivers in Ostermann et al. (2016) (Sect. 1.3). The top view was described verbally within the interview as showing the driving scene in the direction of travel (cf. Fig. 1). The additional environment information reduces blind spots around the vehicle. Further, the top-view can support the estimation of speed and lane position of other road users to enhance situation awareness. The depiction showed 17 locations for positioning the screen within the HGV cabin and requested the participant to indicate three preferred positions, ordered from the most to the least favourable position.

2.2.5 ADAS use questionnaire

We assessed a variety of ADAS to discover drivers' (visual) information needs and to unveil potential problems of technology acceptance. The current use of ADAS was determined using a 10-point Likert-scale with the anchors "very often" and "never" in the English version and "sehr oft" and "gar nicht" in the German version. The drivers rated the frequency of use of each type of ADAS that was available in their current HGV. The form showed 11 types of ADAS and supportive technology: (1) adaptive cruise control (ACC), (2) forward collision warning (FCW), (3) lane departure warning (LDW), (4) lane keeping assistance (LKA), (5) cruise control (CC), (6) lane change assist (LCA), (7) camera monitor system (CMS; for rear traffic), (8) a second window in cabin doors (WIS; on knee height), (9) automatic emergency braking (AEB), (10) fresnel lens (FL), (11) additional mirrors (AM). The ADAS shown on the questionnaire were selected based on a literature review on current truck driver assistance systems (Ostermann et al. 2016).

Moreover, participants reported demographic data (age, gender), the brand and model of the HGV, and the yearly mileage in 10,000 km intervals. Additionally, the driving experience in years working as an HGV driver was reported. Accidents at merging sections were not assessed as the likelihood of interviewing a driver experiencing such an accident is rather low.

2.3 Procedure

The participants were recruited at HGV service areas within the Netherlands and Germany and a logistics company. The operators of the service areas consented to the study. The presence of researchers from the Delft University of Technology was indicated via signs at the front entrance and the restroom doors. The signs showed the Delft University of Technology logo with a brief incentive text about the study topic and compensation. The interview took place at a dedicated table in a quiet part of the restaurant. The interviewer approached the drivers either after parking their truck or in the restaurant after they had finished their dinner. The interview was designed to last 20 min, but depending on the driver, it was slightly shorter or considerably longer (up to 45 min). First, casual topics such as the daily drive were discussed to relax the drivers and to reduce scepticism towards science. Drivers were informed about the scope of the study, provided written informed consent, and were informed that voice recording started.

Before the start of the interview, the sketch of the freeway merging section was explained (Fig. 1), handed to the drivers, and completed by the drivers without verbalising. Next, the interviewer asked the interview questions sequentially according to the following predefined structure: first (1) tasks, visual behaviours, and perceptions (e.g., gaze sequences), and second (2) critical interactions with other road users while merging, with the provided sketch (Fig. 1) still present. Critical interactions were explained to the drivers as near-crashes or situations that were perceived as dangerous. The third (3) topic concerned attitudes towards ADAS in general and while merging. Within the above topics, the following sub-topics were addressed: Within topic (1), mirror use while merging, tasks of the driver at specific segments of the on-ramp; within topic (2) critical interactions depending on the road layout and vehicle type, strategies while merging to cope with varying traffic conditions, HGV specific challenges; and within topic (3) satisfaction with ADAS, the use of current ADAS, usefulness of future ADAS and locations for new in-vehicle information systems (IVIS) in current HGVs. After discussing the use of current ADAS in (3), drivers completed the 'ADAS location assessment' (Sect. 2.2.4) and explained their choice verbally. Finally, after the interview was completed, drivers completed the demographics and the current ADAS use questionnaire (Sect. 2.2.5). While filling the ADAS use questionnaire, participants were not requested to verbalize. However, all drivers explained their choices while doing so.

Throughout the interview, the interviewer made sure that the participants elaborated on each predefined topic. For example, participants were requested to describe critical situations not only occurring with cars but also with other HGVs. The interviewer kept the focus on describing situations involving high traffic density, where workload is assumed to be high.

2.4 Processing of interview and questionnaire data

The quantitative data analysis was executed using R software, a free object-oriented programming language designed for statistical computing and graphics. The qualitative interview analysis was carried out with Atlas.ti 8.0. Atlas.ti 8.0 provides a GUI with functions to support thematic grouping and counting text elements to analyse text in a structured manner. Original interview quotes in German were translated into English. Semantic overlap of both the interview and the questionnaire are reported together, whereas topics solely addressed within the interview are addressed at the end of the Results section.

3 Results

3.1 Merging behaviour: sketch

HGV drivers received a sketch of the merging section and were asked to note down the sequence of actions and tasks while merging their HGV onto the freeway (Fig. 1). One

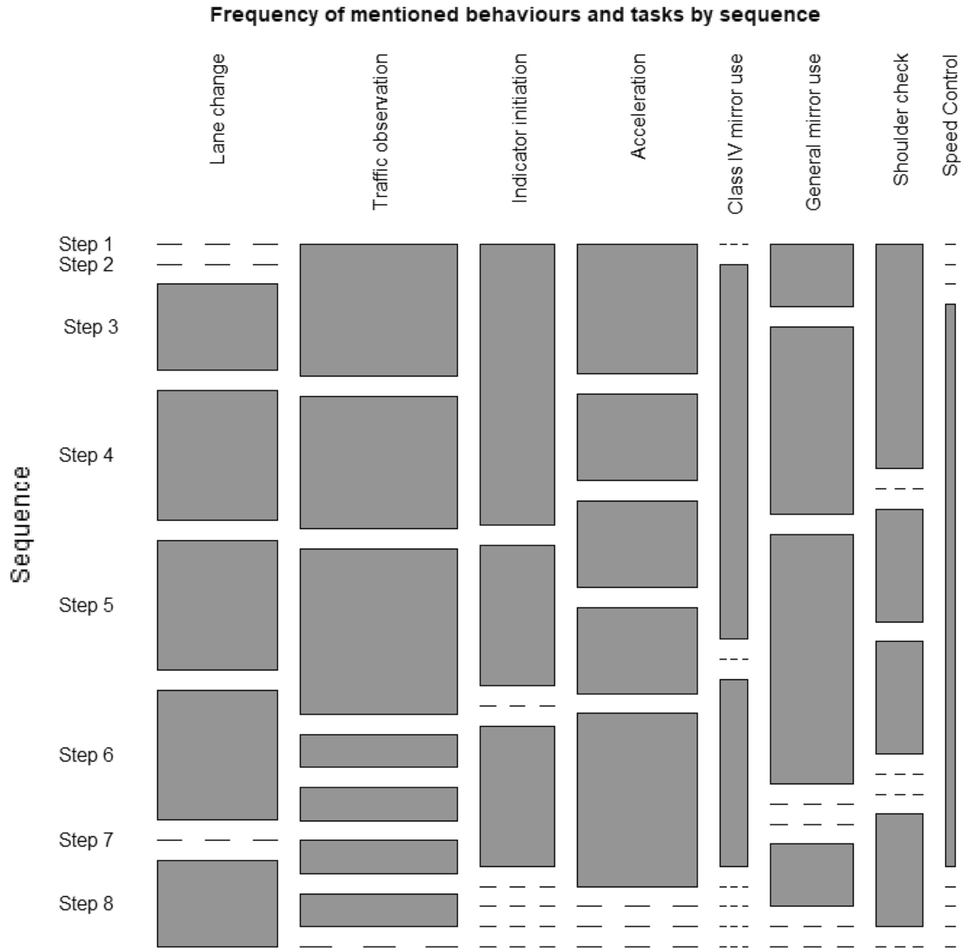

Fig. 3 Mosaic plot of the mentioned behaviours. The width of the cells linearly corresponds to the overall frequency of the particular task/action. For example, 'traffic observation' is the most reported task. The heights of the cells represent the frequency of occurrence of that behaviour as the n-th step. For example, 'traffic observation' is reported most frequently as the third step

driver was not willing to write and, therefore, excluded from this analysis. HGV drivers reported between 3 and 8 tasks and actions, including the lane change itself. The steps were semantically classified and analysed concerning frequency and sequence.

Figure 3 shows the relative frequency of reported actions and tasks within each step of the sequence. Visual behaviours are reported more frequently at the beginning (i.e. general mirror use, shoulder check) of the merging procedure as compared to the end. Accelerating and the use of the Class IV mirror (see Fig. 4 for illustration) were also frequently mentioned at the beginning (first and second step, respectively) of the merging task.

Four aspects were identified by a large portion of drivers: (1) 12 out of 14 drivers reported acceleration behaviour at any point during the merging manoeuvre; (2) the use of the indicator was mentioned by 8 out of 14 drivers; (3) over the course of merging, 14 of 14 drivers reported 'visual behaviour to observe traffic'. Lastly (4) 13 out of 14 drivers reported concluding the merging procedure with a lane change (cf. Fig. 4). However, major variations in the sequential order of behaviours were reported between drivers.

Figure 4 dissects reported behaviours at the level of individual drivers. In the plot, shades of orange represent visual behaviours to observe traffic, purple and blue represent speed-related behaviour and green the lane change. At the beginning of the merging procedure, drivers reported more visual behaviour ($n = 7$) than acceleration/deceleration behaviour ($n = 3$). Visual behaviour precedes acceleration for most drivers (Fig. 4). Visual behaviour at the beginning was reported to be either a shoulder check (i.e., looking through the side window), the Class IV mirrors, or reported as "look for traffic", "observe rear traffic", "traffic density", and "looking left" (grouped under the category 'general traffic observation'). The reported behaviour exerted on the mid of the acceleration lane is related to general mirror use and general traffic observation. Two drivers reported controlling speed while being on the acceleration lane (reported as "speed control"). Visual behaviour preceding the lane change includes visual behaviours to observe a variety of situational aspects (e.g., shoulder check through side window to "look for distance [to rear traffic]", "look for length of ramp", Class IV mirror to check "whether someone is next to the truck" and Class II mirror use to observe traffic).

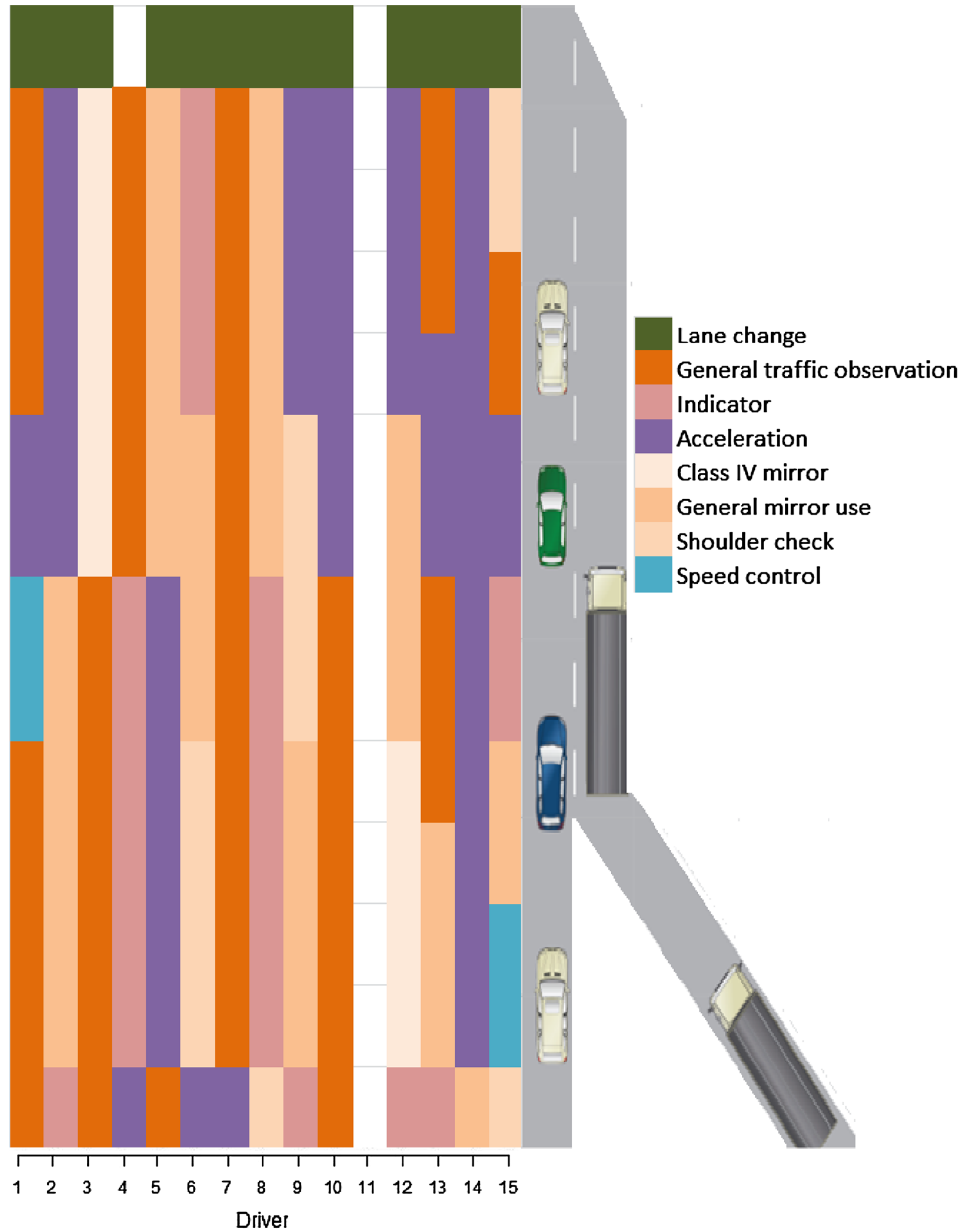

Fig. 4 The sequence of behaviours throughout the merging procedure. Colours represent behaviours, columns participants. The heights of the cells corresponding to the first and last steps are fixed. The heights of the cells in between the first and last steps were proportionally adjusted over the number of mentioned steps for that participant

The initiation of the directional light signal (the indicator) varied between participants (8 out of 14 reported using the indicator). Most ($n=4$) drivers reported initiating the indicator at the start of the acceleration lane, whereas one driver reported initiating the indicator immediately before changing lanes (cf. Figs. 3 and 4).

3.2 Merging behaviour: Interview

The merging behaviour was further addressed in the interview to obtain more detailed information. Six participants (Driver 3, 4, 5, 9, 14, 15) stressed that the overall processing, perception, and executed actions are highly automatic (i.e., unconscious). Drivers 4 and 5 said about the merging process: "It goes automatically". Driver 14 underscored the effect of experience and practice of the procedure: "you drive for a long time, you do it very automatically", and Driver 9 referred to the speed of execution and the ease of actions: "sometimes relatively quick, simple, and very self-executing processes".

3.2.1 Visual behaviour while merging

Visual behaviour while merging was reported to have different purposes and drivers used various information sources during the merging manoeuvre. At the start of the ramp (i.e., not yet at the beginning of the acceleration lane), 6 out of 15 drivers reported using either the left side

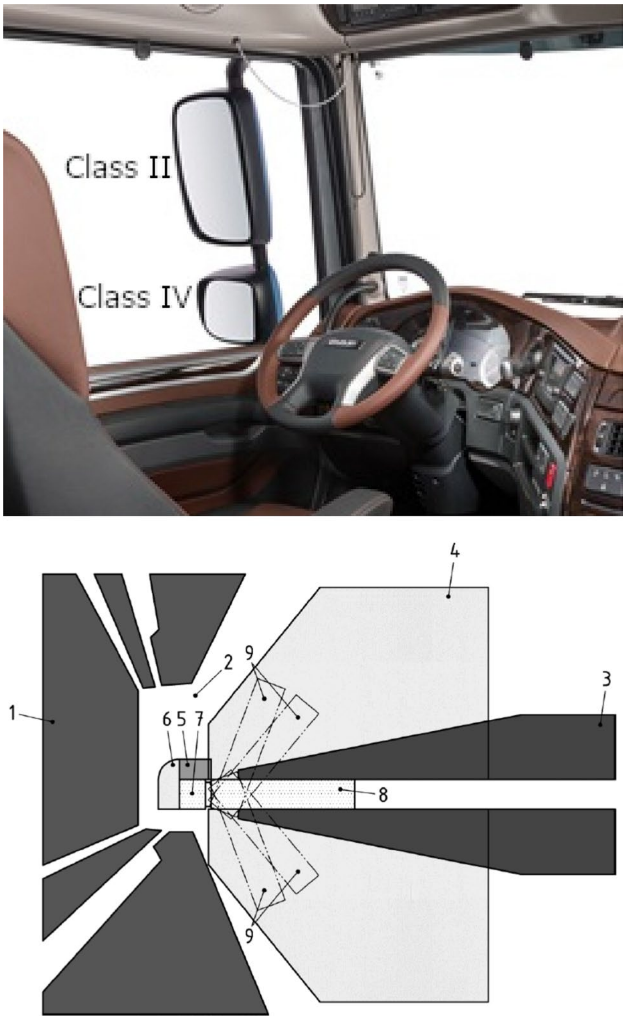

Fig. 5 Illustration of mirror classes at the driver's side (left; modified: transport-online.nl, 2017) and illustration of direct and indirect sight based on ground plane coverage (right, ISO 16505:2019; International Organization for Standardization 2019). (3) Class II mirror and (4) Class IV mirror. Class IV mirrors have, due to convexity a wide field of view. The size and convexity of Class IV mirrors reduce depth perception and object size

window or the Class IV mirror. These mirrors are used to analyse traffic density and overall traffic conditions. For example, Driver 12 stated about the Class IV mirror: "The small [mirror] is actually only for orientation: is it busy on the road or not?" and Driver 15 referred to the field of view provided by the Class IV mirror: "At that moment, the small one, the ramp-mirror, is interesting, because I have a wider view" (comparing it to the Class II mirror; see Fig. 5 for illustration). Drivers reported that the Class IV mirror is less relevant in general for merging and not used except for global traffic analysis. For instance, Driver 10 stated rarely using the Class IV mirror while mainly using the Class II mirror: "No, actually while merging not at all, maybe sometimes shortly, but normally you are using here [merging section] actually only the large mirror". Class IV mirror usage on the right side was not reported: In general, drivers agreed that the Class IV mirror at the right side is too far away and used only in urban environments. Driver 8 commented: "The right one [mirror], I actually don't need it at that moment" and Driver 15: "I use this one [Class IV, right side] only if I have to reverse over the passenger's side, so that I see at least something/a little". A general problem drivers mentioned by referring to the Class IV mirror was the small size of observed objects, distortion of distances, and the limited view compared to the window, e.g. Driver 8: "when I am looking through the [side] window, then I do see way more than within the constrained field of view of the mirror, so I look outside".

While being on the acceleration lane, some drivers mentioned using solely the Class II mirrors. These mirrors are used to observe the behaviour of the adjacent freeway traffic ("I look actually, like I said, I have two mirrors, I look actually only in the large [mirror], in the upper one,…", Driver 9). According to Driver 12, the Class II mirrors are important to "…observe, what they [other traffic] are doing, if they change lanes and indicate, if they are able to change lanes, because if the left lane is busy, then it won't happen and you have to stay slow". Additionally, Driver 1 pointed out that while being on the acceleration lane, the speed of approaching traffic is assessed via the Class II mirrors "you can see the speed of the other vehicles". Further, drivers refer to speed as an attribute of the other traffic behaviour, e.g. Driver 11: "if you see the other vehicle is considerably faster than you are, then it won't work".

Drivers with more than ten years of experience remarked that prior to regulation changes in 2007 by the EU regarding indirect vision (Directive 2003/97/EC 2003), they were used to analyse traffic solely via the Class II mirrors, e.g., Driver 3: "When I was young they didn't have that curved, small mirror; they only had the large one, so it was going well". Drivers hardly commented on visual behaviours during the lane change itself: Only 1 out of 15 drivers reported glancing in the Class IV mirror before changing lanes ("I always use the curved one [Class IV mirror] when I have to change lanes. Then, I am looking at that one [Class IV mirror], because I cannot see in the big one what is at my front wheel"; Driver 3). Four out of 15 drivers reported that traffic ahead is important, and they need to look straight to observe the preceding traffic. These drivers stressed that they mainly have to look in the direction of travel while merging.

Mirror use to estimate the position of the trailer of the HGV during/after changing lanes was not reported. Questions regarding overshooting and positioning of the truck were regarded as irrelevant (e.g., the response of Driver 3 about the trailer position "it is coming with me"). HGV drivers reported having an idea of the size of the HGV so that

Table 2 Listed are all reported problematic behaviours of other road users while merging onto the freeway, including the type of vehicle associated and the location of these behaviours

Problematic behaviour of other traffic	Quotes	DriverID (similar not quoted Driver IDs)	Location of other vehicle's behaviour	Vehicle type
Accelerating	"So you think, but, he is not coming, and you can change lanes before him, and suddenly they are next to you because they accelerated"	15	Right freeway lane	HGV
Lane change middle/left lane to right freeway lane, closing gap	"What can happen, ah, that someone from the left lane changes again to the right and then does not consider that others are merging…"	8, (12)	Right freeway lane	Car
Merging early (behind the HGV) to the right freeway lane	"They are behind me and they come to the left before I go on the freeway, and then they will be next to me and I have a problem"	2 (11, 1, 13, 14, 15)	Right freeway lane	Car
Continuing at merging speed parallel to the truck, ignoring the truck	"They are continuing steadily"	9 (15, 13)	Right freeway lane	Car
Slow speed while merging	"…because the cars are so slow and because they do not realize, so the drivers today, they merge with too low speed"	10 (9, 14, 15)	Acceleration lane	Car
Passing on the right side at the end of merging lane while changing lanes	"When I go to the left, then I look in the right mirror because someone behind me will pass me by on the right side"	1 (3)	Acceleration lane	Car
Car merging earlier to the outermost left lane	"…and that they [cars] then behind me directly go to the left side"	5 (4)	Acceleration lane	Car

Driver IDs are displayed for drivers reporting these problematic behaviours

they know the length and the behaviour of the articulated vehicle (e.g., "you know your vehicle's width, you know that it fits", Driver 8).

3.3 Interaction with other road users and infrastructure

One of the goals of the interview was to identify critical situations while merging and the behaviours of other traffic that may ease or complicate the merge. We used a similar approach to the critical incident technique (Flanagan 1954), as we asked about critical interactions and probed drivers on the course of events to identify moments that raised criticality. All 15 HGV drivers reported that the vehicle types on the right lane of the freeway and the acceleration lane affect the merging procedure. Drivers stated that cars are causing conflicts because of reckless driving behaviours, while other HGVs are generally cooperative. With our interview technique, we identified various problematic behaviours while merging (see Table 2 for an overview).

The HGV drivers reported that the deviant behaviours of car drivers gave the impression that the car drivers were under time pressure. Six drivers referred to an attitude change among road users over the last decade concomitant with the increased amount of traffic. Driver 4 stated that cars "…are in a hurry, they have to work" whereas Driver 3 stated: "the cars are always in a hurry". Driver 14 referred to a more general change in behaviour "the problem is simply the mentality. It is that everyone wants to be first".

When asked about the challenges of merging, the most frequently occurring first response of drivers was that there are 'none', which contradicts the fact that they reported several situations (Table 2) that cause problems while merging. In response to the question about the frequency of critical situations, most drivers admitted that there is a high frequency of critical situations (e.g., "critical situations are happening daily", Driver 10). While talking about critical situations, drivers frequently reported that they are trained and experienced to cope with various types of critical situations. For example, when confronted with the question about critical situations while merging, Driver 6 responded; "Yes, that happens every day. We are trained for that", whereas Driver 14 stated: "there were actually lots of situations, but you have to honestly say, for that, I am observing traffic…". It appeared that drivers have a different perception of the criticality of a situation. Driver 12 said that he "hasn't had a critical situation because he could mitigate the situation, so that no accident occurred."

Table 3 Examples quotes concerning reliance on other road users and courtesy behaviour

	Driver ID
Quotes: Reliance	
"Among us truck drivers, no matter whether Germans or foreigners, normally you try to go to the left, so that the other [driver] is able to merge, you slow down, so that the other can go back and then the matter is settled. That is more cooperative,…" "Everyone knows, there is someone who wants to merge"	15
"If everyone takes care a bit, I say, then it works"	14
"You give a sign to the left and you wait until somebody gives place to you"	2
"The people who drive the car [right freeway lane] have to keep a little bit of headway"	5
"I haven't had a dangerous situation, so that a car driver or truck driver did ignore me completely [while merging]"	9
Quotes: Courtesy	
"It is just like that, so that a lot of truck drivers, they are going to, and they flash headlights, it is not according to the rules, flashing lights, so that you, they took note of you and let you merge or even virtually changing lanes in order to clear the lane fully"	9
"…Of course, so if there is a truck coming [approaching from rear], in [the] normal case, you get always the headlight flash, yes, that is how it is, no matter what nationality, at most you get the headlight flash and then it is the sign so that you are allowed to merge"	10
"…so either they change lanes or they give you the headlight flash, so that it is possible to merge, then it regulates by itself"	14
Interviewer: "If nobody would do that [showing courtesy], if nobody would do it, would it get very difficult?" HGV driver: "Definitely, depending on traffic density, for sure"	13
"The truck on the freeway driving lane moves aside and you get flashing lights"	10
"I myself have had it rarely that the acceleration lane did not suffice, just because no one let me merge or, more precisely, let me merge onto the freeway"	9
"Courtesy lane change to the left; I would say that easily 90% of all truck drivers, they let their colleagues merge"	8

3.3.1 Courtesy behaviour

All drivers indicated that it is important that other traffic yields to an HGV at the acceleration lane. Common behaviours were courtesy yielding by either decelerating or changing lanes to the adjacent left lane of right freeway lane traffic. Another form of courtesy yielding of right freeway lane traffic was to flash for drivers on the merging lane. The headlight flash appears to be a commonly accepted signal to indicate to the HGV driver that he is allowed to merge. All drivers explained that they are aware of the traffic rules and that they, as a merging vehicle, need to yield to traffic on the freeway. However, 11 drivers reported having an expectation about other road users' behaviours, in the sense that the freeway traffic needs to be attentive about what is happening on the acceleration lane and are expected to yield out of courtesy. Moreover, drivers reported exerting a passive driving style to prevent accidents. Drivers were aware of the lengthy procedures that come along with accidents; hence, drivers stated not to force others to adapt to their behaviour while merging. To illustrate, Driver 8 reported having a theory of mind about the other drivers and always being prepared for errors of others: "I simply say, I like to think for others [drivers/traffic] and I know what it is kind of stress, and it is only one second he gains and does not help him…". All 15 drivers agreed that the community of HGV drivers is helping each other while merging (Table 3).

Drivers reported a variety of situations encountered while merging with regard to the amount and type of vehicles travelling on the freeway lanes, the acceleration lane, and the infrastructure. The global traffic condition has a large impact on the perceived ease of merging. The difficulty of merging an HGV concerns dense but non-congested traffic. Drivers reported that congested traffic is not more challenging than free-flow traffic. Low speeds enable the driver to merge while driving within the queue of merging traffic at the acceleration lane and other road users usually exhibit courtesy behaviour ("If there is a queue, you can slowly drive on with the queue and you give a sign to the left and you wait until somebody gives place to you.", Driver 1). Furthermore, congestion not only enhances the awareness of the merging situation but also increases the available time for assessing the situation.

3.3.2 Coping with deviant merging behaviour

Strategies that drivers developed while merging were mentioned only sparsely, as the main focus of the interview was on describing the interaction with other road users. Nonetheless, some coping strategies were identified. Drivers reported exceeding the merging lane if communication or a thorough assessment of traffic failed, particularly when driving with a full payload. One driver reported merging early if he detects that a following car intends to merge earlier than him, thereby avoiding the situation of being blocked while changing lanes.

In case multiple vehicles were following and preceding the HGV at the acceleration lane, drivers reported that to

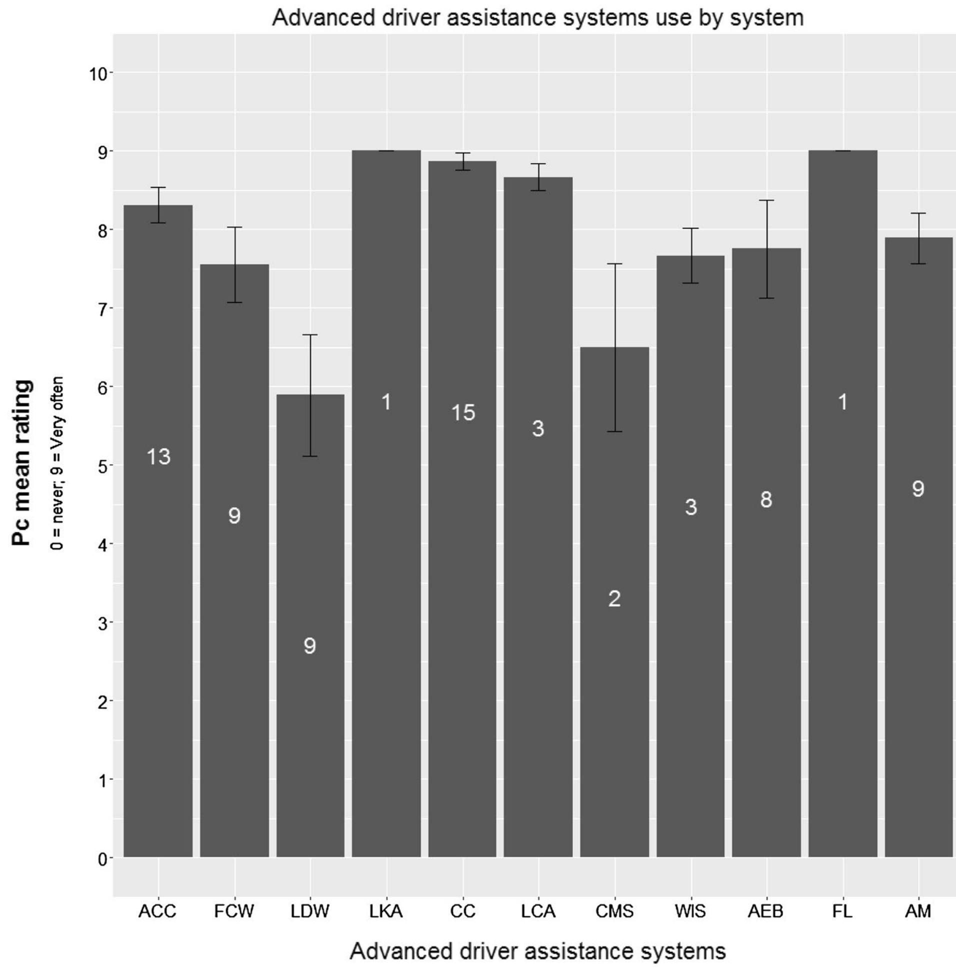

Fig. 6 Proportion corrected mean ratings (number of drivers displayed within each bar) and standard error (SE) of the frequency of ADAS use per ADAS type. Overlap of systems is possible as drivers may not have been able to distinguish, e.g., ACC from CC. *ACC* adaptive cruise control, *FCW* forward collision warning, *LDW* lane departure warning, *LKA* lane keeping assistance, *CC* cruise control, *LCA* lane change assist, *CMS* camera monitor systems, *WIS* window in side door, *AEB* automatic emergency braking, *FL* fresnel lens, *AM* additional mirrors

slow down at the start of the ramp, especially if the vehicle in front is another HGV. A preceding HGV may impair the success of the merging procedure, as the situation requires two large gaps on the freeway.

3.4 ADAS use

At the end of the interview, the drivers received a questionnaire to assess their current use of ADAS. ADAS equipment varied substantially across HGVs, even though all HGV drivers reported driving models not older than 3 years since production. All HGVs were equipped with a longitudinal aid (ACC or CC, if combining responses). 8 to 9 out of 15 HGVs had LDW, FCW, and AEB (see Fig. 6). Three drivers indicated driving HGVs with more recent ADAS such as Lane change assist (LCA, three drivers) and rearview camera monitor system (CMS, two drivers). Drivers rated the overall frequency of use on a 10-point Likert scale with the anchors “almost never” and “very often”. The drivers rated only the systems that were available in their HGV. Figure 7 shows the mean ratings (only rated systems were taken into account; proportion corrected) of ADAS per participant. It can be seen that all drivers reported frequent use of ADAS (range 6.2–9.0). Further analysis of the frequency of use per system revealed that the longitudinal ADAS ACC ($M=8.3$) and CC ($M=8.7$) were used most frequently, whereas LDW was reported being used the least (see also Sect. 3.4.2). The high rating of LKA by one driver turned out to be because he mistook LKA for LDW.

While completing the questionnaire, drivers spontaneously reported information about how the systems are used in certain driving situations and why. In addition, shortcomings of the systems were indicated. Trust-related concerns, negative emotions, and behavioural adaptation to particular ADAS were expressed. However, in general, a positive attitude towards ADAS was reported (“I am glad that assistance systems exist and I say they should definitely, in particular ACC, be a must-have”, Driver 9).

3.4.1 Longitudinal control ADAS

The reported frequency of use of ACC ($M=8.3$) was similar to CC ($M=8.7$). ACC was reported to not function properly in particular driving situations. For example, some drivers

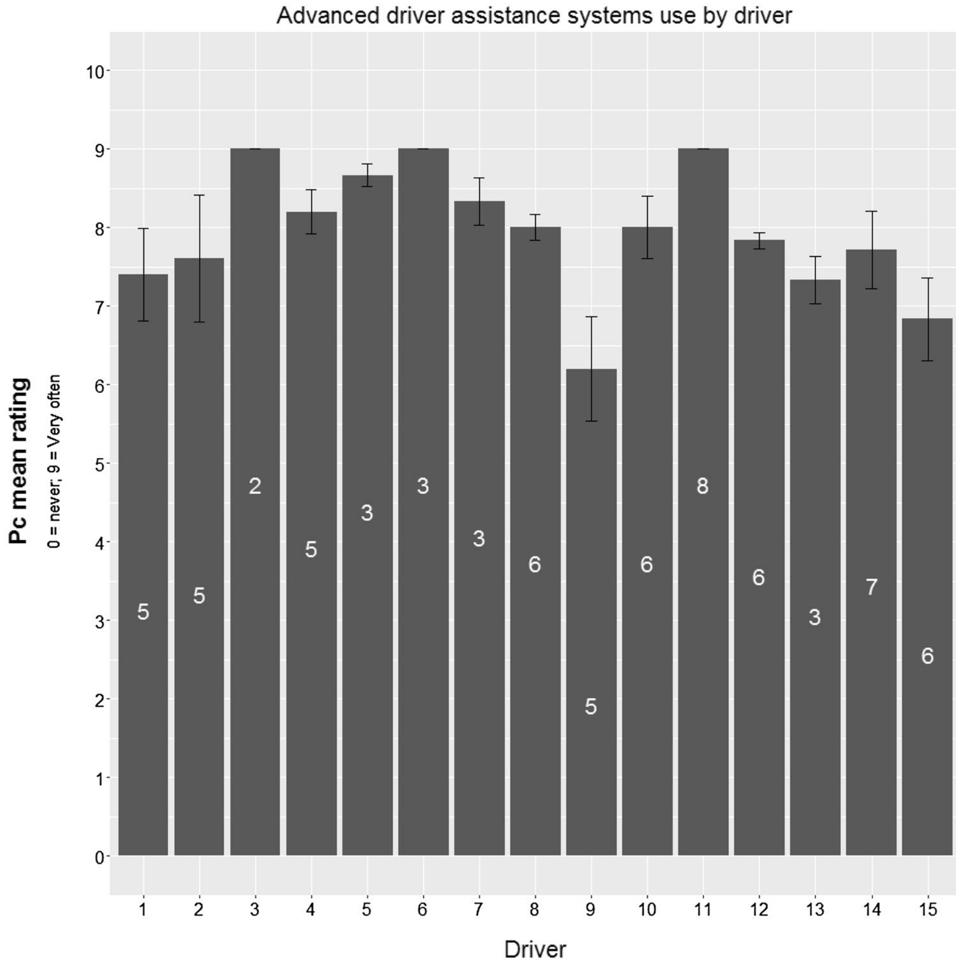

Fig. 7 Proportion corrected mean ratings (number of driver assistance systems displayed within each bar) and standard error (SE) of the frequency of ADAS use per participant. ADAS which were not rated were not included in the calculation. The number of ADAS used is displayed within each bar. High mean ratings indicate frequent use

complained about the abrupt braking that occurs when traffic ahead changes lanes, causing a reduction of headway sensed by the ACC system. On the other hand, more modern ACCs, which brake more smoothly, seem to allow driving at uncomfortably small headways ("I would brake earlier than the assistant […], I needed to convince myself to say I rely on the assistant", Driver 8). The drivers further reported that FCW is sometimes triggered even if situations are not perceived as critical (e.g., at toll- and traffic sign-bridges on freeways), annoying the drivers. The most criticized systems were AEB and LDW (7 and 10 drivers, respectively), the former in particular due to false positives. AEB was perceived as a sudden, uncomfortable intervention in the control authority of the driver. AEB could be triggered, for example, as a response to directional changes of a preceding vehicle or a vehicle that cut in while the HGV is changing lane. Because directional changes and close passing frequently occur in urban traffic (e.g., on roundabouts and crossings), AEB concerns were strongly related to urban and not to freeway traffic. Driver 15 reported a rear-end strike accident because the AEB system was triggered, even though the HGV could have passed the preceding vehicle safely.

> "Yeah, it is often the case, yeah, I'd say that it does not precisely recognise, there is someone turning, and I continue driving straight passing him and it is dropping the anchor, and I would have passed him or it releases throttle or brakes. The problem is that the brake is sometimes very jerky (…) it is always turned on, but in urban traffic…" (Driver 15).

False (or undesired) AEB interventions on freeways were commonly triggered by car drivers that were exiting the freeway while the HGV driver was about to merge at combined merging and exit lanes. The exiting car was decelerating and cutting in front of the HGV while the HGV was accelerating. Moreover, one driver reported being under surveillance by the back office, which gets notified about AEB interventions, placing additional stress upon the driver. The feeling of being under surveillance and being blamed for inappropriate behaviour when the driver was not at fault negatively affected the perception of ADAS. However, in general, drivers acknowledged that new technology improves road safety, particularly during freeway driving and in congested traffic. As Driver 14 stated: "these emergency braking assists etcetera, that is a very cool thing,…”. Furthermore, drivers stressed that ADAS substantially reduce workload (“driving with cruise control is more relaxed”, Driver 1; “Because it is more comfortable and it facilitates the work for everyone, not facilitate, but less stressful”, Driver 14).

3.4.2 Lateral control ADAS

Drivers were generally negative about LDW. They reported to be scared by the sudden activation of the system and annoyed by the frequent false positives caused in narrow rural roads and at the (many) construction sites on freeways. In these two cases, drivers reported having to go over the lane markings, henceforth triggering the LDW. Seven drivers reported switching off their LDW.

> “That gets on my nerves in particular in construction zones, just, you don’t think about it and then it starts [vibrating] at the steering wheel, I usually turn it off, because sometimes you have to cross the lane a little and every time the thing goes off, as well when you are at narrow rural roads. It is annoying.” (Driver 15).

Moreover, use based on need was reported. Specifically, it was mentioned that LDW is used when driving at night while feeling tired, as an attentional back-up that prolongs the driving time even though adequate rest would be appropriate: “…you can, during the night on freeways, it should be against falling asleep, but in construction zones you have alarms continuously” (Driver 10). Only one driver reported having all systems switched on permanently, arguing that the safety benefit overweighs negative experiences. “I have them switched on all the time; I cannot understand how people can turn them off” (Driver 11).

3.4.3 Visual ADAS

The drivers appreciated systems that were designed to reduce attention-based errors and increase situation awareness. All drivers using a lane change assist (LCA) and camera monitoring system (CMS) reported that they did not want to miss them. Rear-view camera systems were not only reported to be used while manoeuvring but also on freeways, to observe rear traffic. Within cities, a typical scenario was described causing frequent problems with the following traffic. Reversing a few meters with an HGV seems a major cause of accidents according to the drivers as following vehicles are hidden behind the trailer within the blind spot.

> “You often have to reverse i.e. somewhere at a company or anywhere about 2, 3 m and you don’t see anything, if there is something behind me […] because often cars tailgate up to a meter and then you don’t see them in the mirrors anymore with a tractor-trailer.” (Driver 10).

The problem of observing rear traffic in the blind spot behind the trailer was reported to be resolved with a CMS. Driver 14 reported that “…[he has] an additional rearview camera. Now I can observe rear traffic behind me, that is a very nice thing”. The older drivers reported not to be amenable to new ADAS, because they would retire soon and it is effortful to use and adapt to driver aids “Maybe for the new drivers, but for the old ones, it won’t work” (Driver 4). Older drivers generally commented that visual support systems should consider age-related vision deterioration, which impairs the deciphering of displays that are either placed in proximity or at a far distance from the driver. Four drivers were concerned about the visual load they are exposed to in challenging driving situations while driving current HGVs. Drivers argued that it would be impossible for them to absorb more information because mirrors and current in-vehicle information systems already occupy the maximum of their cognitive capacity. The interaction of drowsiness and the amount of visual information also raised concerns about the visual load (“You know, the problem with cameras and screens is, it is too much”, Driver 5).

3.5 ADAS location

At the end of the interview, HGV drivers were verbally confronted with the idea of introducing a new ADAS for the merging procedure. The system was described as to provide a top view of the driving situation on a screen. The drivers were asked to rank three favoured screen locations out of 17 within the cabin (Fig. 2). For each location, a rank-count score was calculated. For each naming of a location, either three (first rank), two (second rank), or one (third rank) point was assigned and summed to a final score of all drivers per location. Results show that the dials and the mid-A-Pillar were favoured most having a score of 17 (Fig. 8). The second choice was the top of the mid-console with 15 points. The third choice, with a score of 15, was the bottom of the A-Pillar. In general, locations in proximity to the driver were preferred. Some drivers insisted on ranking only locations they evaluated as feasible, thus leaving inferior ranks blank.

Drivers expressed clear opinions about where the screen should be placed, emphasizing that the front window has to be free of visual obstruction. The front window was seen as an option if the top-view is being implemented as head-up display (HUD). Concerns were mentioned about interference between mirrors and other in-vehicle information systems, both in terms of possible locations and information that might get confused due to visual overload and proximity. Five out of 15 drivers (Drivers 4, 5, 6, 7, 12) argued that the truck is already equipped with too many systems.

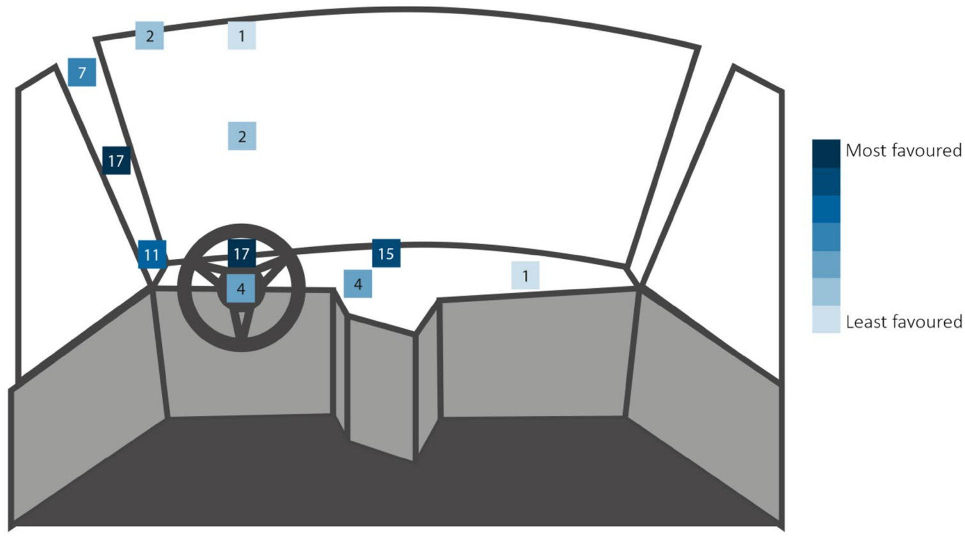

Fig. 8 Final rank-count score per location. Non-mentioned locations are not displayed. High numbers (dark coloured squares) indicate favoured merging ADAS locations of the drivers. The same rank-count scores appear on backgrounds with identical colours. Note: Front window and steering wheel were proposed by Driver 4 and 5

In particular, the board computer was reported to have too many options paired with an external navigation system. Toll-boxes were also mentioned to be placed in the field of view of the drivers, therefore, limiting the possible screen locations.

> "it is not pleasant for the driver if there is something attached to the window, so it is enough, toll-boxes, you do not need more attached gadgets, thus it is best to place it within the cockpit or integrated into the navigation system" (Driver 13)

4 Discussion

4.1 Interview goal

This semi-structured interview aimed to identify challenges while merging an HGV onto the freeway for the design of future support and automation systems. The study covered three main aspects: (1) visual behaviour and cognitive processes of the merging procedure, (2) the behaviour of other road users while merging, including critical driving situations, and (3) the current use of, and attitude towards, ADAS.

4.2 Merging behaviours and cognitive processes

The interviews suggest that HGV drivers' merging behaviour was guided by automatic mental processes. Common behaviours identified while merging were (1) a global traffic analysis, followed by (2) observation of rear traffic and acceleration, concluding with (3) the lane change. However, there were large individual differences in the number of reported behaviours, suggesting that not all drivers were able to retrieve their procedural knowledge. Merging is a highly dynamic and situation-dependent task, while drivers were provided with a static description and provided written responses. Thus, drivers may have instead inferred their response from a rationalised reconstruction of the procedure than their actual behaviour. These findings can also be explained with the theory on schema activation: Schema theory describes that well-learned routines and actions are automatically triggered based on the particular (driving) situation, which can vary vastly while merging (Norman and Shallice 1986). The large individual differences are in line with Kassner et al. (2010), who found that reported sequences in merging varied considerably across car drivers.

Mirrors of HGVs vary with respect to size, convexity, and field of view. According to the HGV drivers, Class II mirrors (large mirrors at both sides of the truck cabin) on the left side hold the highest relevance among mirrors; they are used to observe traffic and search for an appropriate gap. Class IV mirrors (small mirrors at both sides of the truck cabin) are reported to be used only to assess overall traffic conditions at the start of the merging. In general, the mirrors were highly appreciated, although the source of visual information (which mirror is looked at) was not the primary concern of the drivers; the behaviour of other road users posed a larger concern.

4.3 Interactions with other road users while merging

Identified challenges in merging were related to the behaviour of other road users in dense traffic. Cars appeared to be a key source of critical driving situations, whereas other HGVs were seen as cooperative. The difference between interacting car drivers and HGV drivers can be explained in multiple ways. A car can be hidden within the blind spots around an HGV, whereas an HGV cannot (Robinson et al. 2016). Additionally, the acceleration capability of cars enables quick position changes that can be missed by HGV drivers while observing traffic. A lack of experience in driving an HGV may make it difficult for car drivers to envision the problems encountered by HGV drivers, whereas a mutual problem awareness among HGV drivers can explain their courtesy behaviour (Shanteau 1992).

Norms of communication on the road help HGV drivers safely complete the merging procedure. The headlight flash appears to be a widely accepted signal to indicate courtesy yielding within the HGV community. Interestingly, HGV drivers reported to expect courtesy behaviour from others and to rely on communication and courtesy while merging. This finding ties into a simulation study of Hidas (2002), which found improved traffic flow if the simulation included reactive traffic. HGV drivers underscored that they help each other as HGV drivers, pointing to cooperative in-group behaviour (cf. Brewer 1979; Tajfel et al. 1979).

Critical situations were reported when other traffic is not communicating or violating the established norms of communication. The reasons why such communication norms are violated can only be speculated about. A driver-related factor might be inattention (Klauer et al. 2006) or insisting on the traffic rules (no courtesy yielding). Situational factors that inhibit courtesy behaviour are related to infrastructural design, traffic density, and temporary changes to the road layout. To summarise, other road users complicate the merging procedure, whereas courtesy and active communication ease merging.

4.4 ADAS are widely used but can be improved

Overall, drivers reported a high use and positive attitude towards current ADAS. Longitudinal support ADAS showed more frequent use than lateral support ADAS. Most criticised were AEB and LDW: AEB because of its abrupt and vigorous intervention paired with false positives, and LDW due to its inappropriateness in various driving situations (e.g. construction work). In contrast, an early simulator study by Kozak et al. (2006) found that LDW was well accepted among drivers. Combined alerts (haptic and audio) also showed high acceptance in FCW systems (Lee, Hoffman and Hayes 2004). These conflicting results may be explained by the difference between simulator studies and on-road driving. In the latter, a large variety of situations may cause false alarms, hampering system acceptance. AEB might have greater perceived utility for the drivers compared to LDW, thus exhibiting higher tolerance for false alarms/interventions. However, the drivers rated AEB negatively in urban environments, as the perceived utility might be lower compared to non-urban environments as rear-end crashes on freeways are frequently reported in the news and accident statistics.

The attitude towards ADAS appeared to be shaped by experience, which is in line with the trust literature (Ghazizadeh et al. 2012). The HGV drivers agreed that ADAS are helpful, although concerns were raised about their reliability and the number of systems (affecting workload). LDW was regarded as a backup system in case driver state was not appropriate, which hints at a dangerous misuse of the system. LCA and CMS were valued positively in line with Liao et al. (2017), who found that HGV drivers requested support for merging from service areas. The critiques of the LDW can be interpreted as dissonances caused by a mismatch between the LDW system's knowledge (i.e., what the LDW system detects) and the driver's knowledge (i.e., what the human driver perceives), see Vanderhaegen (2016). Disssonances, in turn, may be associated with automation surprises, annoyance, and disuse.

Visual ADAS display locations close to the driver's eyepoint were favoured. Space that is in accordance with ISO-standards and that does not conflict with current in-vehicle systems (e.g., toll boxes) is sparse within the HGV's cabin. The top of the mid-console, the dials, and the A-pillar were identified as possible new ADAS locations. Essential to the drivers was that windows are kept clean, a finding which concurs with Ostermann et al. (2016), who stressed problems with the limited direct sight available to HGV drivers.

4.5 Recommendations for future merging support and automation

One goal of this study was to identify HGV drivers' needs for support and automation in freeway merging. As described above, HGV drivers appreciate their current ADAS, even though these systems sometimes fail to provide adequate support. For example, AEB sometimes disrupts merging by abrupt interventions, whereas lane change assists (e.g., blind spot warning systems) may prevent accidents but not resolve the core problem in merging, which is timely identification of the behaviour of other road users. Hence, blind-spot warning systems help to avoid a lateral crash but do not ease the manoeuvre for the driver as a whole. From the interviews, needs were identified in two main domains: (1) perception of surrounding traffic and (2) communication and coordination to achieve and detect "courtesy behaviour".

Regarding perception, future ADAS could enhance the visibility of other road users' behaviours and intentions. The HGV drivers indicated that CMS, which remove the blind spot behind the trailer, are highly appreciated. In the future, mirrors will be replaced by CMS within the cabin, resolving blind spots to the front and rear (Zaindl 2016). Blomdahl (2016) raised concerns about impaired communication of drivers to other road users through CMS compared to current mirrors, because of the fixed field of view. Dreger et al. (2020) found that drivers can be cognitively overloaded with visual ADAS, reducing the potential benefits of driver aids. Actual support for identifying road users' intentions is not foreseen using either classical mirrors or CMS. Solutions may be found augmenting visual information in CMS.

The merging procedure is currently solved through cooperative acts, such as courtesy yielding. Zimmermann et al. (2014) successfully implemented a cooperative lane change concept, where drivers communicated their intentions to change lanes in a driving simulator. Although these authors demonstrated that a cooperative approach was feasible and improved safety by raising clearance between vehicles, the time for communication with a 100% successful lane change took 30 s, which may exceed the time available for situation-based decision making in real-world driving.

External human–machine interfaces (eHMI) are already proposed for automated vehicles (Habibovic et al. 2018), and may help in both manual driving and automated driving to communicate intentions. eHMIs may raise the transparency of drivers' intentions, for example, by displaying whether a road user is showing courtesy to an HGV driver. Additionally, in-vehicle information systems (IVIS) could provide situation-based information such as traffic density (on the on-ramp) and speed/gap advice (on the acceleration lane). In cases where other traffic is not motivated to show courtesy behaviour, future ADAS need to provide action alternatives, such as speed advice and visual cues to find a new gap. Guidance for the driver, haptic or visual, can be achieved by the use of predictive controllers such as in Wang et al. (2015). Information based on environment perception and vehicle state could be shared between vehicles via V2V and V2X communication to coordinate merging.

In conclusion, this study provided insights into how to support HGV drivers while merging. The results showed substantial individual differences in reported merging behaviour. Furthermore, it became clear that cooperative behaviour between truck drivers is an important aspect of successful merging, whereas conflicts with car drivers are common. The truck drivers regarded their ADAS as useful, but also reported to misuse them and remarked on the abundance of devices in their trucks. Support systems presenting situation-based information may help bridge the period from manual to automated driving in mixed traffic.

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Supplementary material

Supplementary material is available for download here: https://doi.org/10.4121/uuid:2e192bdb-1309-48e4-be5c-84965638b2e2.

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