Design of a Human-Machine Interface for Truck Platooning

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Abstract
Despite the advantages that truck platooning has for fuel consumption, road safety, and use of existing road infrastructure, it does not simplify the job for the drivers. Truck drivers have to maintain a reasonable level of situation awareness while having a very limited vision of the road and dealing with considerable amount of information. This paper presents the first iteration of the development process of a platooning human-machine interface (HMI). The results indicate what information is required to be presented to the drivers at each phase of platooning.

Author Keywords
HMI development; platooning; user-centered design

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces

Introduction
A heavy-duty vehicle platoon consists of a number of trucks which are interconnected through vehicle-to-vehicle (V2V) communication and drive at a very close distance (Figure 1). The longitudinal control (i.e. speed and inter-vehcile distance) of trucks in a platoon is automated. The short inter-vehicle distance and automated longitudinal control

Figure 1: Platoon of trucks on the road. Image source: Scania

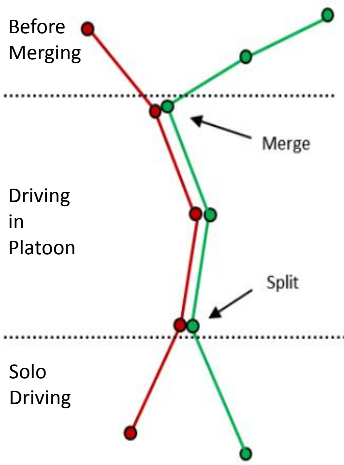

Figure 2: Four phases of platooning scenario: before merging, merging, driving in a platoon, and splitting.

have significant benefits for fuel consumption, road safety, and the use of the existing road infrastructure [2].

COMPANION[1] is a three-year European research project aiming at investigating the platooning concept in daily transport operations [2]. This paper describes the development process of the on-board platooning human-machine interface (HMI), which aims to support drivers in different platooning maneuvers (e.g. speed increase, lane change).
In COMPANION, platooning consists of four phases: before merging, merging, driving in the platoon, and splitting (Figure 2). Each of these phases consist of several maneuvers. As the longitudinal control is automated, drivers are only responsible for the lateral control of the truck. However, drivers are required to take over longitudinal control of the vehicle as well in cases of hazard (e.g. system fail).
Aside from the information regarding the control of the vehicle, drivers have to keep track of a considerable amount of information related to their transport assignments. Each transport assignment has an assignment plan which includes information such as truck ID, the route to follow, time and location for departure, arrival, stops for rest, and opportunities for platooning with other trucks. Other information items such as predefined speed and inter-vehicle distance to reach optimal platooning effect in terms of fuel consumption, are also presented to the drivers. Apart from these, while performing platooning maneuvers, drivers also receive information about the other trucks involved.
It is clear that a driver in a platoon has to deal with a far larger amount of information than in normal driving condition. It is therefore important that the driver maintains a sufficient level of Situation Awareness (SA) [3]. In platooning, the limited road visibility due to short inter-vehicle distance, and a high amount of in-vehicle information can cause an impaired understanding of situations and possible erroneous reactions. Moreover, the dynamic context of driving and time sensitivity of platooning maneuvers such as merging to and splitting from the platoon, make it challenging to select the required information and decide accordingly. Therefore, it is important to know what information should be presented to the drivers at each platooning phase to increase their situation awareness.
In the last few years, several projects investigated HMI solutions for platooning [6, 5] each of which applied different interaction concepts to support drivers in performing platooning maneuvers. However, existing work on HMIs for platooning investigate mainly concept art and design studies [7, 1]. Due to the criticality of driving in a platoon, and managing considerable amount of information, there is a need for real-world tests and evaluations with end-users to ascertain the usability and acceptance of an HMI. This work extends the state-of-the art by integrating drivers in the HMI development process for a platooning scenario in concept development, prototyping, and real-world evaluation. Following we will present the results of the first iteration of platooning HMI development process, which consists of user requirement analysis, and design and evaluation of paper prototypes. The results indicate what information is required to be presented to the truck drivers at each platooning phase. These results will be used for developing the software prototype of platooning HMI to be tested in real trucks on a test track.

Method

Our main objective in designing the platooning HMI was to support drivers in performing platooning maneuvers and increase their situation awareness. Presently, driving in close distances as defined in platooning (0.5 s, 1 s, 1.5 s and 2 s, where 0.5 s equal approx. 11 m at a speed of 80 km/h) is not yet legislated [4]. Therefore, it is not easy to estimate

[1] http://www.companion-project.eu/

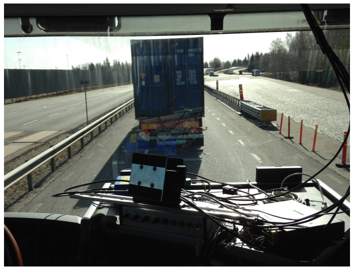

Figure 3: Platooning scene on a test track. Distance to the front truck is about 10 m

Figure 4: Examples of information item sketches for top: target speed and upcoming change, bottom: merging and splitting maneuvers. Preferred sketches highlighted in red.

what information is required to assist drivers. Hence, we followed a user-centered design (UCD) approach, in which we included experienced truck drivers in the development process from requirements analysis to prototype evaluation.

User Requirement Analysis

We extracted user requirements in three steps: 1) interview with drivers and observation on their daily transport assignments, 2) observation of drivers on a platooning test drive, and 3) distribution of questionnaires among truck drivers. Following, we discuss the steps in detail.

Interview with Target Users

In the first step, we aimed to investigate the state of the art technologies used in the cockpit and required information while driving. We interviewed two experienced male truck drivers in an unstructured fashion and observed them while they were driving on a duty transport trip for three and half hours. We asked about their daily assignments and routine, and assistant systems used in the truck.

We found out that drivers receive their assignment plan one day in advance. The plan includes only the time and location for departure and arrival. Drivers are free to choose their route plan, speed, and resting time (as long as they follow the laws). They widely use cruise control but not adaptive cruise control. Drivers mentioned that they rarely cooperate with each other on the road and in cases that they do, to coordinate driving plans with each other (e.g. taking a specific highway exit, resting places); they use more mobile phones rather than the truck radio. "This is due to the wide variety of drivers' nationalities (languages) crossing Germany" one driver pointed out. We asked drivers about the optimal location of a platooning HMI in the cockpit. Results declares that drivers prefer having a display either integrated in the instrument cluster or where they do not have to turn their head to look at (not further than 45 degrees of the field of vision of the driver).

Test Drive Observations

After collecting initial requirements from truck drivers in normal driving conditions, we ran an observation study while driving in a platoon of two trucks on a test track. Figure 3 (taken during this observation) shows that due to the short inter-vehicle distance, drivers have a far less clear vision of the road in comparison with the normal driving condition. No information regarding assignment plan or platoon state was displayed. The only existing HMI regarding platooning was a green button on the steering wheel which turned on V2V communication when pressed. Drivers used truck radio to communicate the time to merge, the chosen path, acceleration and deceleration, lane change, and braking maneuvers. Pursuant to this, all of this information which was communicated via radio conversations needs to be presented to drivers in a platooning HMI.

Questionnaires

In the third step we distributed questionnaires among 12 male truck drivers between 27 and 59 years old ($M = 47.33$, $SD = 8.67$) with an average of 20 years of truck driving experience ($SD = 9.31$). The questionnaire consisted of two parts: the first part included questions asking drivers about the driving assistant systems (DAS) they use currently and their influence on their jobs. The second part, started with an introduction to platooning concept and asked drivers about their impression about it and problems and solutions they could foresee in a platooning scenario.

Questionnaire Results

Results show that cruise control (85%), onboard computer (67%), and adaptive cruise control (66%) are the mostly used DASs. Most of our participants are used to have DASs in their working environment. 75% of the participants said

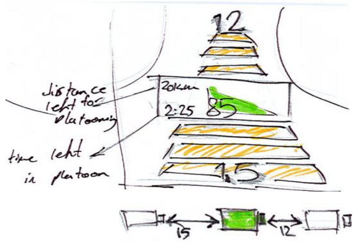

Figure 5: Paper prototype 1, driving in platoon view. Distance to the front and rear trucks: 12 and 15 meters respectively. Current target speed: 85 km/h with upcoming decrease. Position: 2 in a platoon of 3. Distance left in platoon: 20km. Time left in platoon: 2 hours and 25 minutes

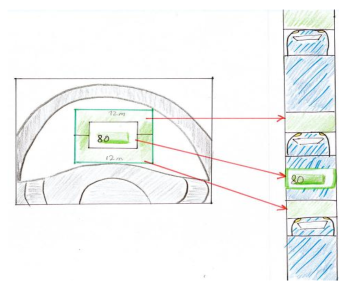

Figure 6: Paper prototype 2, driving in platoon view. Distance to the front and rear trucks: both 12 meters. Current target speed: 80 km/h with no upcoming changes. Position: 2 in a platoon of 3. The middle (white) area represents ego truck's position in relation to front and rear trucks. It can move up and down to indicate distance changes. The color(green) indicates sensor status and encodes required drivers' action.

that DASs have made their job easier, while at the same time 40% of them believe that there are circumstances that assistant systems can make their job more difficult due to information overload or a high learning curve. 70% have mentioned that the existence of assistant system has had a positive influence on their job.
The main problems that our participants could foresee in platooning are lack of trust in the behavior of the driver in the front vehicle, reliance on technology, and lack of knowledge about the driving environment due to the limited field of view. They declared that having an assistant system which continuously presents information such as speed, distance to the next vehicle, the decisions and actions of the system, and a graphical representation of all vehicles could be helpful.

Development of Interaction Concepts

As mentioned before the platooning process consists of four phases. In each of these phases, specific information is required to help drivers perform properly (e.g. while merging, drivers need to know the final inter-vehicle distance). Therefore, we assigned information items (e.g. target speed, gap size, merging location) extracted from the requirement analysis to each platooning phase. We ran brainstorming sessions in which we discussed different designs for presenting each information item. These designs were evaluated with HMI experts and the most preferred ones were transferred into paper prototypes (Figure 4). Based on our interview results, we decided to locate the platooning HMI in the instrument cluster, which can also be beneficial in terms of display size, expected location, and assumed minimun glance times. We developed several paper prototypes consisting of different views for each platooning phase: before merging (inform about upcoming platooning, navigate and drive to merging area, identify target vehicle), merging (position behind target truck, approach target truck, wait for free gap, close gap), and driving in platoon. Each information item in the prototypes was chosen from the most preferred designs. Figure 5 and Figure 6 show two different prototypes for the driving in platoon view. In each of these prototypes, distance to the front and rear truck, target speed and future speed changes, and overall platoon view are displayed.

Evaluation and Results

For the evaluation of the paper prototypes we conducted an interview session with three experienced male truck drivers. The interviews were recorded on camera and took about one hour per participant. As an introduction we presented the overall concept of platooning in a video, the phases and discussed general questions. The evaluation method is a semi-structured interview where we discussed the paper prototypes based on their use in the specific platooning phases in this order: before merging, merging, and driving in platoon.

General

In general, the drivers stated that information about the front vehicle is needed, distances should be represented in km and not in hours or minutes, resting times should be shown, the system should be reactive in a way that it provides the maneuvers of each phase and adapts to the outside state (e.g. distances). Drivers prefer not to interact with the system too much while driving. Further, a video stream of the road scene ahead could be useful but would also very likely distract from driving. Sensors should be used to provide missing information from the environment, and only important information or statuses should be emphasized with audio signals. The participants rated the presented phases as manageable and not too complicated. However, they all expect a learning curve which might require addi-

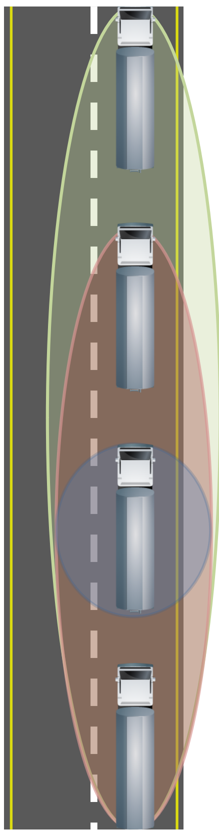

Figure 7: Information horizons in a platoon:. Blue: close horizon, Red: medium horizon, Green: far horizon

tional training on a test track or in theory, which is supposed to increase trust in the system.

Before merging

For the time before the actual merging takes place, drivers are led to the merging area. For this, drivers require information if the merging area can be reached in time, if there are any road incidents (e.g. traffic jam), the distance to the platoon (i.e. the target vehicle) in km, and the speed required to reach the platoon. It should be considered that drivers nowadays only have sparse knowledge of the road network. Thus, city names and points of interest (e.g. an IKEA warehouse) shouldn't be used as waypoints, rather kilometer markers along the road, service areas, and highway exits should be used. It was also stated that a sat nav style announcement system could be useful to warn of upcoming events or road incidents.

Merging

While merging, two trucks decrease the distance to each other to reach a defined target distance (e.g. 10 m). For the merging truck (which is in our case always the backmost truck), the participants stated that the system should present the steps of the merging phase in an overview (e.g. waiting for free gap, decrease of distance).Presentation should be in an informative fashion and drivers should always have the power to interrupt the process. They would like to know the distance to the front vehicle, that it is also aware of the merging, that the system has recognized the own presence and plan, and also the next step of the procedure in advance. Further, information is needed if there is a vehicle intruding (i.e. a vehicle cutting in between the target truck and oneself), that the vehicles in the platoon are all connected to each other via a communication link (important for a common braking) and how much time is left to drive, speed, distance to the merging area, and time until merging. It was pointed out as helpful to have information when the driver is in the proximity of the target vehicle and have a message which indicates that merging is now possible

Platooning

While platooning all trucks maintain a steady velocity and distance. In relation to this, it was stated that distances to the front and back vehicle are of interest but not crucial. However, changes of the velocity of the platoon should be shown because it can help to understand reason for perceived velocity changes. The next step should be shown (e.g. splitting), connection status of the vehicles and system awareness of the own presence in the platoon. Weather and traffic data should only be shown if they have a considerable effect on the platooning plan. Against our assumption the participants stated that a platooning overview, where all trucks are shown at one with distances, speeds, etc., is not needed and would only add unnecessary information. In relation to this, it is preferred to only show information related to the own vehicle and only little information regarding other vehicles. Changes in sensor readings should be made visible by light color of display elements (e.g. from green to red). Moreover, acoustic signals should be used for important information. General information about the status of the system should deliver a "everything is okay" message to the driver. It was also mentioned that it would be useful to know that in the case of an emergency braking the own truck is able to perform this maneuver safely.

Lesson Learned

The participants repeatedly stated that information related to their own vehicle is more useful than information related to the overall platoon. From this result we learned that required information in all platooning scenarios can be divided into three horizons. The **close horizon** contains information regarding the own vehicle: sensor status, upcoming speed changes, position in platoon, future maneuvers, and breaks for resting. The **medium horizon** provides information related to the front and rear truck, distance to them and their speed. In the **far horizon,** information about all trucks in the platoon, common plan, and future maneuvers are considered (Figure 7). We conclude that truck drivers rate close and medium horizon information as most important in platooning. This can be explained with the need of personal safety of the drivers. For them, the most important aspect in platooning is that they are safe, which means that braking is always possible, sensors are working properly, and the system is running and aware of oneself. The participants also mentioned that they do not often think far ahead while driving, which supports this view. Therefore, information about future maneuvers in an assignment plan and all platoon trucks were declared as not relevant at all times.

Future Work

The main objective of our work is to develop an HMI which is usable and increases drivers' situation awareness in all platooning phases. The presented results indicate what information is needed at each phase and in which fashion it should be presented. The next step is to transfer the results into a working software prototype. This prototype will be used for user testing in real trucks on a closed test track. It will be evaluated while merging, platooning, emergency braking and splitting. The evaluation goals are to investigate learnability, usability, and situation awareness. For learnability, we plan to conduct a training session with the test drivers and observe their performance during the drives. Usability will be tested using the think-aloud technique in combination with video and audio recording of both the truck cabin and the HMI simultaneously. Drivers will be asked about aspects of the HMI while driving. Furthermore, after the drivers performed all platooning phases and maneuvers, they will be asked to rate the overall usability of the HMI in questionnaires. After each platooning phase, questionnaires will be distributed to assess the situation awareness of the drivers. A final session will conclude the tests where each driver will be interviewed individually for qualitative feedback on the HMI. Further, the software will be integrated in a driving simulator to investigate further aspects of usability and situation awareness which are impossible or hard to do in the real trucks.

The results collected from the test track evaluation and simulator studies will be used to as input for the further development of the final COMPANION onboard HMI.

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