Integrating Prediction and Optimization Display Elements Effecting the Human Driving Behavior

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Abstract: This contribution is focused on the development of the interface between the human driver and hybrid vehicle. By analyzing the state of art regarding the functional design of the displays from existing hybrid vehicles, it can be observed that only the actual state and history of relevant variables like fuel consumption, state of charge, and distance to empty are displayed. This information is important for the human driver to analyze the realized previous behavior, but what exactly the driver should or could do in next minutes to improve the driving behavior during driving is usually not displayed. In order to improve upcoming behavior and related consequences and therefore to solve the task for further efficiency improvement, a new interface has been developed to help the human driver to drive more efficiently. By applying the new interface, the human driver can perceive the actual driving situation and predicted corresponding consequences. In comparison, the suggested optimal driving behavior and its consequences will be displayed as well. With the help of the new interface, the human driver can decide which behavior should be taken to improve the actual driving behavior.

1. INTRODUCTION

With the increasing of automotive technology, the focus of vehicle developing has been changed from former basic transportation need to the enhancement of safety and efficiency of vehicles. More hybrid vehicles are brought into production and operation to reduce the usage of gasoline and the emission. Manufacturers have developed many kinds of Advanced Driver Assistance Systems (ADAS). The idea is to improve the driver's behavior to avoid an accident as much as possible or to reduce the losses of lives and properties. However, those ADASs cannot help the driver to perceive the driving environment completely. An incomplete perception of a hazardous situation can cause the driver to take wrong decisions leading to dangerous consequences. For more efficiently driving, the human driver needs more information about the hybrid driving situation, so guidance is necessary to improve the current situation.

Within a previous publication Söffker et al. [2013], an action space is calculated to realize an online supervision of the human with respect to upcoming behaviors. The key idea within this publication is to calculate the next possible actions, to evaluate them and therefore to detect the intended next steps in both hazard-oriented information (HOI) and optimal behavior-oriented information (OBOI).

The main idea of this contribution is focused on the detection of the intended next steps. If the detected intention includes hazards or non-optimal behavior, suitable suggestions can be done. The suggestion may be displayed in a suitable manner using an interactive interface between the human driver and the vehicle to effect the human driving behavior. In Fishbein [2010], it is stated that humans intend to act different from the actual behavior. One can not be sure that the actual behavior is exactly the same as the intended one. The goal of this contribution is to detect the intended behavior and to find out whether the intended behavior is suitable, optimal, or not. The actual human behavior can be improved with the help of assistance systems, which is the main intention of this research work. The detection of the intended next steps can be described as the prediction about the next driving actions and related consequences. Furthermore, also the options with respect to optimal behavior and resulting consequences should be provided to the human driver, so that the driver can make the right decision.

One of the purposes of developing ADAS is to improve the driver's situation perception and therefore to improve her/his situation awareness (SA) Endsley [1995]. Based on a suitable SA the decision quality should be improved. A complete and correct perception of the current situation is also necessary for the realization of safe interaction sequence. Besides, the cooperation between humans and assistance systems is an interesting topic. It can be highly critical for the system to take over the guidance from the driver Mulder [2012]. The dynamic balance between humans and machines is discussed in principle in Flemisch [2012] and described by the four cornerstone concepts: ability, authority, control, and responsibility. In Sivaraman [2013], the scope of cooperation systems is divided into four main areas, which are in-vehicle systems cooperation, vehicle-driver cooperation, cooperation across vehicles (Vehicle to Vehicle), and cooperation with vehicles and infrastructure (Vehicle to Infrastructure).

The information about the environment should be presented to the driver in a simple and understandable way, should not cause confusion no matter how complex the variables behind, so that the human driver can make perfect decisions in time and does not need to spend time to think about the meaning with respect to the interpretation of the symbols etc. The options provided to the driver should also be similar to this: easy to be understood, to be interpreted, and therefore to be chosen and followed. The novel concept of this contribution is to display the consequences of current driving behavior as well as the ones of the calculated optimal driving behavior. The optimal driving behavior is simplified and displayed in a way, that they can easily and quickly be executed. By comparing both effects, the human driver can recognize that there is another choice to behave better or more efficiently. For those drivers, who want to improve her/his driving behavior, she/he only needs to follow the guidance.

The interface used in this contribution is designed to be used in combination with a driving simulator, which is coupled with a Hardware-in-the-Loop (HiL) hybrid test rig, so that the driving situation of real hybrid power resources can be used. The key point of this paper is to establish a new paradigm, in which the complex driving information can be simplified and provided to the human driver to increase her/his SA.

In this contribution, a small concept study briefly repeating the state of the art is given. Therefore the displays of four different vehicles are introduced and compared with respect to their properties to provide information able to affect the humans behavior (and not only to inform). The idea of online driving assistance based on the Situation-Operator-Modeling (SOM) approach would be introduced focusing to two different aspects. The detailed online driving assistance will be implemented by using a professional driving simulator. First results will be discussed.

2. STATE OF THE ART

The information to be used for display and assistance is resulted from vehicle data as well as the measured environment. Using an interface they are fed back to the driver. In this way, a loop between the vehicle's behavior and the human driver is realized, so that the driver's behavior may/can be influenced by the system.

In order to help the driver to recognize the status of the vehicle, the Human Machine Interface (HMI) between the human driver and the vehicle is designed. Most of the vehicles provide the display with basic information like: current velocity, state of fuel, Revolutions Per Minute (RPM), and fuel economy etc. Usually this information is displayed on the instrument panel. With another option, the Head-Up Display (HUD) can present part of the information in a more appropriate way.

2.1 Human Machine Interface (HMI)

The interface between the human and a technical device (here: vehicle) is called Human-Machine-Interface (HMI). According to Varalda [1998], a HMI can be basically described by interactions, such as: information, warning, advice, and control. Varalda Varalda [1998] concluded that there are two types of output information from the vehicle: visual (verbal, numerical, and graphical) and auditory (verbal and tonal). The HMI related technologies, practices, and implementation in the current and upcoming industry trends are discussed in Vasantharaj [2014]. Actual HMI technology is based on multitouch and multimodal technologies. This includes touch recognition, proximity and gesture recognition, face/eye recognition, voice recognition, handwriting recognition, haptic feedback, etc. More specifically, HMI for electric vehicles (EV) is studied in Stromber [2011] to develop the information, which should be presented. In Cai [2012], soft aid, soft intervention, and hard intervention are realized by visual interface, auditory interface, and tactile interface, respectively to discuss how to coordinate multiple types of assistance. As discussed in the first part, the HMI in vehicle should be designed in this way, that the information is simply to be perceived and no confusion is caused. Further, it is stated in Li [2012] that the interface may confuse the recognition of the driver. It is a challenge to figure out how to help the driver to maintain a clear awareness between the virtual and the real scenes.

2.2 Instrument panel

Instrument panel (here refers to the control panel in a vehicle) is also called dashboard, dash, or fascia. Usually the basic states of the vehicle are shown on the instrument panel, such as speedometer, tachometer, odometer, and fuel gauge. Indicators are also displayed on the instrument panel, such as lighting indicators, indicators for oil pressure, engine coolant temperature, charging system etc. Beside this basic information, in order to help the driver to drive more safely and more efficiently, indicators are displayed as well. Particularly in hybrid vehicles, the information about the actual state of the usage of the different energy sources is necessary and usual. In the following, the instrument panels of several hybrid vehicles are introduced.

In Ford Fusion, the speedometer is placed in the middle of the instrument panel as shown in Figure 1. The "PWR" represents the power requirement. When only gasoline is being used, the traditional tachometer "RPM" is displayed as shown in Figure 2 (left). The tachometer will be changed into "EV" (Figure 2 middle) or "POWER" (Figure 2 right), when only the electric vehicle mode is operated or both of the gasoline and electric power are used. The state of charge (SOC) and the fuel gauge are displayed on both sides of the speedometer. The arrow in the indicator of SOC shows the battery charging or discharging processes. The columns on the right hand side indicated the history graph of average fuel economy. Each column stands for the fuel economy within 10-minute interval. It can also be set to 20-minute interval or 60-minute interval. Those columns are updated each minute. The history graph can be changed into short term driving efficiency as shown in Figure 3, which are measured over the last few minutes. The leaves and vines (right side of Figure 3) will occasionally appear and disappear to indicate the change of the driving efficiency. The more leaves and vines are displayed, the more efficiently the driver drives. Besides, Ford Fusion also displays the distance to empty. It indicates the estimated distance, which the vehicle can drive with the fuel remaining in the tank under normal driving conditions. The energy flow, which shows the directions of energy is moving through the vehicle's

Fig. 1. Instrument panel (Ford Fusion NN4 [2014])

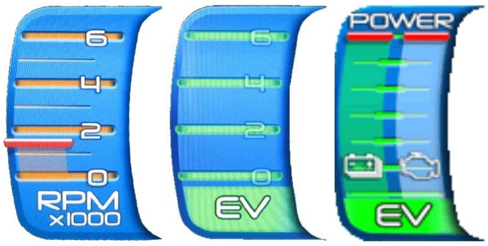

Fig. 2. Display of energy resource being used (Ford Fusion NN5 [2014])

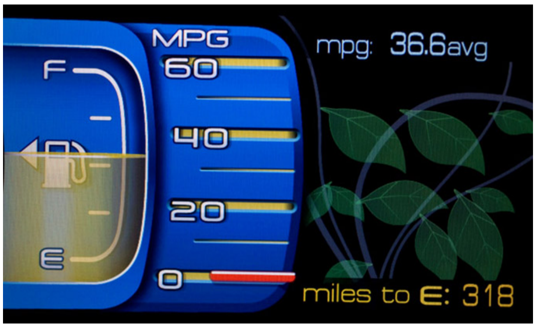

Fig. 3. Display of efficiency information (Ford Fusion NN6 [2014])

drivetrain, is displayed on the touch screen at right hand side of the instrument panel.

With the same topology, the interface of Ford Focus as shown in Figure 4 displays the speedometer in the middle of the instrument panel as well, but the tachometer is not displayed. Usually the speedometer and the tachometer are a pair displayed in the instrument panel. At right hand side of the speedometer is the display of efficiency information. It has the same function with the leaves and vines in Ford Fusion. The more butterflies are displayed, the more efficiently the driver drives. The SOC and the distance to empty for the battery are displayed together. At left hand side of the SOC displays "Brake Coach". It appears after the driver presses the brake pedal. It helps the driver to maximize the amount of energy returned into the regenerative braking system. Instead of "Brake Coach", one can choose to display the "Range View", "Energy Coach", and "Energy History". The "Range View" shows the driver the range/distance relative to the next charge point entered in the navigation system as well as the performance. The "Energy Coach", shown in Figure 5,

Fig. 4. Display of brake coach and efficiency information (Ford Focus NN7 [2014])

Fig. 5. Display of energy coach (Ford Focus NN7 [2014])

Fig. 6. Instrument panel (Toyota Prius NN8 [2014] NN9 [2014])

helps the driver to accelerate, brake, and cruise with best efficiency. The current behavior is displayed with a progress bar, which is compared with the suggested best one. From the difference between those two bars, the driver can get the knowledge if she/he behaves well. The "Energy History" displays the same information as the history graph in Ford Fusion.

The instrument panel of Toyota Prius shown in Figure 6 upper is much smaller than the ones of Ford. Here no traditional speedometer and tachometer are available. Instead, the speedometer is displayed in digital as shown in Figure 6 (lower). The display on the right half area can be switched among the energy flow, hybrid system indicator, and the history diagram for fuel consumption. Prius does not only show the history diagram for different time intervals, but also shows the comparison between trips as well as months. This area can also be switched into the driving ratio, which represents the fuel saved by charge. In this way, the driver knows how much benefit directly got from displacing fuel with electricity.

Fig. 7. Instrument panel (VW Jetta NN10 [2014])

Fig. 8. Display showing the energy flow (VW Jetta NN11 [2014])

The interface of VW Jetta as shown in Figure 7 displays the traditional speedometer, and instead of the tachometer, it displays the "Power Meter". The "Power Meter", which is marked from 0 to 10, shows how much power it is being used. In this way, the hybrid system indicator can be displayed. It begins with "OFF" and ends with "BOOST". The green "CHARGE" section is activated when the vehicle is braking or charging. The blue section indicates the best efficient driving behavior with using the power alternative between the electric and the gasoline engine power. From "6" to "10", it represents the vehicle is using only gasoline engine power. Both of the energy resources are being used when it indicates the "BOOST". The energy flow as shown in Figure 8 can be found in both middle of the instrument panel and the touch screen. The energy flow in Jetta is in 3D version. The moving of the energy flow can be displayed with animation effect. The energy history as shown in Figure 9 is also displayed in the touch screen. The Jetta provides the driver to review the electric power being used during the last thirty minutes of the current trip.

As a conclusion from the current state of the art of displayed information in hybrid electric vehicles it can be stated, that the current design of interface can provide the general information of the vehicle and the environment. Most of the vehicles also judge the driving behavior of the driver and provide suggestion, but in an abstract way, such as the Ford Focus. It tells the driver that the current behavior by using fuzzy logic: good, not good etc. The driver can notice the difference but she/he gets no detailed idea about how to improve the displayed result.

Fig. 9. Display showing the energy consumption (VW Jetta NN11 [2014])

2.3 *Head-Up Display (HUD)*

With the help of Head-Up Display, which is a transparent display on the windshield, the human driver does not need to move the sight away from the street to get the information about the vehicle and environment. This information is displayed in the sight of the driver. Some vehicle manufacturers have already applied HUD to the vehicle, such as BMW, Ford, Audi, Toyota, Buick etc. But the problem is that some drivers can not stand anything blocking their view, otherwise it would be distracted for them. By improving the options for brightness level and location, the HUD is more and more popular and accepted.

Till now by most HUDs, part of basic simple information is chosen to be displayed, such as speedometer, tachometer, and the speed limit of the street etc. as shown in Figure 10. It is more convenient to use HUD than the instrument panel to display the navigation information as shown in Figure 11. The instruction, for example, turning at an intersection, is presented when the action is necessary to be carried out. The human driver just needs to keep eye directly on the street and intuitively follows the instruction.

The driver assistance system can also be applied by HUD such as pedestrian detection and related visualization as shown in Figure 12. But most of the advanced driver assistance systems are not commonly applied or mass produced using HUDs. In the meanwhile the concept has already been tested inside simulators (as shown in Figure 13 from BMW NN2 [2014]). The adaptive cruise control (ACC) is combined with forward collision warning (FCW). Here the warning displayed on HUD can be superimposed perfectly to the frontal vehicle, the suggested next motion is also provided to the human driver. People pass different judgements on the HUDs. The HUDs appear for some test persons as very helpful because appropriate information can be projected into the field of view, but others judge them as gimmick and useless because they can not stand anything in front of their eyes. Instead, they find the HUDs can distract them. The reason for that is that the instructions are still individual and can not be merged into the real surrounding. Assuming with increasing technology development, the instructions or warnings could be so well designed that one can not tell the difference. Maybe then the HUDs would be more acceptable.

Fig. 10. HUD (BMW NN1 [2014])

Fig. 11. HUD (BMW NN2 [2014])

Fig. 12. HUD (BMW NN3 [2014])

Fig. 13. HUD (BMW NN2 [2014])

3. IDEA OF ONLINE DRIVING ASSISTANCE

Firstly introduced in Söffker et al. [2013] will be discussed within this contribution more in detail. They are based on the structure and concept of the Situation-Operator-Modeling (SOM). As illustrated in Söffker [2001] within this modelling approach the interaction is focussed. Therefore related parts of the real world are understood as a sequence of scenes changed by actions. The scenes and actions can be modeled with the modeling items situation S as well as the operator O. The approach of SOM brings out a uniform and homogeneous modeling approach, which makes the description of human learning, planning, acting, and the formal description of human errors possible.

According to Söffker et al. [2013], the HOI can be calculated with the help of a suitably designed cognitive driver assistance system including the interaction logic of the driver-vehicle system and the calculated technically realizable situation awareness of the intelligent vehicle. Actions from the environment and the driver are analyzed. Based on this, the upcoming action spaces can be calculated for the near future (next interaction steps). If hazards occur, a warning is displayed or the system will take over the task for emergency case. The unintentional lane change is one type of hazards. When the system detects the vehicle drifting close to the lane markings, it will alert the driver. For even worse case such as forward collision, the system will initiate autonomous partial braking or full braking power to avoid the hazard. By using the SOM approach, the interaction behaves as a sequence of actions, but the action will not be chosen randomly based on the internal interaction logic between the driver and the vehicle. Assuming a goal- or task-oriented interaction from the human driver (the driver will act logically realizing goals), the related next actions can be defined on a formal base. This may lead to the fact that the several actions are possible, they may also include driver specific statistics; but definitively allows also the situated definition of not suitable actions. This allows the realization of the HOI.

By integrating the measured information of the human's driving action in combination with an online optimization approach, related information about the situated optimality of the human driver's behavior can be defined and visualized, so here it is suggested to allow the human driver always to judge her/his own behavior with respect to the calculated optimal behavior. The prediction approach of Söffker et al. [2013] is based on the analysis of the past measurements of the velocity and related fuel consumption. The calculated as well as the real behavior and the corresponding consequences can be displayed on the interface. Here a loop as shown in Figure 14 between human, environment, and technical system is closed by the interface. The system state, safety status and etc. are visualized to affect the human acting and decision behavior with the help of the internal prediction algorithms.

The interface in this contribution is designed for the driving simulator $SCANeR^{TM}$ studio, which is a driving simulator software package, to be used for vehicle ergonomics and advanced engineering studies as well as for road traffic research and development. The interface can be edited by using the programming language of the software. For the realization of the test runs, the driving simulator is connected to another test rig realizing the electrical hybrid drive, built at the Chair of Dynamics and Control. In this way, the new interface, which includes both HOI and OBOI, can consider the actual situation of the power management of both energy resources: gasoline and electrical power (OBOI), as well as the driving situation with respect to other vehicles (HOI). In this contribution the hazard here describes the situation of forward collision.

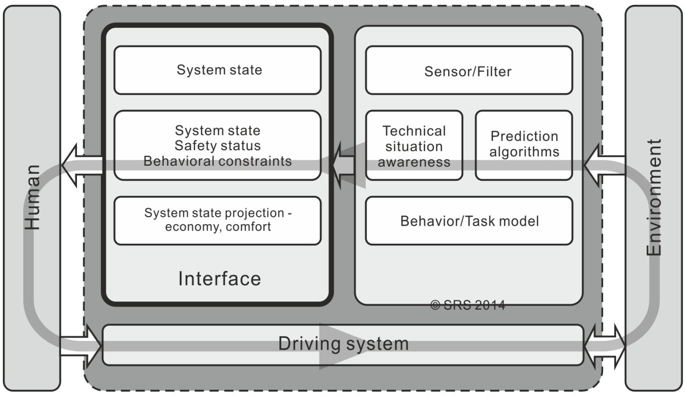

Fig. 14. Concept of Human-Vehicle loop Söffker et al. [2013]

The realization of the HOI is based on the vehicle status in relation to the (simulated) environmental status and is used to describe the situation with respect to forward collisions. Usually the hazard situations are dangerous or can lead to extreme situations with dead persons. The HOI, which displays the risk implicitly to warn the driver before the hazard situation really occurs. The realization of OBOI is based on the comparison between the actual situation, the predicted one, and the optimal one. Based on the analysis of the driving behavior for past time period, the driving pattern of the human driver can be determined. Furthermore, the minimum and maximum distances, which the vehicle can run, will also be displayed, so that the human driver can catch the driving situation and the related potential for the future. The current behavior may not be the appropriate one to reduce the consumption. By applying suitable calculations for the optimal driving behavior, the OBOI will be displayed. The detailed parameters are the suggested driving velocity and the corresponding minimum and maximum reachabilities. The realizable distances to be achieved using the current driving and the ones becoming possible applying the suggested optimal are displayed based on the same scale. With this comparison the human driver can judge his/her driving behavior and drive more efficiently. From a systematic point of view this extension will help to integrate the human driver closer into the control loop realizing efficient car driving.

The chosen parameters are displayed on the visual screen of the driving simulator with corresponding form and art as shown in Figure 15. The human driver perceives the information and may/will change the current behavior to the suggested more ecological one. If she/he does change her/his current driving behavior into the suggested way, the effect of the behavior can be directly observed. Therefore a loop between human, environment, and technical system is realized including the visualizing interface. The battery shows the SOC. The two vertices on the base represent the minimum and the maximum reachabilities, respectively. They are denoted by the concrete numbers, which describe the exact distance the vehicle can drive under current situation. The "V_op" indicates the optimal velocity. The number behind it displays the suggested optimal velocity under the assumption that the driving pattern does not change. The two sides of the blue bar indicate the minimum and the maximum reachabilities

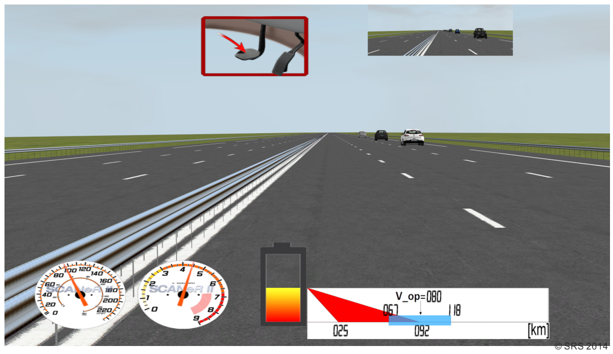

Fig. 15. Designed interface providing suggestions to the driver

under the suggested velocity. In this way, the driver can get the information about the benefit when she/he changes the current driving behavior.

4. REALIZATION OF THE ONLINE DRIVING ASSISTANCE

4.1 Implementation of online driving assistance

In order to test the effects of the designed interface to the human driver, first initial experiments were done to detect initial bugs and even drawbacks, which could not be detected during the design. The purpose of these first experiments is not only to understand the advantage of displaying HOI/OBOI, but also to test the design of the interface. The test drivers were first asked to take a 5 min test drive in order to become familiar with the driving environment. Afterward, the driving scenarios were taken to be tested.

The task for the test drive is a simulated high way scenario. Four scenarios are tested for the mentioned two types of information, which means each test driver should drive four times. These scenarios are listed in the following:

- Without HOI: there is only one vehicle on the highway beside the ego vehicle. When the distance between the vehicles is too small that they have to brake to avoid the forward collision: they should press the brake pedal. This process is repeated for 10 times and lasts for ca. 5 minutes, which is dependent on the behavior of the driver. During driving, the time to collision (TTC) when braking is measured. The term TTC is defined by Hayward [1972] as: "The time required for two vehicles to collide if they continue at their present speed and on the same path". It is used to rate the severity of conflicts.
- With HOI: the process is the same as the former one, but here the warning is displayed when the system detects the possibility to collision. The TTC when braking is also measured.
- Without OBOI: the test drivers are asked to drive for five minutes. The velocity is measured for the whole process.
- With OBOI: the test drivers are asked to drive also for five minutes. The meaning and function of OBOI are explained. They can drive as they want. They are allowed to follow the OBOI advise or to ignore the

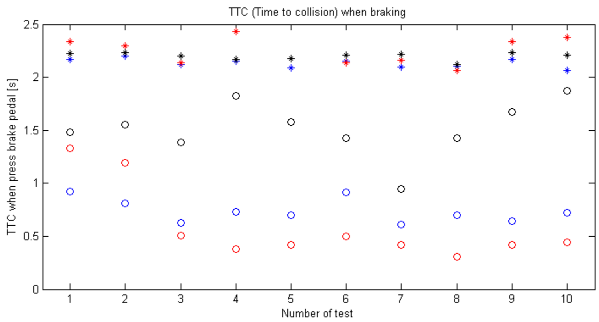

Fig. 16. Comparison of TTC with and without HOI for three test drivers

advise. The velocity is also measured for the whole process.

The first scene without any display tests the driving pattern of the test driver. It can be aggressive with smaller TTC or careful with larger TTC. Based on this, the scene with HOI is tested to be compared with the former one, in order to obtain the difference between two scenes.

The third scene without any display records the driving velocity of the driver for regular conditions without any influences. The driving pattern may/can be affected by displaying OBOI. In order to detect the effect of displaying OBOI, the driving velocity with the display of OBOI is compared with the former one as well as the suggested velocity.

4.2 First Results

The results for the tests of the HOI are shown in Figure 16. It represents the TTC between the ego-vehicle and the frontal one for each test drive. The circle stands for the TTC without displaying HOI. The star stands for the TTC with displaying the HOI. The driver-related results are described by different colors. The resulting average TTC without HOI of three drivers for ten test drives is 0.9494 sec. By contrast, the resulted average TTC with the HOI is 2.1920 sec. According to Hayward [1972], the lower the TTC, the higher the risk of a collision. The average TTC with HOI is doubled than the TTC without HOI. Displaying HOI helps the driver recognizing the potential danger earlier so that they have time to handle and prevent it.

The results for the test of the OBOI are shown in Figure 17, Figure 18, and Figure 19 for three test drivers, respectively. The optimization algorithm is not applied in the test drive. Instead, a sine wave is displayed as the suggested optimal velocity. The corresponding actual reachabilities (minimum and maximum) are calculated related to the SOC and the current velocity. The optimal reachabilities (minimum and maximum) depend on the difference between the actual velocity and the suggested optimized one. The smaller the difference is, the larger the optimal reachabilities are. In this way a pseudo optimal algorithm is designed. If the drivers drive as they want and ignore the OBOI, the optimal reachabilities would be very small. When they try to follow the suggested velocity, the optimal reachabilities would be larger. It means that with the current state of fuel and charge the vehicle can run further when the driver follows the suggested velocity. Once the

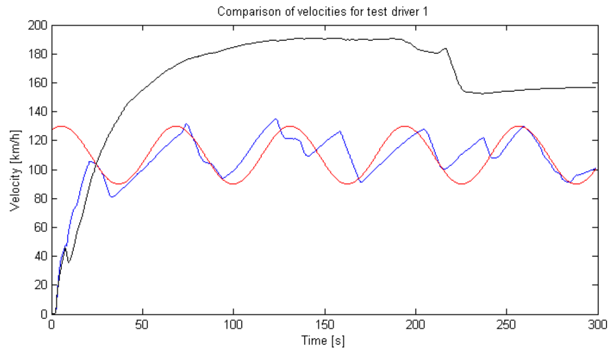

Fig. 17. Comparison of velocities with and without OBOI for test driver 1

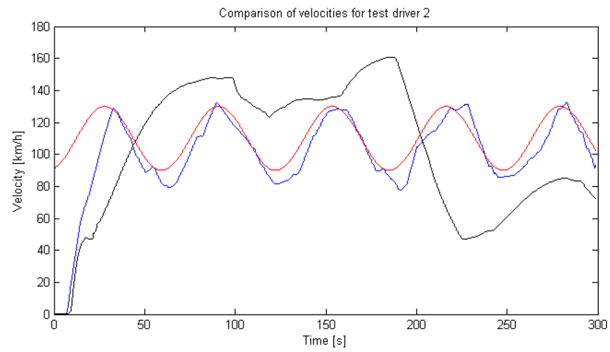

Fig. 18. Comparison of velocities with and without OBOI for test driver 2

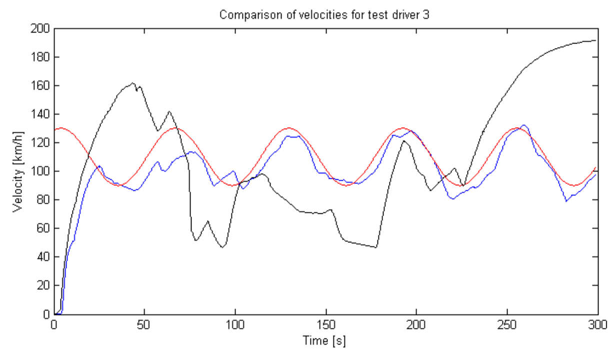

Fig. 19. Comparison of velocities with and without OBOI for test driver 3

driver get the benefit, they would like to continue following the suggestion. The black curves show the velocity of ego vehicle without OBOI. The red ones are suggested velocities and the blue ones are the real velocity of ego vehicle when the OBOI is displayed. Although the suggested velocities and reachabilities have no optimization algorithm behind, the drivers chose to follow the instruction. They really got the benefit when they change the current driving behavior into the suggested one.

After the driving, each test driver was asked about the usability of the assistance system as well as the design of the interface. The test persons find the HOI helpful to deal with the imminent danger. The OBOI displays too much information at the same time. But when they get used to it, they can focus on the information what they need. The location of the suggested velocity is too far away from the speedometer, which may lead to distraction.

5. CONCLUSION

In this contribution, additive information is used to stimulate the human driver to behave differently. The information is additionally added to the interface in two different ways: HOI and OBOI. The HOI is used to show those upcoming conflicts leading directly to hazards with respect to humans, systems, or environments safety. In the context the HOI refers to the warning displayed on the interactive interface between the human driver and the vehicle when the possibility of forward collision is very high. The OBOI is denoted as the information feeding back the consequences of the operators and actual behavioral interaction strategy in relation to calculated optimal ones. The detailed application is the suggestion to affect the driver so that the driver tends to behave more efficiently. First initial experiments are carried out to test the effects of the interface and to obtain the feedback of the drivers. Results show that in the context of HOI, the TTC to the frontal vehicle becomes larger when a forward collision may be possible. By showing the comparison of the consequences between the actual behavior and the optimal behavior, the behavior of the driver changes as suggested.

As next steps, the topology of the interface should be rearranged according to the first evaluation. A real optimization algorithm should be used in the experiments instead of the pseudo one. The actual first results are based on a small sample set, so additional tests with a larger number of test drivers (about 20) for both scenarios (with and without assistance) have to be made.

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