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CITYMOBIL: HUMAN FACTORS ISSUES REGARDING HIGHLY-AUTOMATED VEHICLES ON AN eLANE

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ABSTRACT

When introducing dual-mode vehicles, highly automated vehicles and cybercars, in the near future, human factors issues need to be taken into account. In case of highly autonomous or semi-autonomous driving, there are several human factors concerns such as; transition of control, loss of skill and dealing with automated system errors. The results of one out of four CityMobil experiments studying the eLane concept for dual-mode cars are described. The eLane concept brings together the road infrastructure and the technical development in vehicle automation to allow automated driving in the near future. In the experiment the reactions of the driver are observed in case of system errors or unexpected events, focusing on the transition of control and interface design. Concluding from the results of the experiment and based on current state of the art literature, suggestions are given for future research regarding automation in urban transport.

INTRODUCTION

This paper describes a study, conducted for the European CityMobil project (1). It describes the human factors' aspects in advanced urban transport systems i.e. future forms of public transport, the (semi-) automation of the driving task, dual-mode vehicles and co-operative support systems for vehicles and infrastructure. Dual-mode vehicles are vehicles that can be driven in a more manual/lightly assisted mode as well as in a highly automated mode. These dual-mode vehicles look like ordinary cars, but they are equipped with a lateral and longitudinal guidance system, a human-machine interface, car-to-infrastructure communication system and an obstacle detection system. Although a dual-mode vehicle can drive in various types of traffic scenarios, this paper will focus on the so-called eLane scenario. In an eLane scenario, the driver driving a dual-mode vehicle uses a specially equipped eLane, allowing different forms of automated driving.

The eLane: A concept for automated driving

The project CityMobil deals with several concepts for bringing automation into the urban environment. One of these concepts is the eLane, originally proposed for CityMobil by DLR (2). In general, the eLane concept brings together the road infrastructure and the technical development in vehicle automation to allow automated driving in the near future. The eLane is a lane which is especially certified, if necessary equipped and/or specially designated for automated driving. The equipment for an eLane that is needed on the road will be as slim as possible to keep costs down, e.g. a combination of clearly visible lane markings detectable by an in-vehicle machine vision, a database and a wireless data transfer capability such as GPRS or UMTS. A key point for the concept is to ensure that vehicles are only allowed to drive highly or fully automated if a minimum quality of the automated driving can be assured. Urban expressways are a promising starting scenario for eLanes, because here the environment is well structured and with a moderate so that automated driving can be handled by state-of-the-art sensors and automation technology. Also, these types of roads ensure that there are no pedestrians, bicycles and level crossings and that the two directions of traffic are separated by constructive means.

Within the CityMobil consortium two eLane scenarios are discussed; closed (or dedicated) eLanes and open eLanes. Closed or dedicated eLanes are reserved for authorized vehicles in automated mode. Vehicles driving solely in automated mode on one specific lane will enable the formation of platoons so that the convoys of coupled vehicles can drive together to achieve maximum throughput. The interactions with conventional traffic, driving in manual or assisted modes, will be limited to special interchanges sited at the entrances and exits of the eLanes. This eLane scenario is clearly linked to scenarios of an automated highway system (AHS) which has been under research since the early 1990s (3). The main disadvantage of a dedicated eLane is that it is quite expensive to devote road space exclusively to automated vehicles. Especially in the initial phase there will be not enough authorized vehicles to fill the lanes and therefore platooning is not possible or not needed for increasing the throughput.

In contrast, open eLanes allow a mixture of traffic including conventional, non equipped vehicles as well as vehicles driving in automated modes. Compared to a closed eLane, open eLanes are more challenging for the automation, because of the interaction with non-automated traffic. On the other hand, state-of-the-art assistant systems such as Adaptive Cruise Control (ACC) or Lane Keeping Assistant Systems (LKAS) already handle operation in mixed traffic, so there is a good chance that this challenge can be met. The platooning capability of an open eLane would be lower in the beginning, compared to a closed eLane. However, when the percentage of automation capable vehicles increases, the capacity gains of platooning can gradually be used. The probability that two or more adjacent vehicles are equipped for platooning is high so that no closed eLane is needed any longer (for a detailed discussion of dedicated lanes vs. mixed traffic systems, see (4)). The interaction between non-automated cars and automated platoons is still subject to research. In general, eLanes can be used by fully automated vehicles (cybercars) or highly automated vehicles, that can be operated either manually or can drive automatically (dual-mode vehicles), or in the future can be switched between different levels of automation, from manual and assisted driving up to highly or completely automated driving.

Human Factors for highly automated vehicles

There are at least four human factor issues that play a major role in the success of highly automated vehicles on an eLane 1) supporting the driver with the appropriate level of automation, 2) the transitions between manual and higher levels of automated driving, 3) possible loss of operating skill, 4) drivers' responses to system errors.

Level of automation

When talking about automated driving, there are more classifications than just fully automated driving. There is a gradation of assistance and automation between the outer positions of manual or automated driving. This spectrum between fully-manual and fully-automated control can be divided in five gradations: manual, assisted, semi-automated, highly automated and autonomous/fully automated (5). Research has shown that different levels of automation in dual-mode vehicles are leading to different human factors problems, e.g. loss of situation awareness, high or too low workload, and possible loss of skill (6-10). Automation of tasks originally performed by human operators can have negative effects for the efficiency and safety of human-machine-systems, because the task of the operator often changes from actively operating to passively monitoring the system (11). In case of system failures, the passive monitor suddenly needs to become an active driver again, requiring a fast response to a dangerous situation.

Transition

For dual-mode vehicles, transitions from the driver to the vehicle and vice versa take place each time the driver switches the driving mode for example from manual to highly automated driving when situated on a eLane. The transition of control to such a highly automated system seems to be relatively new in road vehicles. By taking a closer look at modern vehicles, it becomes clear that the issue of transition already arises. There are several driver assistance systems in the vehicle that take control of a couple of driving subtasks. Cruise control, for example, regulates the speed of the vehicle; Adaptive Cruise Control (ACC) combines the regulation of speed with a distance control, and the Lane Keeping Assistant System (LKAS) supports lateral guidance of the vehicle. Each of these systems implies a transition of control from the driver to the assistance system and the other way around. We postulate that similar principles of the transition can be applied to the complete spectrum of assistance and automation (5, 6). Firstly, transitions of control can occur from the driver to the system and the other way around. And not only between manual and automated driving but also between all of the different levels of automation. For example, the driver can decide to switch from assisted to highly automated driving or the automation can initiate a transfer from fully automated to semi-automated driving. Secondly, the transition can be differentiated according to the question who initiates the transfer of control. This can be either the automation or the operator. For example, in case of emergency, the automation initiates a transfer of control back to the driver whereas the driver initiates a transition of control to the automation in case of turning on the ACC of his car. In sum, the fundamental questions for a classification of transition of control are: 1) Who has control and to what degree? 2) Who should get control and to what degree? 3) Who initiates the transition?

Loss of skill

Automation may lead to loss of skill and in case of fully automated systems, loss of skill may be high after some time. If people are able to perform a task relatively well, but they do not perform this task for a long time, they lose the skill to perform that task. In aviation, flight crews are known to disengage automated systems on a regular basis to refresh their training (12). Consequently, while it is extremely important for users of an automated system to be adequately trained and experienced in using and understanding the system, maintaining this training and experience is also a crucial component in order to ensure that control is regained as soon as a system malfunctions (13). However, dual-mode vehicles are not expected to induce a loss of skill since drivers will still partly drive their cars manually. However in case of large scale implementation of dual-mode vehicles and eLanes, it will also be necessary to have a minimum requirement for a driver to manually operate the vehicle, to ensure that they can cope with system failures.

Responding to system failures

When acting as a supervisor, it is likely that the driver's workload will be quite low and whilst this may feel comfortable to the driver, there is also the possibility that the driver will be bored and will start doing other things or feel 'out of the loop'. In case of a system error there is a sudden and possibly unmanageable increase in workload, requiring the driver to quickly and efficiently reclaim control of the driving task that is if the driver even notices! Bainbridge (11) warns that with high automation the task of managing an error or fault in the system becomes more difficult. The human operator either has to be exactly familiar with how the system works, or be provided with adequate feedback and information about whether or not the system is working effectively. Consideration needs to be given to both of these solutions and the interface design. The use of too many auditory alarms or too many visual displays is clearly not desirable or practical and is likely to lead to driver overload. Norman (14) suggests that for best results an automated system should provide up to the minute communication about its operation to the driver (15). As well as keeping the driver up to date and in the loop, it ensures that changes in system capability are not a complete surprise to the driver, and that the driver is able to take control efficiently and without experiencing a sudden peak of workload.

Regardless of the method by which operators are informed about the failure of a system, it is clear that upon failure of an automated task they need to know the point at which it is appropriate to take over from the system and how to achieve this task successfully**.** Stanton and Young (9) suggest that driver's characteristics and their beliefs about who is in overall control of the car will have an effect on their behavior and how they interact with automated systems in the car. In some circumstances, users' 'mental model' of a how a system should behave does not actually match the observed behavior of the system. Bredereke and Lankenau (16) refer to this phenomenon as *mode confusion*: a situation which can sometimes lead to an (unpleasant, so unsafe) surprise by the user. Nevertheless, the idea is that driver's beliefs and expectations of how a system works determine how they interact with the system and what they expect (13). Clearly, it is important that the correct mental model of the system operation is perceived by drivers, and that they understand the system's limitations and are capable of recognizing and taking over control when the system is malfunctioning.

EXPERIMENT: THE COMPARISON OF TWO eLANE INTERFACES

The aim of the CRF driving simulator experiment was to design and test a vocal versus an acoustic user interface for a dual-mode vehicle driving on an eLane. In the first condition, the human-machine interface was acoustic ("beeps") and had an additional visual display. In the second condition the acoustic and visual interface were supported by vocal messages (i.e. spoken words). The purpose of the interface was to support the transition of control between driver and automated vehicle and vice versa, both initiated by the driver and by the system. Furthermore, system errors were simulated in the experiment, such as transitions in which the eLane was not functioning. The users' attitudes and reactions towards the dual-mode vehicle and the interface were assessed with questionnaires and driver performance was analyzed

METHOD

Participants

Twenty four participants (5 female, 19 male drivers) took part in the experiment with ages between 21 and 46 years. On average they had their driving license for 10 years, with an annual mileage of 15.000 km/year. All participants had experience with the CRF Virtual Reality Simulator (i.e.>3 drives).

Driving Simulator Scenario

The CRF driving simulator provides 45° vertical and 135° horizontal field of view. The mock-up is a seat with a steering wheel placed on a moving base with 6 degrees of freedom. All participants drove the same simulated scenario with different situations (e.g. automatic and manual overtaking, sudden lane changing) which forced participants to do various driving maneuvers. The road consisted of 3 lanes, 4 m wide, plus an emergency lane 2.5 m wide. The track, that was a 17km long ring, was driven along cyclically clockwise. In some areas of the highway the eLane was simulated (Fig. 1) in order to allow to test of the driver interfaces usability. The multi-lane road was uniformly populated by cars and trucks statistically guaranteeing the presence of 4-5 visible vehicles in front of the participant. Some vehicles had the function to generate dangerous situations in a controlled way.

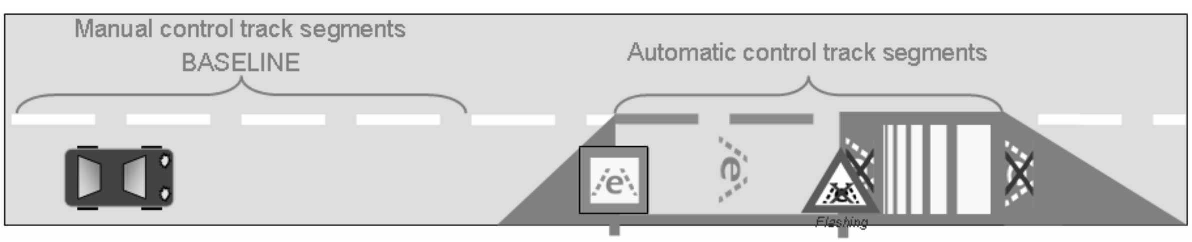

FIGURE 1 Example of the multi-lane one-way track. The right lane was divided in numerous segments: automatic and manual control ones. The automatic control segments (eLane) were identified by specific blue lines and icons on the pavement and by specific road signals.

Driving task

Participants had to perform the driving task as their primary task. They were instructed to maintain an average speed of 70 km/h. The participants were not instructed to overtake slower vehicles, but their spontaneous overtaking behavior was monitored. This allowed, in the cases of automatic driving, to study the behavior, for example the driver voluntarily taking control of the vehicle while it was in the automatic state. There were two scenarios: 1) Manual driving; on road segments where the users had to drive themselves, thus maintaining the longitudinal and the lateral control of the car, using pedals and steering wheel. 2) Automatic driving on the eLane; on road segments where the longitudinal and lateral control was controlled automatically by the system. The automatic driving was achieved using the Wizard of Oz technique. This is a technique whereby the experimenter (“the Wizard") sits in a separate room and acts as the automated system, making all steering wheel actions and longitudinal control. The participants were unaware that the system was not ‘real’.

Secondary Task

The participants were also asked to perform a secondary task. This task was introduced to distract the users and to avoid that they focused their attention too much outside of the vehicle or to the dual-mode vehicle interface. So, it was possible to test the designed interfaces in a situation of divided attention. The secondary task was the interaction with an in-vehicle information system (IVIS), with different difficulty levels (Fig. 2). A recorded voice asked to press specific buttons or a sequence of buttons: i.e. “press TEL button”, “press NAV button”, “dial 25 47 85” etc. The strings of numbers and the presentation time between the different secondary tasks, varied. The task was randomly presented in order to avoid expectation or learning effects.

Dual-mode Vehicle interfaces & experimental design

Two different interfaces were used for communicating the eLane functions to the driver:

- Acoustic interface (visual + acoustic messages by means of beeps). The visual information was compensating for the generic level of acoustic information. In fact, a simple “beep” could not be able to explain the exact meaning of the warning.
- Vocal interface (i.e. visual + acoustic + vocal messages) The visual display was simpler because the vocal message provided the necessary information. Each vocal message was preceded by an acoustic signal.

A colored icon was always present on the display, specifying the system status: the grey icon indicated ‘off’ (but eLane was available) and the green icon indicated ‘on’. In case of danger the amber icon indicated a warning, while the red icon indicated the automatic deactivation status (Fig.2). The exact timing of the interface messages is described in the result section.

It was a within-subject design in which all participants tested the two interfaces in three drives (baseline, manual and automatic drive) that were randomized to minimize order and sequence effects. A number of events happened during the drives; 1) entering and exiting an eLane, 2) infrastructure out of work and 3) system break down.

FIGURE 2 Visual interface of the dual-mode vehicle and IVIS interface used to create the secondary task.

Procedure

After being instructed about primary and secondary tasks, participants were trained for about 10 minutes per driving condition. Then, the actual experiment started with a baseline drive, followed by a manual and automatic drive (on the eLane) each lasting 10 minutes. After each drive an adapted version of the AIDE-HMI questionnaire (17) was filled in.

Data recording

The variables investigated were actions on steering wheel and pedals, the users' responses to the system errors, entrance/exit to an eLane, and overtaking. Also, a subjective evaluation of the system (perceived usability, perceived evaluation of the driving performance, willingness to buy the system and perceived image of the system) was provided.

RESULTS

Only the main results will be reported in this paper. Student Test and Chi square Test were used to compare mean or percentage values.

Driving performance

Average speed during baseline

When the participants were using the vocal modality, they maintained, in the baseline manual driving segments, a significantly lower average speed (55 km/h) in comparison to the same situation with the acoustic modality (61 km/h).

Transition of control at the beginning of the eLane

Before entering the eLane, an acoustic pre-warning (Fig.4) advised the driver that the system would be active in 200 m (for both conditions). When the car was in the eLane area a second warning message advised the user that the system was ready and it could be activated, by pushing the On/Off button and leaving the steering wheel and pedals. And for the vocal interface only the voice said the last part of the second warning ”Push the button then leave steering wheel and pedals”. More then 93% of users activated the system when the system became ready for the automatic driving. Almost the 85% of users activated the system in maximum 5s (RT Mean: 2.8s) after the availability warning (Fig.3). There were no statistically significant differences between Vocal and acoustic modality. Considering, that it was not a critical situation, the response to both the acoustic and the vocal display can be considered as adequate responses.

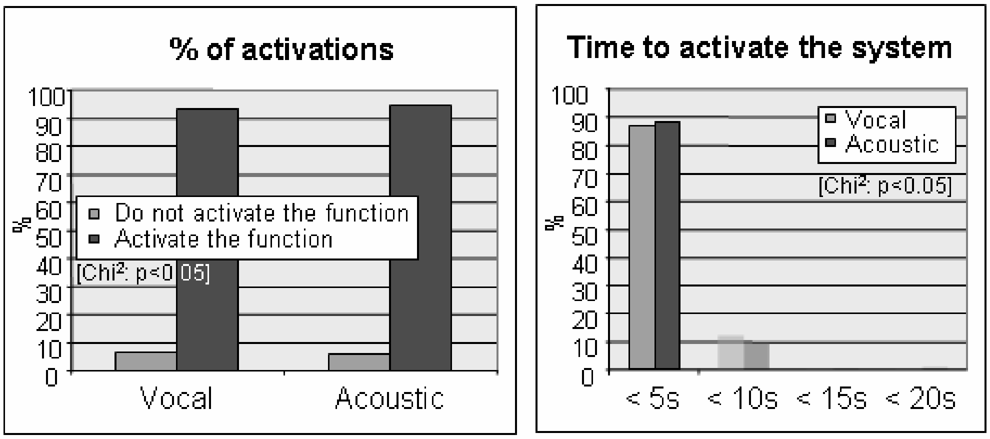

FIGURE 3 Users’ activations of the automatic driving and time to do this operation.

Transition of control at the end of the eLane

To notify the pre-warning, the same feedbacks (icons and acoustic signals) for vocal and acoustic modality were used. Specific vocal messages were used for the first and the final warning (Fig. 4). All drivers took control of the car at the end of the eLane in all conditions. There was a significant difference in response to the deactivation warning between the two interfaces. The acoustic modality recorded the pick of answer at the FIRST WARNING step (36% Acoustic; 50% Vocal) whereas the vocal modality at the PRE-WARNING step (40% Acoustic; 55% Vocal). When keeping the type of situation in mind, both HMIs seem to result in equally effective responses from drivers.

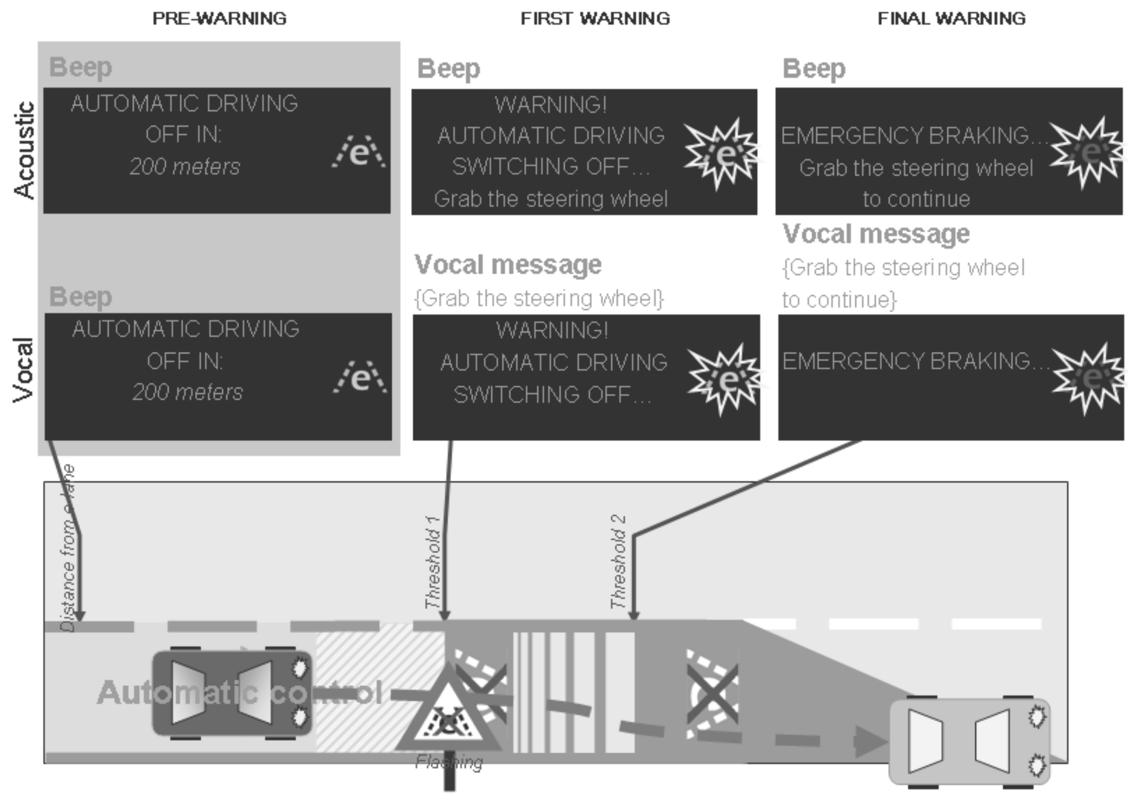

FIGURE 4 HMI sequence for the transition of control at the end of the eLane.

System Failure

In case of a system failure, the system gave a pre-warning to inform that the system would be deactivated in few minutes. A second warning stated the system had been deactivated and that the emergency parking maneuver was beginning. 85% of drivers took control of the car in case of failure. For the other 15% of drivers, the Wizard simulated an emergency parking. There are no significant differences between vocal and acoustic modality (Fig. 5). The vocal modality showed significantly shorter response times compared to the acoustic one (Fig. 5).

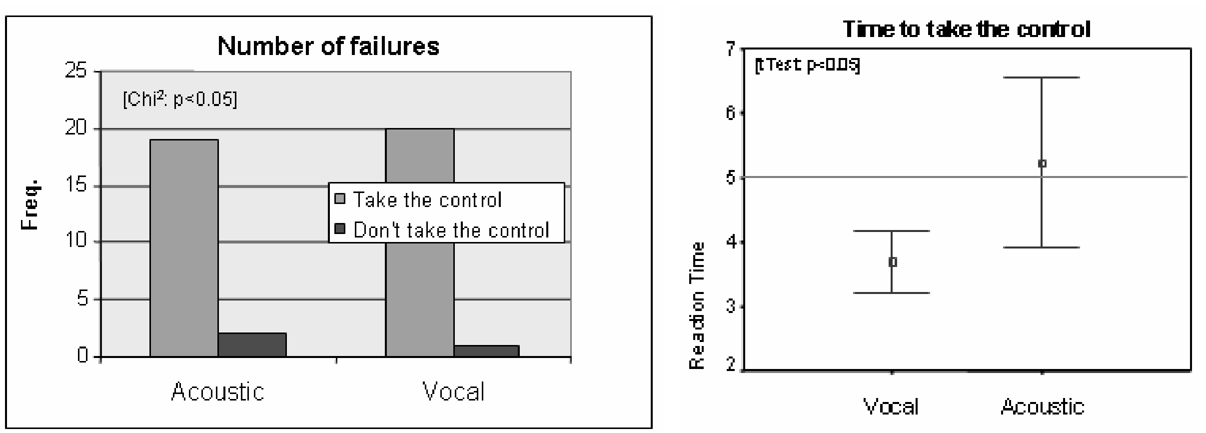

FIGURE 5 Users' taking controls of the vehicle in case of system failure (left). Users' reaction times to take controls of the vehicle in case of system failure (right).

Infrastructure out of work

When the infrastructure was out of work, at the beginning of the eLane, a flashing road-signal informed the driver about this problem. If the driver pushed the ON/OFF button anyway, the display visualized WARNING! System out of work (same for vocal and acoustic modality combined with an acoustic signal). In case of acoustic modality, there were no differences between the percentage of drivers that recognized the infrastructure out of work and vice versa. On the contrary, in the vocal modality, a significant greater number of drivers didn't recognize the out of work status of the infrastructure (Fig. 6). There are no differences between vocal and acoustic modality in the On/Off push button reaction time.

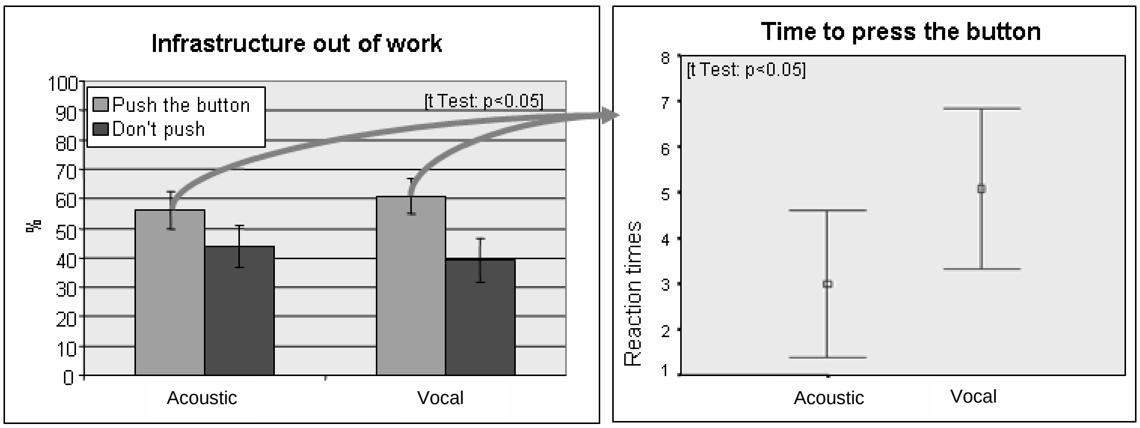

FIGURE 6 Users' pushing On/Off button and time to do this operation (left). Users' reaction times to press the button (right).

Subjective evaluations

Interface evaluation Questionnaire

The visual information of the acoustic interface is considered more necessary than the visual information of the vocal interface.The visual information of both interfaces are considered *Necessary*, *Adequate*, *Pleasant*, *Comprehensible* and *Legible*. The Acoustic interface is considered neither *Soothing* nor *Frightening*.In general, the acoustic/vocal information of the vocal modality is considered more *Comprehensible*, *Adequate* and *Soothing* in comparison with the acoustic modality. More than 70% of users prefer the vocal modality. Users think that the vocal modality reduces distraction during driving, it is considered more comprehensible and could be very useful during the learning phase. The vocal message is also considered a bit annoying but it is possible to design a vocal interface that could be deactivated by expert users (except for the fault event).

Driving performance evaluation Questionnaire

Users think that all conditions were *Safe* but the vocal modality is considered as *Safe* as the manual driving (Baseline) while the Acoustic Modality is not (Fig. 7). The users trust the system. And, for this dimension, there are no differences between the acoustic and vocal modality. 80% of drivers prefer to have a mixed automatic-manual system, to be used in the automatic modality in specific situations only 1) the manual modality: Urban area, traffic jam, overtaking situations, mountain and curves streets. 2) the automatic modality: Traffic jam, straight and high velocity streets and highways.

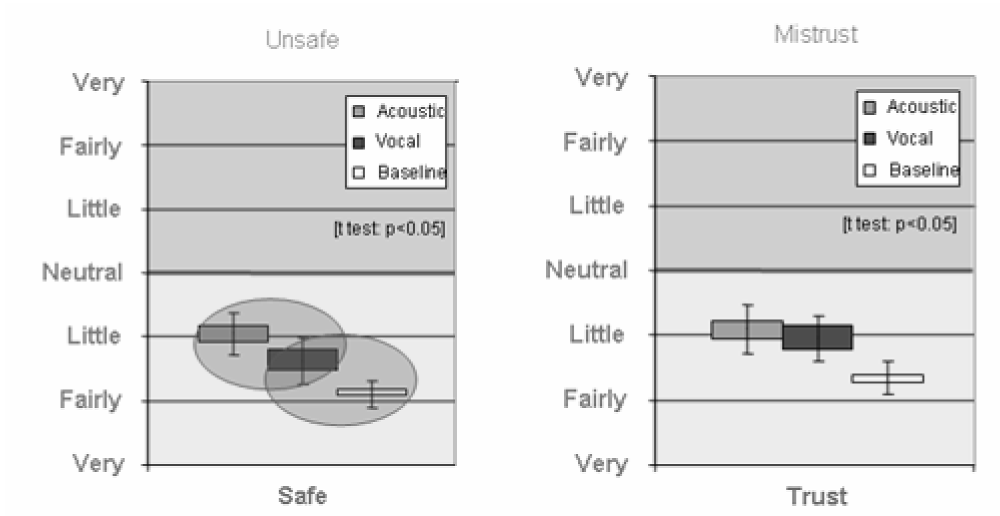

FIGURE 7 Answers to the questions: "How did you feel during the driving?" and "Your attitudes towards the automatic driving was?"

CONCLUSION

A good level of drivers' performance was observed in most of the test cases. It seems that the vocal modality increases the general level of awareness, inducing a significant reduction of the average speed during the manual control and anticipating drivers' answers, when there is just the visual information. The vocal modality could be considered more adequate in the first impact and it is very important to inform in case of automatic system deactivations. Moreover, in some cases, the vocal modality reduces reaction times even though response times in this experiment were not too time critical. In general, drivers trust the system and respond properly during the automatic maneuvers. The infrastructure was sufficiently informative. It was found that a rather high number of people didn't recognize the infrastructure was out of order. In this case, it could be useful to inform the users not only with the road-signals but also with an on-board message, especially with the vocal interface.

Regarding the Perceived Usability of the Automatic System, the system evaluation is positive. In fact, it is considered satisfying, amusing, pleasant and interesting and also easy to use, easy to remember, easy to learn. Driving in Automatic Mode with the vocal modality is considered safe like driving in Manual Mode. The vocal modality is perceived safer than the acoustic one. The vocal modality is preferred. Drivers judge that this modality can reduce the distraction, is more comprehensible and useful during the learning phase. At the same time, vocal messages can be a bit annoying, but this aspect can be solved with a dedicated design that allows the deactivation to expert users. In case of fault event the vocal modality seems to be the better one, because it shortens drivers' reaction time.

The visual information of both interfaces is evaluated positively. In general it is considered: necessary, adequate, pleasant, comprehensible and legible. The visual information for the acoustic Modality is considered more "necessary than for the vocal modality; For both interfaces the most problematic labels are: "Automatic Overtaking", "Fault", because these messages are not sufficiently salient and probably require a pre-warning. The vocal information is more comprehensible, adequate and soothing than the acoustic one. Anyway, both interfaces are evaluated necessary, pleasant and easy to hear. A mixed automatic - manual modality is the preferred one, with automatic driving in case of medium and low traffic, straight and high velocity streets and manual driving for medium and high traffic, in the urban context, overtaking and for mountain streets.

Summarizing, both designed interfaces are turned out to be pretty usable and satisfactory, although the design could be optimized for specific traffic situations. Also the interfaces should result in the right response in case of unexpected events in open eLanes and mixed-traffic. It is extremely important to be prepared for all types of situations before these systems are actually introduced in traffic.

OUTLOOK

In order to study this topic in different situations, other experiments were conducted for CityMobil that cannot all be reported here. However a short overview will provide the reader with the opportunity to seek further information about the other experiments once available (18).

ITS Leeds study: Thirty drivers were asked to drive two simulated routes in a within-subjects design with a main factor of automation. Driver behavior in a 'normal' driving condition, where all driving maneuvers and decisions were made by the drivers, was compared to fully automated driving, where lateral and longitudinal control of the driving task was dictated by a series of controllers. In this condition, drivers were asked to take their foot off the pedal and their hands off the steering wheel and allow the car to be driven for them. Situation awareness in both driving environments was measured by computing drivers' response time to unexpected traffic situations, such as an illegally parked car in the lane, an example of a scenario which could not be successfully dealt with by the controllers. The implications of such automated driving on drivers' situation awareness and safety will be discussed.

TNO study: This driving simulator experiment is about situational awareness when driving a semi- and highly autonomous car. The main question is whether a driver is still aware of when he needs to respond and when the system will cope with the situation. And in case of transition of control back to the driver whether the driver is still fast enough to respond to critical events. In a 3 x 30 minute drive (city road, rural road and motorway), the driver encountered normal and critical events. In total, 43 participants took part. Condition 1 (control condition) had the driver drive a normal car. In condition 2, the driver drove a semi-autonomous car with longitudinal control (a near future focus), combining current technology. In condition 3, the driver drove a highly autonomous car, with longitudinal <u>and</u> lateral control (a more futuristic focus). Situation awareness (what does the driver still need to do and what can the system cope with) in all conditions was measured by computing drivers' response time to unexpected traffic situations, such as a car puling out of the parking lot. The implications of such automated driving on drivers' situation awareness and safety are discussed.

DLR study: The study is about the eLane concept in general, the functionalities of an eLane automation and the HMI design of the transitions. In the first part of the study a structured interview with potential users was conducted to record their expectations about the eLane concept in general. In the second part we tested two different variants of the vehicle automation ands the appropriate HMI designs focusing especially on the controllability of different transitions. The two automation variants were compared in a usability assessment which took place in a fixed-base driving simulator and in addition during a test drive with the DLRs research vehicle FASCar on a test track. System variant 1 can be driven either in manual or in highly automated mode on an eLane. The eLane automation takes over lateral and longitudinal vehicle control. The gas pedal is implemented as an active actuator and provides the driver via movement with haptic information about the automation actions. Additionally, visual and acoustic information about the eLane automation status is displayed. System variant 2 adds one more component, a semi-automation, to the dual-mode vehicle described above. An intelligent cruise control (ICC) is available on all lanes so that the driver is only responsible for steering. The main research questions are about the acceptance and controllability of the eLane automation and its transitions as well as about the differences between the two system variants.

Concluding, Human Factors aspects play an important role in automated transport to properly tune the system to human capabilities and limitations. When talking about (semi-)automatized and dual model vehicles, it is important to design a proper HMI, to ensure the driver understands how the system works, that (s)he does not loose the skill of driving and that the transition from manual driving to autonomous driving and vice versa is done in a safe way. In the CityMobil project, various Human Factors aspects are being studied, in driving simulator studies and on the road. The experiment described in this paper focuses on closed eLanes. The study showed that HMI design is indeed important and may lead to different driving behavior and acceptance of the system. Overall, the eLane concept is something that is well accepted by drivers, even though none of the drivers had any experience with this concept. However, further fine-tuning needs to be done, focusing on driver response to system failures, user expectations about the system, the mixture of automated and manually driven vehicles, the time it takes to take over control again and other issues. The results of the TNO study, the ITS Leeds study and the DLR study will be available at the end of 2008 (18).

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