

EFFECTS OF SIMULTANEOUS MULTI-MODAL WARNINGS AND TRAFFIC INFORMATION ON DRIVER BEHAVIOUR

Clemens Kaufmann (FACTUM OHG, Austria),
Ralf Risser (FACTUM OHG, Austria),
Arjan Geven (CURE, Austria),
Reinhard Sefelin (CURE, Austria)
clemens.kaufmann@factum.at

ABSTRACT: It is expected that the number of in-vehicle telematic systems will increase rapidly over the next years, leading to an increased amount of information a driver has to deal with. In the scope of the research project LIVES¹, the organisations CURE and FACTUM OHG have investigated how these systems could be used optimally to improve the safety on the road. To be able to answer the research questions formulated by FACTUM OHG, CURE developed a driving simulator specifically tuned to these questions. The driving simulator made it possible to investigate the effects on the driving behaviour using different modalities for information and the effects of simultaneously submitted information. The results of these experiments were used to formulate guidelines to increase safety. These guidelines focus on the optimal use of auditory, visual and haptic information for the driver as well as on the simultaneous communication of more than one system.

1 Starting point

It is expected that the number of in-vehicle telematic systems will increase rapidly over the next few years. This will lead to an increased amount of information a driver has to deal with besides the primary task of driving. The main advantages of telematic systems are or should be the ability to increase both the safety and the comfort of the driving task. These advantages, however, might be compensated by additional perceptual and cognitive load, as the driving task is extended with the task of reacting correctly on the information, directions and warnings that these systems provide. This will especially be the case when the driver receives different information simultaneously from these systems.

The research institutes CURE (Center for Usability Research & Engineering) and FACTUM OHG (Transport- and Social Analyses) investigated in the year 2006 in the Austrian study LIVES how the human machine interface (HMI) of different telematic in-vehicle systems should be designed in order to guarantee an optimal use of diverse systems [1]. It dealt with the integration of disjunctly developed systems, that are not a priori matched to one another. Thus, the driver may run the risk of being distracted by unimportant or interfering information during possibly critical situations.

¹ German title: LIVES - LenkerInnenInteraktion mit VErkehrstelematischen Systemen

2 Development of hypotheses

One main focus of the project was the identification of new requirements to drivers which might appear through the implementation of telematic systems into cars. Especially the effects on the driver and his/her behaviour while he/she gets simultaneous information from two systems were tested. Another focus was on the search for the optimum modality in which information should be submitted to the drivers.

Based on a literature study several telematic in-vehicle systems and situations, where systems submit either information (traffic news) or warnings (too little distance to the car ahead etc.) to the driver, which suited the project objectives best were selected. These information and warnings have different priorities with regard to the driving task and the driver's reaction in different situations. Three priority levels were defined:

1. Warnings which need an immediate reaction by the driver
2. Latent instruction – no immediate reaction of the driver is needed
3. General information – no immediate relevance for the driving task

One of the main questions was: "What is the best way and the best modality to submit information or warnings in order not to distract or to overload the driver?" Based on literature the following matrix was established, in which the priority levels are set in contrast to the three modalities acoustic, visual and haptic.

Table 1. Classification of information into priority levels and modalities

modality type of information	acoustic	visual	haptic
warnings, high priority	suited well, it can be instinctively handled. Speech is not adequate [2]	not adequate, modality is too slow to transfer the information in critical situation	hardly any literature, short breaking impulses could lead to an erroneous interpretation of the driver
medium priority	acoustic signals are experienced as hindering and therefore should not be used for this level	suitable. Drivers can partially decide themselves when they want to receive the information	pedal-Feedback or vibration on the steering wheel helps the driver to adapt to the speed limit without nervousness [3]
general information, low priority	possible, but not optimal, driver is distracted from the driving situation	adequate, distract driver not directly. Driver can decide himself if and when he wants to receive information	hardly any literature available

For the first level, the warnings, it becomes clear that acoustic signals (with the exception of speech) are the most appropriate ones. The driver can handle the signal instinctively. Visual as well as haptic signals are not adequate for this priority level, because they are either interpreted too slowly or lead to misunderstandings [4].

For the medium priority level the visual information is seen as the best solution, because messages of this type are not too penetrating (like acoustical signals). Haptic feedback, like it is used for example for ISA (Intelligent Speed

Adaptation) systems, is also seen as adequate. If the driver is speeding above the limit the accelerator pedal gives a counter pressure which informs the driver about his/her erroneous behaviour [5].

For the general information on the third priority level it looks as if the visual information were the most appropriate one. The reason for this is that the driver could decide him/herself when he/she wants to receive the information. Also acoustic signals are adequate, but have to be announced in some way in order not to distract the driver from the driving task. No literature was found for the haptic signals on this level.

Based on the matrix above the following **hypotheses** for the systems which were tested were formulated:

- If level 1 warnings are submitted acoustically, than they have less negative effect on the driving behaviour than if they are submitted visually.
- Latent instructions of level 2 have less negative effect on the driving behaviour if they are submitted via the haptic channel than if they are submitted acoustically.
- General information of level 3 has less negative influence on the driving behaviour if it is given visually than if it is submitted acoustically.

In order to test these general hypotheses five scenarios, which represent typical situation in real traffic, were developed. For these scenarios the driving task was defined as "primary task" while the secondary task consisted of the tasks given by the different telematic systems. In every scenario two systems submitted information/warnings/instructions to the test persons. The task of the test persons was to react correctly to these information/warnings/instructions. In order to test the hypotheses the test persons drove through the test track twice while the modality in which the information in the different scenarios were submitted changed.

In the following, an overview about the scenarios and the systems which were used.

Table 2. Overview of the experimental design of the simulation test

		Course A		Course B	
		Test situation 1 & 2	Control Situation	Test situation 1 & 2	Control Situation
Scenario 1	Route Guidance Information priority level 2	acoustic	traffic sign	haptic	traffic sign
	Traffic news Information priority level 3	acoustic	-	acoustic	-
Scenario 2	ISA Information priority level 1-2	haptic	traffic sign	acoustic / visual	traffic sign
	Traffic news Information priority level 3	acoustic	acoustic	acoustic	acoustic
Scenario 3	Parking information Information priority level 2	acoustic	traffic sign	visual	traffic sign
	Additional parking information Information priority level 3	visual	-	acoustic	-
Scenario 4	Pedestrian warning Information priority level 1	visual	-	acoustic	-
	Route Guidance Information priority level 2	acoustic	traffic sign	haptic	traffic sign
Scenario 5	Distance warning Information priority level 1-2	visual	traffic sign	acoustic	traffic sign
	Traffic news Information priority level 3	acoustic	-	acoustic	-

3 Simulator set-up

In order to give answers to the formulated research questions and hypotheses a driving simulator based on a 3D development environment (BLENDER – open source) was developed.

The test track consisted of roads within build up area and rural roads. Traffic signs were virtualised in order to guide the test person through the course, and speed limits as well as overtaking bans were announced. The general speed limit was 50 km/h but on certain parts of the test track there was a 30 km/h limit. Random generated traffic volumes but also virtualised cars and pedestrians based on the behaviour of the test person appeared during the test rides.

The duration of one drive through the whole test track was about 15 minutes. Altogether, including a five to ten minutes adaptation phase before each test drive, the duration of the test was about 45 to 50 minutes.

A customary steering wheel for racing games was used as well as two pedals (acceleration and breaking pedal as in a car with automatic gearing). A simple engine noise reflecting the driven speed was heard.

The picture of the test track was projected with two beamers on a white wall. The test person sat approximately two meters away from the wall.

Data about deviation from the optimum driving line, control of pedals (speed) and steering wheel movements (deviation from the zero position) were logged during the whole test ride. In addition, all test rides were filmed with two video cameras.

The haptic information was given by two vibrating electro-motors which were put on the left and right side of the test persons seat. For the haptic route guidance only the motor on the side in which the test person should go vibrated, for the ISA warning both motors were vibrating when the test person drove above the allowed speed limit.

4 Evaluation

The sample was distributed in the following way. Eleven men and eight women participated in the simulator tests: The test persons had a mean age of 37,5 years with a standard deviation of 11,8:

Table 3. Sampling distribution

	Male	Female	Total
Under 30 years	4	3	7
between 30 and 49 years	5	3	8
50 years and above	2	2	4
Total	11	8	19

The yearly driving performance showed that eight test persons drove less than 5.000 kilometres the year before, six drove between 5.000 and 10.000 kilometres, three between 10.000 and 20.000 and finally two test persons had a yearly driving performance of more than 20.000 kilometres.

Four test persons stated that they had experience with computer racing games while 15 test persons answered that they did have not. Seven test persons did not have any experience with the warning and information systems used in the simulator study while twelve participants said that they already had used one of the systems at least sometimes.

Two evaluation methods were applied:

4.1 Statistical evaluation for speed and steering wheel movements

In order to make the data of the test persons and for each situation comparable only the data logged ten seconds before and after each scenario (test situation and control situation) was taken for the statistical evaluation. Mean speeds for the various situations and standard deviations of the steering wheel movements were used to calculate significance's between the control situation and the two test situations and within the test situations (Mann Whitney U-Test).

4.2 Behaviour observation with the help of the video recording

In order to evaluate differences in the behaviour of the test persons in each situation the recorded material was seen through with the help of a standardised observation sheets. In these sheets specific criteria were defined which cannot be identified in the logged data, e.g. overtaking where the test persons were not allowed to overtake, conflicts with other road users, etc. The observed driving behaviour in each test situation was compared between the control situation and the two test situations and within the test situations. The aim was to evaluate possible differences of the effect of the modalities in which the information/warning was given, on the driving behaviour. Furthermore, on the three parking places the test subjects were asked about the traffic news which they received during the test- and control-situations, and answers were also evaluated.

5 Results

In the following some basic results for each scenario are presented:

Scenario 1: The driven speed was significantly higher in the first test situation in comparison to the control situation (46,73 km/h to 34,83 km/h, $p=0,026$). Also the standard deviation of the steering wheel movement in both test situations (acoustic route guidance/acoustic traffic information & haptic route guidance/acoustic traffic information) was significantly higher than the one in the respective control situations (32,71 to 26,22, $p=0,000$ & 32,25 to 24,90, $p=0,008$), Additionally the behaviour observation showed that with haptic route guidance three test persons did not follow the correct route.

Scenario 2: The standard deviation of the steering wheel movement was significantly stronger in the situation where acoustic/visual ISA-warning was used in combination with simultaneous acoustic traffic news than in situations where a haptic ISA system was tested in combination with simultaneous acoustic traffic news (17,2 to 14,9, $p=0,011$). The behaviour observation showed no differences in the driving behaviour between the two test drives.

Scenario 3: No significant differences in speed and standard deviation of the steering wheel movement between the two test drives. More erroneous turns on the parking place were observed while using the visual route guidance in combination with the additional acoustic information where to park, in comparison with the situation in which an acoustic route guidance was tested in combination with additional visual information.

Scenario 4: The standard deviation of the steering wheel movement was significantly lower in the situation where acoustic pedestrian warning was tested in combination with simultaneous haptic route guidance in comparison to the situation where a visual warning system was used in combination with simultaneous acoustic route guidance (29,7 to 32,1, $p=0,040$). The behaviour observation showed that the visual warning was detected later and that it was also more often ignored by the test persons.

Scenario 5: The standard deviation of the steering wheel movement was significantly higher in the situation where an acoustic distance warning system was tested in combination with simultaneous acoustic traffic news in comparison to the situation where a visual distance warning system was used in combination with acoustic traffic news (22,9 to 20,7, $p=0,045$). The behaviour observation showed that the participants ignored the acoustic warning more often than the visual one.

The results of hypotheses tests were transferred back to the matrix in which the information given on different priority levels was combined with the three modalities. The following table gives an overview about the comparison between the literature results and the results of the simulator study.

Table 4. Classification of information into priority levels and modalities

modality priority levels	acoustic	visual	haptic
warnings, high priority	Confirmed by the results of the simulator study	Confirmed by the results of the simulator study	Was not tested within these project
medium priority	Confirmed by the results of the simulator study	Confirmed by the results of the simulator study	Confirmed by the results of the simulator study
general information, low priority	Confirmed by the results of the simulator study.	Was not tested within these project	Results of the simulator study are not clear in this respect

Additionally, general results show that

- None of the test persons could accomplish all tasks or reacted correctly to all given information
- None of the test persons could answer all question concerning the traffic news correctly

This underlined that simultaneous communication should be avoided whenever possible, as it may lead to an overload situation for the driver. Hence, it is recommended to delay the communication of less important information until a higher-priority warning has been resolved.

6 Workshop and resulting guidelines

The results were presented to Austrian telematic experts during a one-day workshop. Additionally to the comments which were collected with respect to the results also feedback about the matrix, future trends and recommendations for the formulation of the guidelines were obtained.

Finally, the results from the literature study at the beginning of the project, the results of the simulator study and the recommendations produced by the experts were used to formulate guidelines for the optimum use of in-vehicle telematic systems. These guidelines were compared to international guidelines [6-8] so that at the end several LIVES-recommendations were the outcome of the project:

- Information and warnings have to be as simple as possible; they should include clear instructions for the drivers, what kind of actions have to be taken; it has to be clear for the driver what he/she has to do

Table 5. Recommendations classified into priority levels and modalities

modality priority level	acoustic	visual	haptic
warnings, high priority	sounds earcons and analogue signals ² , but no speech		can be exceptionally used; for instance related to exceeding of limits (speed, distance to the car ahead)
medium priority		symbols and pictures in the direct visual field of the driver	user should train the handling of the haptic signal before using it in real traffic
general information, low priority	sounds and speech (also if much information has to be submitted to the driver)	symbols, pictures, text and maps; information should be understood within two seconds	

Submitting simultaneous information:

- There should be the possibility that priority level 3 information can be turned off in order not to interfere with information of higher priority.
- The simultaneous submission of information to the driver should, if possible, generally be avoided. The possibility to receive information from two different sources is limited and distract the driver from the driving task.
- For certain priority level 3 information speech could be used. But one should not submit more messages from this area simultaneously. Priorities have to be set, submission should happen consecutively.
- Information with lower priority should be submitted in such a way that information/warnings of higher level priority can be understood without any problems.

It is possible to submit the information with the same content multi-modal so that two or more modalities are used and strengthen the information. This can reduce the reaction time of the driver.

- The use of different modalities, especially acoustic and visual, for the simultaneous submission of the same information is possible without disadvantages.

² Sounds - noises, tones: random mapping, the signal has no direct link to the content of the information

Earcons - mnemonic mapping, the signal has a semantic link to the content of the information

Analogue signals -analogue mapping, the signal is according to the information modified along a dimension

- The use of acoustic and visual information in combination with haptic submission of the same information is possible for priority level 2 warnings. There, the acoustic and visual signals support the understanding of the haptic signal

7 Conclusion

The aim of this project was on the one hand to give recommendations for which modality should be used to submit information to the driver while considering the priority level of the content. On the other hand, the goal was to look how simultaneous information submitted to the driver influences his/her driving behaviour. This was done in the light of the fact that more and more in-vehicle telematic systems are today implemented in cars in order to inform, warn and help the driver. Conclusions were drawn as a result of simulator tests as well as from comments by experts in different settings.

Research work in this project provided indications for what modalities should be used for different kinds of information and warnings in order to address the driver in the best way, without interfering too much with the driving task. Acoustic information can be used when low priority information is submitted, as it is usually not too much disturbing. However, this modality also should be used when the driver should (urgently) be warned, because information forwarded via this channel is interpreted very fast. Visual information should mainly be used for low and medium priority information. Like for the acoustic modality it is essential to consider how visual information should be prepared for the driver. Low-priority information can be presented in detail (like maps). The higher the priority becomes the more simple the information should become (symbols). The haptic modality can with advantage be used for the medium priority level.

Simultaneous submission of information should be avoided unless two different modalities are used to submit the same information. If different types of information become relevant simultaneously a "workload manager" or "dialogue manager" could help, that "decides" what information should be presented to the driver first and what information could be suppressed for the moment and provided later, under better preconditions. Although such technical solutions are much sought for, their development must be based on socio-scientific findings, such as the guidelines described in this project. With the help of this research, solutions for both individual systems and combinations of systems can be developed.

The clear advantages in using a simulator was that with the help of this approach many different information and warning systems could be tested (which would be rather complicated in real traffic). Especially for the warnings of priority level 1 the controlled setting of the simulator would not have been achieved in real traffic. The approach allowed to gain basic results concerning the research questions in a cheap and easy way. The sample size was rather small but the statistical evaluation nevertheless showed significant differences between the used modalities and systems. Moreover, the results of the simulation study were discussed with experts and compared with the actual literature in order to validate both the outcomes and the final product, namely the guidelines.

However, more research within this field has to be done. For instance, there is hardly any literature according to haptic information which may be seen as a good possibility for in-vehicle telematics, as this channel is not used so far. More information also has to be gathered about technical solutions to avoid simultaneous submission of information (“dialogue manager”). Furthermore, recommendations and directives for HMI application should be continuously adjusted. Not least, clear instructions for the use of telematic systems, and for training for their use, should be given.

8 Acknowledgement

This project was funded by the project line I2 – Intelligent Infrastructure of the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT) in co-operation with Österreichische Forschungsförderungsgesellschaft mbH (FFG),

9 References

- [1] internal project report: Geven A., Kaufmann C., Risser R., Schrammel J., Sefelin R.: LIVES -LenkerInnenInteraktion mit VERkehrstelematischen Systemen (FACTUM OHG, Vienna, 2006)
- [2] Wickens, C.D., Gordon, S.E., & Liu, Y.: An introduction to human factors engineering (New York: Addison-Wesley Educational Publishers Inc., 1998)
- [3] Lee, J.; Stoner, H. & Marshall, D.: Enhancing interaction with the driving ecology through haptic interfaces. IEEE International Conference on Systems, Man and Cybernetics, 2004, 1, 841-846.
- [4] Rombaut, M.: Prolab 2: A driver assistance system. (Mathematical Computer Modelling, 22(4-7), 1995), pp.103-118
- [5] Kaufmann, C. & Risser R.: Die Effekte der Verwendung eines aktiven Gaspedals AAP in einem Feldversuch in Lund (Zeitschrift für Verkehrssicherheit 4/2003, 2003) pp. 184-190.
- [6] 2000/53/EG: Empfehlung der Kommission vom 21. Dezember 1999 an die Mitgliedstaaten und die Industrie über sichere und effiziente On-board- Informations- und -Kommunikationssysteme: Europäischer Grundsatzkatalog zur Mensch-Maschine-Schnittstelle (Bekannt gegeben unter Aktenzeichen K(1999) 4786).
- [7] Japan Automobile Manufacturers Association Guideline for In-vehicle Display Systems — (Version 3.0., 2004)
- [8] Green, P., Levison, W., Paelke, G., Serafin, C. (1994). Suggested Human Factors Design Guidelines for Driver Information Systems, The University of Michigan Transportation Research Institute (UMTRI)