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Future information and assistance systems for train drivers and evaluation of their usability

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Abstract

Even though train protection systems are used to avoid critical situations, the train driver remains responsible for the continuous monitoring of signal aspects and the derivation of suitable reactions. This requirement persists, although the position of signals shifts more and more from trackside signals to in-cab displays, especially with advanced levels of train protection and automatic train control. Errors in the detection and interpretation of signal- or display information and driver distraction may lead to severe accidents. Aim of our research at the DLR Institute of Transportation Systems (ITS) is to develop innovative concepts of the train driver's workplace in order to secure a safe and efficient railway system that keeps the driver 'in the loop'. Therefore, we follow a user centred approach. The train driver participates directly in the development and evaluation process of new systems supporting the work in the driver's cabin. Using our driver's cabin simulator recently built at the ITS as a flexible vehicle platform in a simulation environment, we are able to investigate the driving behaviour and the train driver's information processing during his or her task. Based on the results, we derive concepts in order to optimize the presentation of necessary information and give recommendations how to assist the train driver. In the present paper, first concepts for supporting the train driver in keeping attention are described as well as our simulation environment and the methodology used.

1. Introduction

Today, train protection systems are often used to avoid critical situations in railway traffic. However, the train driver remains responsible for the continuous monitoring of signal aspects and the derivation of suitable actions. The requirement persists, although monitoring shifts somewhat from trackside signalling to in-cab displays. This shift is due to the ongoing implementation of advanced levels of train protection and automatic train control (e.g., continuous train control system LZB and European Train Control System ETCS, level 2). In these cases, especially mode transitions (like switching from full- to limited supervision or to Class B-systems) need to be anticipated and detected alongside other possible disruptions. Errors in the detection and interpretation of such a signal or display information may lead to severe accidents.

Signals passed at danger (SPADs) are one of the most common and consistent causes of incidents in international railway operations and can be attributed to errors of the train driver. The German railway accident examination center [1], for example, has registered 462 non-technical failure SPADs out of a total 752 reported incidents in 2011. In 2012, out of 723 incidents 415 were SPADs [2]. Retrospective investigations concerning the development of these incidents uncover complex and highly individual interactions between various performance shaping factors. These factors are, for example, type of signal, time of day/ year, weather conditions, driver experience and other person related aspects (see [3]). A closer look reveals that besides these factors errors also often result from a disadvantageous human machine interaction.

Great effort has been put into the prevention of passing signals at warning and stopping aspects by developing assistance or automation technology. Train protection systems serve, for example, to signalise and monitor braking curves, monitor speed restrictions and stops at main signals. They also initiate a forced emergency brake in case of violations. However, although these systems have helped mitigating the severity of consequences of SPADs, they have not eliminated the issue ([4,5], see also [3]). Catastrophic accidents, like the Hordorf train collision in Germany in 2011 [6] or the derailment in Santiago de Compostela in 2013, can still occur if a train driver fails to attend to rail-side signals where such technologies fail or have not or not yet been equipped.

Even with well operating systems in place, inadequate interpretations of and reactions to signal aspects can still cause critical incidents, for instance by “slipping” past a signal at danger and its associated safety overlap or by unjustified releases of train protection braking [3]. In order to prevent critical incidents, train drivers may not entirely rely on the train protection infrastructure and still need to attend signal aspects and speed limits in their environment. In order to fulfil this task, train drivers need to be familiar with the route they are driving, the surrounding area, signal positions, and speed limits. They also need to know the speed restriction sections as, for example, the position of curves, stations, and constructions sites.

Aim of our research at the Institute of Transportation Systems at the German Aerospace Center (DLR) is to develop innovative concepts of human-machine interfaces at the train driver’s workplace in order to secure a safe and efficient railway system that keeps the driver ‘in the loop’. To reach this aim, we follow a user centred research and design approach. This approach is described in the following section.

2. Research approach

2.1 User Centred Design

A comprehensive perspective in railway systems research requires an approach that does not focus solely on technology. It also has to consider human operators as a crucial impact factor. The Rail Human Factors research at DLR follows a user centred design approach. We directly involve the personnel of the railway industry into the design process. With this approach, we pursue the goal to make a valuable contribution towards the user-friendly, safe and smooth rail transport of tomorrow [7]. Our research is based on three key points: understanding the user (operator), evaluating existing systems, and developing and testing new concepts. Moreover, we transfer established methods from psychophysiology and user-centred design to these three key points of evaluation and design and develop new methods (e.g., questionnaires, simulation environments). The approach is described in detail in [7].

2.2 Developing information and assistance systems for train drivers

Based on our user centred design approach, we execute the following steps in order to either develop future human-machine interfaces for the train driver or to refine existing interfaces:

(1) investigate cognitive functions and procedures implied in the train driver’s work,
(2) develop strategies for error prevention and the design of driver assistance and advisory systems in rail traffic,
(3) translate the strategies into first interface design concepts,
(4) evaluate the concepts, e.g., regarding distraction potential, usability, and intuitive interaction,
(5) refine the concepts according to the evaluation results.

In the following, an example for the application of this process will be described.

2.2.1 Enhancement of the German intermittent train protection system interface

Occasionally, in the context of incident and accident analysis, specific aspects in the design of train protection systems are mentioned as possible causes of attention deficits and resulting errors of train drivers (e.g., [8,9], see [3]). In Germany, the intermittent train protection PZB 90 (formerly known as 'inductive train protection') is the most widespread train protection system. Usually a distant signal informs the driver about the signal aspect of an upcoming main signal. He or she has to attend the distant signal and if necessary, regulate the train's speed and actuate the in-vehicle PZB buttons related to the signal aspect. The PZB automatically elicits a forced brake when either the PZB buttons are not actuated or a violation of the required braking curve is detected on approach towards the main signal, after passing a distant signal with a warning aspect.

The PZB is designed in order to mitigate train drivers' errors in attending the distant signals. Still, the in-vehicle interfaces that inform the driver about a necessary reaction are not safe in terms of the signal safety standards of the railway research. The only signal the train driver may rely on is the trackside distant signal. On rare occasions, in-vehicle PZB interfaces can fail, for example when a PZB magnet on the track is damaged. Then the in-vehicle interfaces do not inform the driver about the necessary deceleration and thus does not prevent human errors with regard to an inadequate brake operation. A delayed braking reaction at the main signal can result and endanger for example other trains in the next block section. Thus, signals passed at danger remain one of the primary causes of railway incidents. In order to develop a new concept of assisting the train driver in keeping attention, we followed the process presented in 2.2:

(1) In a first step, we conducted a deeper analysis of the attention processes and the interrelations of causes regarding attention deficits in the context of the train drivers' workplace. The result is a description of the processes in a system related onset model of attention deficits [10]. System design is assumed to be a central influencing factor in the formation of expectations, states, and behaviour of the operators. In addition, a feedback loop is assumed between operator states and behaviour on the one hand and system related and self-related perceptions of the operator on the other hand. Since passivity and reduced vigilance are relevant symptoms of monotony, they are additionally included in the model. Based on the model and a group discussion with train drivers (N=6; work experience 6-37 years), we drew conclusions concerning disadvantageous design features of the PZB. One key result is that train drivers sometimes tend to confirm the PZB buttons as a kind of automatic reaction towards in vehicle PZB indicators lamps without previously attending all necessary information in the environment, especially the aspect of the distant signal. This can lead to severe incidents.

(2) In a second step, we translated the most important conclusion from the earlier analysis into a strategy for keeping the train drivers' attention: all different signal aspects should be actively confirmed with specific responses.

(3) In a third step, we developed ideas about how to design this additional confirmation action as an input for the human-machine interface (HMI) of the PZB train protection. Three ideas (a signal specific shifting lever, touch screen, and gesture input) were selected as most promising from a usability perspective, regarding low complexity of interaction, feedback, and scope of enhancing the functional range. The concepts were discussed with train drivers afterwards (N=12; work experience 10-38 years). They favoured the shifting interface (see Fig. 1). Thus, we chose the manual shifting interface as a new to develop HMI strategy that could replace the current version of the PZB interface. The refined manual shifting system consists of four different positions: three specific positions for each possible aspect of the distant signal and a neutral rest/ idle position (Fig. 2).

(4) The shifting system was implemented as a prototype in our train drivers' cabin simulation environment RailSET® (Railway Simulation Environment for Train Drivers and Operators) and then evaluated. The current version of the PZB was compared to the new alternative shifting

interface. Nineteen train drivers with an average work experience of 9 years took part in the study. Gaze direction, usability, and cognitive load were measured.

(5) Finally, conclusions for refinement of the tested shifting system were derived (e.g., automatic fall-back of the shifting lever in the idle position, embedding in ETCS, and integration of a head-up display). These recommendations can be implemented in a future version of the prototype.

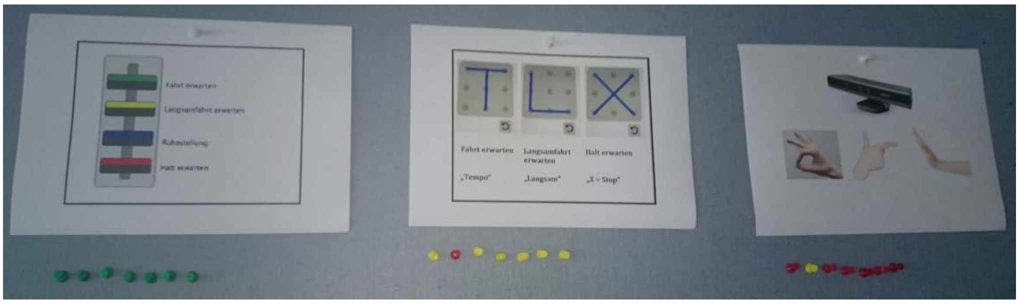

Figure 1. PZB - shifting lever concept (left), touch screen concept (middle), and gesture input concept (right) as concepts for distant signal aspect confirmation in the train protection system PZB. The shifting interface was favoured by the train drivers (green pins).

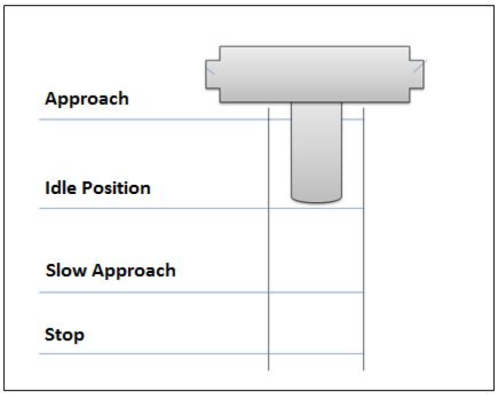

Figure 2. Shifting interface for confirming the signal aspect seen by the train driver. Signal aspects can be: the next main signal shows either approach, slow approach or stop (signal at danger).

2.3 Our simulation environment: The AIM Modular Mockup Rail

In the near future, we will also be able to use our driver's cabin simulator AIM Modular Mockup Rail for executing the steps (1) and (2) in the process of developing new advisory and assistance systems (see 2.2). This will include the investigation of train drivers' cognitive processes as well as the evaluation of prototypes and systems. The simulator has recently been built at the DLR Institute of Transportation Systems (ITS) in the context of the Application Platform Intelligent Mobility (AIM). It is a flexible vehicle platform in a simulation environment with which we are able to implement and evaluate a huge variety of train cabin interior and -control systems. This is a new and unique feature compared to commercial training simulators. Figure 3a shows the perforated plates for mounting any kind of control system, for example, in the form of touch-screen terminals. With the perforated floor plate, variations in the foot pedal- and the driver's seat positions are possible. Figure 3b shows the driver's position and a potential arrangement of control systems around him. With this setup, different arrangements of the control panels in the cabin can systematically be compared. Additionally, a variety of driving environments and situations can systematically be simulated and displayed with a 360° vision system.

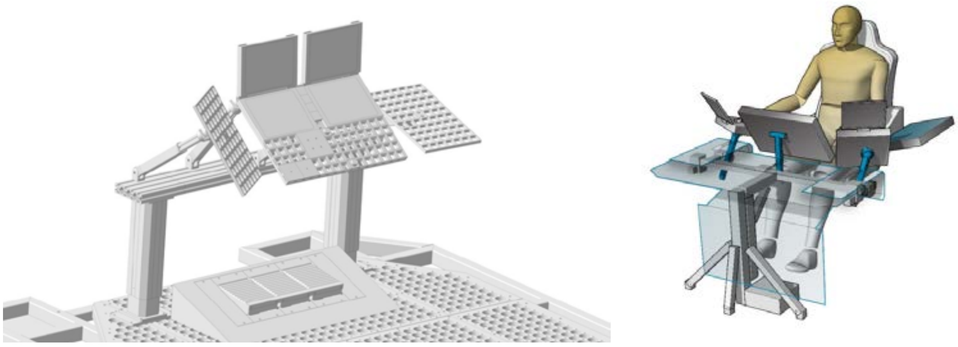

Figure 3. a) perforated plate for mounting interior components, e.g., control panels; b) train driver's position and potential arrangement of control panels

The AIM Modular Mockup Rail can be used in three different setups, namely as a:

1) stand-alone mockup including driver's cab (Fig. 4) with either screens or a projection system displaying the virtual driving environment in front,
2) mockup in the Virtual Reality Lab at the DLR Institute of Transportation Systems with a 360°vision system, or
3) mockup in the Motion Simulator at the DLR Institute of Transportation Systems, mapping real dynamics of acceleration onto the virtual driving environment for a highly realistic driving experience.

Figure 4. AIM Modular Mockup Rail including driver's cab

With our AIM Modular Mockup Rail, we are able develop new approaches for future information and assistance systems. We can also conduct evaluation studies of existing control panels or concepts in development. In collaboration with rail operators and manufacturers, we can implement any cabin design in our simulation environment and test the usability and ergonomics. The mockup can also be used for evaluating light rail control systems and cabin design.

3. Perspective

With the ongoing rollout of ECTS, transitions between different train protection system and mode transitions will be relevant. This is accompanied by high demands for the train drivers. In an upcoming study, we are going to develop assistance for the train driver for coping with theses transitions and maintaining a high level of situation awareness concerning the actual system state and the actual protection or automation level. As in the previous studies, we are going to follow the steps of the user-centred design approach described in chapter 2.2. The prototype of the developed assistance concept will then be evaluated in our simulation environment AIM Modular Mockup Rail.

Aditionally we are planning to conduct evaluation studies in collaboration with rail operators and manufacturers using the AIM Modular Mockup Rail. We offer systematic evaluations of, for example, usability and user experience, ergonomics, intuitive interaction, and efficiency of systems or concepts in development. We pursue the goal to give recommendations for further development of the respective systems and the cabin design as a whole.

4. References

[1] Eisenbahn-Unfalluntersuchungsstelle des Bundes (2012). *Eisenbahn-Unfalluntersuchung Jahresbericht* [Railway accident analysis annual report] 2011. Bundesministerium für Verkehr, Bau und Stadtentwicklung, Bonn, Germany. Online: http://www.eisenbahn-unfalluntersuchung.de/EUB/DE/Publikationen/Jahresberichte/jahresberichte_node.html

[2] Eisenbahn-Unfalluntersuchungsstelle des Bundes (2013). *Eisenbahn-Unfalluntersuchung Jahresbericht* [Railway accident analysis annual report] 2012. Bundesministerium für Verkehr, Bau und Stadtentwicklung, Bonn, Germany. Online: http://www.eisenbahn-unfalluntersuchung.de/EUB/DE/Publikationen/Jahresberichte/jahresberichte_node.html

[3] Giesemann, S. (2013). Automation effects in train driving with train protection systems- assessing person- and task-related factors. In: N. Dadashi, A. Scott, J.R. Wilson, A. Mills. (Eds.). *Rail Human Factors. Supporting reliability, safety and cost reduction* (2013 Proceedings), pp. 139-149. London.

[4] RSSB - Rail Safety and Standards Board (2012). *RSSB Annual Safety Performance Report, 2011/12 - A reference guide to safety trends on GB railways*. Rail Safety and Standards Board, London.

[5] RSSB - Rail Safety and Standards Board (2013). *RSSB Annual Safety Performance Report, 2012/13: A Reference Guide to Safety Trends on GB Railways.* Rail Safety and Standards Board, London, United Kingdom. Online: http://www.rssb.co.uk/SPR/REPORTS/Documents/ASPR_2012-13_FullReport.pdf

[6] Eisenbahn-Unfalluntersuchungsstelle des Bundes (EUB) (2011). *Unfallbericht Zugkollision Überleitstelle Hordorf / Strecke Magdeburg Hbf – Halberstadt am 29.01.2011* [Accident report train collision Hordorf], Bundesministerium für Verkehr, Bau und Stadtentwicklung, Bonn.

[7] Naumann, A., Grippenkoven, J., Giesemann, S., Stein, J., and Dietsch, S. (2013). Rail Human Factors-Human-centred design for railway systems. *12th IFAC Symposium on Analysis, Design, and Evaluation of Human-Machine Systems*, Las Vegas, August 2013.

[8] Baysari, M. T., McIntosh, A. S., and Wilson, A. R. (2008). Understanding the Human Factors Contribution to Railway Accidents and Incidents in Australia. *Accident Analysis and Prevention, 40*, 1750–1757.

[9] Edkins, G. D. and Pollock, C.M. (1997). The Influence of Sustained Attention on Railway Accidents. *Accident Analysis and Prevention, 29* (4), 533-539.

[10] Giesemann, S. and Naumann, A. (2015). Zugsicherungssysteme – Assistenz für Triebfahrzeugführer? [Train Protection Systems – assistance for train drivers?] *Kognitive Systeme, 2015-1.* DuePublico.