Development and Optimization of an HMI for the Remote Control of Automated Trains in Case of a System Disruption: Work-in-Progress

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Important Note: The title of the previously submitted extended abstract was changed from *"Remote Control of Automated Trains in Case of System Disruption"* to the current version, and the name of the authors are updated.

ABSTRACT

Rapid technological development in digitalization and automation entails fundamental changes in transportation systems. However, increasing level of automation raises challenges for human`s role in future transport systems. The EU-project Drive2theFuture investigates the requirements and preferences of transportation users, operators and passengers of the future in order to simulate, regulate and optimize automated use cases and to increase awareness and acceptance. This paper presents a thorough literature review on rail human factors and is a of work-in-progress for a case study about the development and optimization of a Human-Machine-Interface (HMI) concept for automated railway operations. An HMI prototype is being developed in order to provide remote manual intervention in cases of system disruption for the operation with the grade of automation (GoA) 4. A priori risk assessment is conducted in order to identify the risks and mitigation strategies. Besides the HMI strategy and the equipment to be used, the study also explores the requirements of the new job profile, which will be a mixture of traditional signallers and train drivers. The HMI will be tested in the Railway Operations laboratory (EBuEf) at the Technical University of Berlin using the electronic interlocking and the H0 scale model. Train drivers and signallers will participate in the experiments. The performance and the acceptance of developed strategy will be evaluated based on related Key Performance Indexes by using user experience surveys, direct observations, event diaries and user interviews.

Keywords: Human factors, human-machine-interface, railways, automation.

1. INTRODUCTION

In order to achieve the 60 % greenhouse gas emission reduction target of the EU Commission, maintaining a dense railway network and enabling around 50 % modal shift to rail by 2050 is envisioned (EC, 2011). These goals demand capacity increase and more efficient utilization of the existing infrastructure while maintaining a high level of safety. It is widely accepted that the innovation and deployment of smart mobility systems based on digitalization and automation are needed to meet the demands of these ambitious goals.

2. BACKGROUND

Benefits of automated driving in railways include operational efficiency and cost savings by reduction of operator error and dwell times in stations as well as increase in energy savings and the stability of the schedule (Pachl, 2017). The grade of automation (GoA) concept classifies various degrees of automation which are defined according to the functions and responsibilities of the system and staff (UITP, 2012). The GoA 3 and 4 correspond to higher automation in which the human intervention is absent or minimal. However, automation may lack the flexibility and problem-solving skills of human operators in cases of novel situations. It is expected that humans are likely to remain vital to autonomous system performance for many years (Parasuraman et al., 2008). Therefore, the challenge of designing the optimum combination of automated train operation and the human presence arises. The question of the roles, skills and workplaces of the future railway operators should be answered in order to ensure the safety and efficiency of future railway systems. This paper aims to describe the development steps of a Human-Machine-Interface for the remote manual control of driverless trains in case of system disruptions for the GoA 3 and 4. The strategy relies on the optimization of existing HMI systems, as well as iterative user testing and training.

2.1 Rail Human Factors

As the need to shift the mobility from private to public transport and the potential performance and attractiveness of rail transport increases, governments, academia and the rail industry focus more on the increased performance of the system and its users as well as the contribution of human errors and system components to safety (Wilson et al., 2006). This is mainly addressed as rail human factors.

Understanding train driver behaviour and consequences for performance are some examples of research questions in this area. The research on the driving task and high-risk events such as signal passed at danger is one of the earliest examples of rail human factors studies. Hamilton et al. (2005) aims to understand the train drivers` interaction with infrastructure features by utilising cognitive task analysis. Maag et al. (2012) incorporates in their study a driving simulator in order to assess drivers` performance combining the objective data from the simulation and the observer`s subjective ratings. Besides the attempts to understand the operators` role and performance in the context of interaction with in-cab (Verstappen et al., 2017) or control room environment (Cordiner et al., 1999), there are studies for reducing the human error or to increase their performance by understanding and optimizing their job design and workload. The literature of the rail signalling workload is more extensive than that of train drivers. Some of these studies seek to assess the mental workload of signallers or drivers by using various self-reported measures (Thomas-Friedrich et al., 2017) or using physiological measures such as heart rate and brain activity (Brookhuis et al., 2010) or by combining both methods of subjective self-reports and physiological measurements (Crowley et al., 2018). Balfe et al. (2017) utilises the output of on-train-data-recorders to extract train driver taskload. Situation awareness (Golightly et al., 2009), user experience (Milius, 2017), expertise and competence (Rashidy et al., 2018), (Brandenburger et al., 2017) teamworking and coordination (Andreasson, et al., 2019) and reasoning (Jorna et al., 2007) are other human factor concepts that are adapted to railways.

The increasing automation in the rail industry encourages researchers to study its relations to human factors. Main issues include task definitions and transition of future operators` roles, situation awareness and workload. Robinson et al. (2015) investigates the types of train driving tasks and situational factors that might lead to low workload and reduced driver performance. Experience of monotony, vigilance and fatigue under varying task demands or high automation are studied in the works of Dunn et al. (2011), Spring et al. (2009) and Brandenburger et al. (2017). Some studies investigate the effect of the Automatic Warning System and European Rail Traffic Management System on the behaviour of the train drivers (Naghiyev et al., 2017), (Mcleod et al., 2005). Nora (2010) and Hayden-Smith (2013) examines the effect of automation in the rail signalling environment. Series of studies looked into the effect of automation in railway operations on signaller and train driver workload and on railway staff`s tasks in future systems (Brandenburger et al., 2018). Systems such as Automatic Train Protection (ATP) and Automatic Train Operation (ATO) in GoA 2 replace some of the manual tasks of GoA 1, while keeping the driver onboard for monitoring track integrity and completing tasks such as door closure and manual intervention in case of emergencies. Most of the above-mentioned studies focus on this intermediate level of automation. The GoA 3 eliminates the need for continuous human supervision while keeping a train attendant onboard. The attendant is added as a layer of flexibility to the automated system which is able to operate on its own. With the GoA 3 and 4 operation, the question of whether such layer is necessary arises. Additionally, the role and expertise of the attendant as well as the properties of their workplace are the issues that need to be addressed. Brandenburger et al. (2018) presents such example of remote supervision and manual control by a train operator as a new job profile.

2.2 Principles of efficient HMI development

The related literature emphasizes the human-centric approach for an HMI design besides the technology required for such systems. The HMI design can affect human performance, error and the workload experienced by the user. User expectation, previous training and experience should be considered to reduce human error. Naumann (2010) underlines three key methods of user-centred design, namely understanding the user, evaluating existing systems and testing new systems. There have been studies on improving the design of train cabs and its information interfaces, with the technical issues as a focal point (Bondavalli et al., 2009), (Schwenke et al., 2013), (Ruiz-Rodriguez et al., 2010). According to Kauppi et al. (2006) the interface design should support the human operator in the loop and avoid automation surprises. Authors highlight that designing human-centred interfaces for rail dispatchers is essential for an efficient and safe traffic control and for making sound decisions in case of severe traffic disturbances. Gerbino et al. (2002) demonstrated that the interface of a cab signalling system had a direct effect on the performance of the operators. Brandenburger et al. (2018) assessed the subjective acceptance and usability of an HMI system by using self-report surveys. Findings of the study suggest that the variety of information sources and communication options are important for the user acceptance of the system. To summarize, previous research on HMIs considers ergonomics, functionality, safety and aesthetics as the important features of an HMI. The evaluation of existing systems can be done by interviews, observation methods, questionnaires and heuristic models. To analyse and evaluate existing systems is a useful method for optimizing the HMIs and a first step to develop a system that addresses to issues that exist today.

3. OBJECTIVES AND APPROACH

The aim of the EU-project Drive2theFuture (D2tF) is to determine the needs and expectations of traffic participants facing the deployment of automated transport. D2tF takes a comprehensive approach by investigating all transport modes and all types of users. This paper summarizes the research attempt on development of an HMI through optimization for specific use cases in the rail transport domain. The term “automated train” will be used in this paper to describe the driverless train operation with GoA 3 and 4. At a later stage the use cases will be tested in a pilot study where the automated train operation will stop due to a system disruption and an operator in the operations centre will manually drive the train from the place of disruption to the next station or a safe location using remote HMI. The users of the pilot will include railway students as well as train drivers and signallers.The objective is to evaluate alternative HMIs to optimize existing practices through an iterative process for increased acceptance of future sytems. This process includes the optimization of HMI elements, information interfaces as well as the necessary tasks of the operator. The developed HMI will be demonstrated in the pilot site, the Railway Operations Laboratory at the Technical University of Berlin (EBuEf). The laboratory facilities include electronic interlocking, H0 scale model as well as a control centre with a dispatchers` workplace

3.1 HMI Optimization

The first step of the HMI optimization is to identify existing systems and good practices. The benchmarking method includes the HMI of the pilot demonstrator as well as active or prototypical vehicles of different manufacturers or transport systems such as the Nuremberg driverless metro project RUBIN. A questionnaire for data collection, developed within the project framework, that allows a comparison and description of various attributes and functions of the HMI, is used (Mathis et al., 2020). The questionnaire addresses attributes such as the task description, automation levels, feedback on the automated vehicle status as well as audio-visual design properties. To perform a benchmarking, defining the attributes to measure and obtaining relevant information of these attributes is crucial. For this reason, an extensive literature review as well as interviews with relevant contact persons of the analysed systems are used in order to get a better view of the system. Following the benchmarking of HMIs, best practices are identified using expert-rated analysis of the benchmarking results. In the next step, the HMI concept will be further optimized through task analysis and iterative assessment on the pilot site.

3.2 Priori Risk Assessment

The risks related to the user acceptance of autonomous vehicles (AV) are being explored with the use of the extended FMEA methodology (Bekiaris et al., 2005) within the D2tF project (Bekiaris et al., 2019).

Understanding the factors that affect AV acceptance is the first step to increase the acceptance of all stakeholders involved. The risks address to both the pilot test and the potential real-life implementation of the system. The key risks are categorized as technical, behavioural, legal and operational. Selected risks will be rated according to various criteria and possible mitigation strategies will be identified. Some of the identified risks are as follows: Technical; Cybersecurity, impractical pilot test due to high complexity and costs, lack of various control elements of remote HMI compared to in-cab driving desk. Operational; Increase of unemployment, lack of hygiene and care of the automated trains. Legal; Liability of incidents, pilot test issues regarding approvals and delays, standardisation issues. Behavioural; Bias of current railway operators against the automated vehicle systems, low passenger acceptance due to automation-trust issues, user`s cost of new services and willingness to pay, loss of awareness while remote driving, HMI prototype evaluations may not provide conclusive evidence on long-term user experience in real world.

3.3 HMI Design Concept

As part of the HMI development, an initial design concept of the workplace and tasks of the remote driver is determined. One of the objectives of the pilot tests is to investigate the suitable user groups and the impact of relevant training. The proposed task will make it necessary that the operating person is a mixture of train driver, during manual control, and signal box operator, during the automated operation. A literature review on the tasks of train drivers and signal box operators (i.e. signallers) is conducted. Firstly, the tasks as given in the Deutsche Bahn regulations (DB Netze, 2018) are analysed and allocated according to train driver and signalling job profiles of the pilot plan. Secondly, an extensive literature review of the cognitive task analysis of train drivers and signallers is conducted. Identifying the information driver needs to be aware of and process at all times is crucial for the design of the information interfaces for the developed HMI. Some examples of train driver information requirements are the exact location of the train, track characteristics, speed restrictions, wayside signs, awareness of roadway workers in vicinity as well as the people on platforms (FRA, 2009). For the rail dispatchers the task analysis allows for identifying sources of complication and complexity. According to Roth (1998) some of the important challenges for the dispatchers are the management of delayed trains and estimating the time required for unplanned activities, performing prioritization and triage as well as high attention and communication demand. The findings of this analysis are reviewed and used as an input to optimize the initial design concept. Main task of the remote driver is to manually take-over the control of the train in case there is a take-over request placed by the system. The task includes start and stop functions, door closures, speed adjustment, on-sight driving and communication with passengers and other stakeholders. Operator state can be by default monitored with a dead-man-device to ascertain their alertness. Additionally, a maximum speed restriction can be imposed on the remote driving based on the route/type of train. The information which the operator requires in order to be able to complete the assigned tasks are determined. The key components are the real time front-view of the train on a monitor, a driver desk with haptic control elements as well as the dispatcher`s workstation. In the next step, the elements of the HMI are rated based on their need for optimization or change. This evaluation will continue throughout the iterative testing in order to finalize the standard elements.

3.4 Iterative User Testing

Identified HMI concepts will be iteratively tested with different user groups and different test scenarios. The user testing will take place in the railway operation and test centre of the Technical University of Berlin. The test will consist of two phases. The first phase will test the initial concepts and optimize the HMI prototype with the participation of railway students. In the second phase train drivers and signallers will be included to the iterative testing. The objective is to compare the different user groups as well as assess the impacts of relevant training schemes developed within the D2tF project framework.

3.5 User and System Assessment Methods

The evaluation aims of the project are to get feedback from users in terms of acceptance and user experience, assess the subjectively perceived level of workload and the effect of the workplace on the performance of individuals. There will be four main groups of evaluation tools, namely user surveys, direct observations, event diaries and interviews. The user surveys include self-reported questionnaires such as user profile, user experience (UEQ) and mental workload assessment. User behaviour and user performance will be assessed by direct observations as well as related objective measurements. Qualitative analysis will be conducted based on workshops and interviews. To be able to analyse and consolidate the results of the different pilot tests of the project, a common framework is developed within the D2tF project. Every evaluation variable will be matched with indicative Key Performance Indexes that covers a wide area of user acceptance, safety, security, socio-economic and environmental aspects and traffic efficiency.

4. CONCLUSION AND OUTLOOK

This paper presents a work-in-progress for the development steps of a Human-Machine-Interface for remote control of automated trains in case of a system disruption. A systematic review is conducted on the area of rail human factors and the principles of efficient HMI development. The review reveals the challenges and new requirements arising with the increasing level of automation. An optimization process using a benchmarking method, task allocation and a priori risk assessment resulted in an initial design concept. Requirements of the tasks and the principles of the HMI strategy are determined. Optimization of the HMI concept will continue with iterative user testing. The HMI concept will be evaluated for different user clusters and use cases.

ACKNOWLEDGEMENT

This paper has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 815001.

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