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The Influence of Human Behaviour on Automated Train Operation

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Abstract: Automation in rail transport is changing the working conditions for train drivers as well as train dispatchers. Since the monitoring and operation of interlocking devices has largely been summarized in operating centres, the automated driving of and routing of trains is just beginning to develop. In applying new railway management and operation technologies, the question of complete controllability and security without interruption is becoming increasingly important: How can those responsible for safe railway operations exercise and assume their responsibilities under the new working conditions?

In contrast to aviation, there are still relatively few research findings on the influence of human factors in railway operations. This is despite the fact that the introduction and implementation of new automation technology has made the areas of responsibility of employed personnel remaining in the system significantly larger. It can also be said that automating processes, which are designed and created for human perceptions, decisions and actions, may generate uncertainties in the newly designed workstations.

The influence of human behaviour can be examined and investigated specifically by using simulators, which allow a realistic reproduction of socio-technical processes. In view of the imminent development of automated train operation on conventional railway lines, human behaviour was examined on a specially adapted simulator. In addition to the objective of gaining insights and new findings into the reaction times of train drivers in Semi-Automated Train Operations (STO), further useful findings and conclusions of interest could be made for the development of these new forms of train operation. Both quantitative and qualitative methods were used in these experiments.

Beginning with the investigation of Situational Awareness (SA) of train drivers and dispatchers, a method for Human Factor research using data samples of simulators has been developed. With this project of simulation-based research, a contribution should be made to maintain or even increase the high level of safety of the railways in the future, using new forms of operation and technologies. Furthermore, the responsible safety officer within the confines of the basic regulations EU 402/2013 and EN 50126: 1999, which demand the inclusion of human factors in the development of new railway technologies, should be realised

1. INTODUCTION

1.1. The impact of automation on railways

Over the last 20 years, there have been important developments within the Swiss railway system caused by automation. Interlocking systems and devices have been automated and centralized in operation control centres. In the meantime, most of railway stations have no additional staff controlling and ensuring trains with manual rail network operation. However, the development in rolling stock automation has been different: On the one hand are used lots of driver assistance systems. On the other hand, automatically operated trains are still the exception today, even if it would be technically feasible.

These changes in the domain of railway operation procure new conditions in the duties of train operators and train drivers, especially in terms of their collaboration. Former kinds of interaction, which were important for a smooth operation schedule, no longer exist. Today, both groups of staff work independently due to the modernisation of signalling technology. Only in cases of emergency or in extraordinary situations, train drivers and operators are required to communicate directly by radio or by telephone.

In regard to the duties of train drivers as well as train operators, the automation process has caused and still causes to this day a certain shift from operational functions up to monitoring functions. This development creates new challenges in railway operation on the system level. The disappearance of manual duties may cause a loss of system knowledge by the staff, which could have an important impact on their potential behaviour and handling of extreme cases such as disturbances or emergencies. Both of the aforementioned professions must be able to act, react and multi-task at a high level.

1.2. Development of Automatic Train Operation ATO in open railway systems

To understand Automatic Train Operation (ATO), it is relevant to cover the five different grades of automation (GoA) in railway systems. Trains in Switzerland usually operate with

GoA1, which means, that the train driver is responsible for setting the train in motion, door closure, train stoppage and operation, in case of disruption [17]. Furthermore, there is an automatic train protection, which protects the valid movement authority. The next step of automatization is the GoA2, the semi-automatic train operation (STO). In this case, the system starts and stops the train, the train driver monitors the trackside conditions and controls the door closure process.

The Swiss Federal Railways have created a successful pilot test with a train in STO mode in December 2017 [6]. The train was accelerating and stopping the train automatically on a ETCS Level 2 track. The next objective to test is the STO mode on available tracks to collect more data about the interactions between the systems. An important requirement would be the acceptance of the customers and train drivers. In light of autonomous metro systems, it is conceivable that there will be an acceptance for ATO train systems, if a high safety level can be guaranteed

Tab. 1. Synopsis of Grade of Automation in railway systems ([6] adapted)

Grade of Automation (GoA)	Setting train in motion	Train stopage	Door closure	Operation in event of Disruption
0 (not rain protection)	Driver	Driver	Driver	Driver
1 (with train protection)	Driver	Driver	Driver	Driver
2 – STO	System	System	Driver	Driver
3 – DTO (ATO)	System	System	Train attendant	Train attendant
4 – UTO (ATO)	System	System	System	System

In the long-term, trains will be operated in DTO (Driverless Train Operation) mode with a train attendant on board for interventions in event of disruptions (e.g. door disruption). Whereas trains without passengers, like cargo trains or service drive, will be operated in UTO (Unattended Train Operation) mode. Both ATO (DTO / UTO) modes will change the way of operating radically: The pre-condition is the full adaption of ETCS Level 2 on the entire network. Furthermore, the disruptive development will change the tasks of train drivers entirely. Training and regulations must be adapted to the new system. The large return of investment could be worth it, due to the numerous benefits of ATO. For example, the capacity of tracks will increase more than 30%, while the power consumption will be reduced up to 15%. As we see in Nurnberg, the track capacity could increase up to 50% [6].

In his paper, "Towards Automatic Train Operation for long distance services", Daniel Emery explains that there are no ATO systems in operation on long distance railways outside city areas, even if the European Train Control System (ETCS) would be able to use it. In actuality, ETCS is limited by the speed of development of its superior system ERTMS. Emery explains that in a wider geographical scope with complex railway nodes and critical junctions, the set of data should be enhanced. [1]

To prove the feasibility of new automation systems in open railway systems, an integrated simulation could be the solution for a safe and reliable development. Risks can be prevented earlier, which increases the chance of success.

2. HUMAN FACTORS ON RAILWAYS

Human behaviour cannot be measured in an exclusively analytic or linear way. The formation of human decisions is often based on a high level of complexity and therefore, it is not possible to quantify the safety-critical impact of train operator's and driver's professional experience. However, in cases of emergency, this experience could have a crucial impact on the handling of the event.

Currently, there are not many studies and investigations about the effect of human factors in the railway system [4]. However, some authoritative legal bases specify the consideration of human factors. Such as those, the specification for railway application EU 50126 about the demonstration of reliability, availability, maintainability and safety (RAMS), chap. 4.4.1.1, requires special attention to the human influencing factors. For the development of new technologies and technical systems on railways, the Ordinance EU 402/2013 of a common safety method requires in its chap. 2.1.2 for the system definition explicitly states the inclusion of human components.

For a safer railway operation in the future, it is necessary to develop new systems taking into account the complete legal framework. This legal framework includes all legislation, standards and guidelines for development, operation and maintenance.

2.1. Investigation of human behaviour using simulators

The majority of safety-related situations in railway operation shows a large number of interactions. This is the reason why they are too complex to be verified and investigated in an analytical way. One of the most effective methods of investigating human behaviour in exceptional circumstances is the application of simulators which allows for a rich and detailed data collection. A simulation model can be connected with specific hardware (e.g. driver cabs or operator interfaces). In this way, there can be realized specific hardware or software-in-the-loop simulations and tests [11].

Against the background of automation, more results about emerging behaviour of interacting components as well as future railway operators in abnormally situations are necessary. Failures can be created by human or technical parts of the system. Human failures and behaviour effects, known as human factors, influence the system mainly within the operation. In majority of cases, human failure will be detected and absorbed by technical railway safety installations. However, some occasional malfunctions in connection with special environmental or operational circumstances may be too intractable for the responsible staff and can lead to a dangerous incident or even to an accident. Comparable to the hardware or software in-the-loop-approach, simulators can be used to realize a new human-in-the-loop approach. With this approach, it is possible to close an important gap in the future safe system engineering.

In aviation, human behaviour is continuously monitored and investigated by analytical or executable simulation models. As the railway system, in a certain level of automation, has similar conditions for the staff, a great deal of experience in aviation can be used also for train drivers and train operations in the meantime. Furthermore, the technical environment of railway operation can be modelled in a very realistic way, so that the test persons can work similarly to those under real conditions. The repetition of simulator experiments can be conducted under extreme conditions which allows them to be repeated until to have a representative sample for evaluation by statistical methods can be or obtained. This is an example of how human reactions can be investigated within certain limits such as on the occasion of rare events, which is not possible in the real world.

Figure 1: The holistic simulator for train drivers allows for the investigation of human performance under special and extreme conditions, which is not possible in reality. The repetition of such experiments makes it possible to apply statistical methods to allow for the evaluation of the collected data

Currently there are only a few simulators which allows for the participation of train drivers and train operators into under the same experiment. However, in order to study the complex relations and interactions between both categories of staff as well as human-machine interactions, an integrated simulation system containing both, a driving simulator and an interlocking simulator, is required [13]. Such an instrument would be an innovative experimental platform for a new type of human factors investigation on railways to detect vulnerability issues at the system level. The results of these experiments could contribute to risk analysis, examinations of experts and accident prevention. Accidents which already occurred could be investigated according to the reasons or conflict chain in a more profound way using this human embedded simulator. Near Bern, Switzerland, a laboratory with a complete simulator for this purpose of human-in-the-loop testing has been developed.

The workplaces and user interfaces of the driving simulator as well as the interlocking simulator must be designed in a very detailed way to allow for the test participants to become familiar with the surrounding work environment. The signal boxes and driver cabs must be enclosed, so that the participants can become sufficiently absorbed into their work and be allowed the freedom to exhibit their natural behavior concerning habits and routines. An important piece of equipment in this setting, is the motion base, which simulates the vehicle dynamics [11].

In actuality, the laboratory is validated by experimental test drivers before the simulation tool kit can be used for investigations. For a large number of findings pertaining to a human factor's potential, many of which cannot be foreseen, they offer an important contribution to the risk analysis and accident research.

Figure 2: In the DESM laboratory, a complete simulator for human-in-the-loop testing has been developed. The simulator can be configured according to the needs of the experiments. A driving cab of a Swiss locomotive type Re 460 is pictured above. The subjects are situated in an exact replica of their workplace environment, where they can perform as they do in real life work situations

2.2. *Development of a new method to investigate Human Factor on railways*

According to an analysis conducted in Switzerland, the interaction between train operators and train drivers has a casual effect on the course of events. For example, non-safety-critical information, such as the scheduled time of departure, can lead to serious confusions [16]. Problems with different languages and language barriers and the possibility of misinterpretation and miscommunication of rules may also have an important impact on safety. Currently, train operators and train drivers no longer have immediate personal contact in their collaboration due to new technologies in the area of signaling and train control systems [9]. However, in exceptional cases, such as if there are technical disturbances of safety-critical components, the oral communication may have a crucial impact.

Using the developed human-in-the-loop simulator, the train drivers and train operators performance can be measurably investigated and evaluated. One important component of this investigation method is the approach of situation awareness (SA) by Endsely [2], which is applied especially in aviation and considered to be very helpful [3][7][15]. Based on the observed and evaluated behavior of the test participants and according to previously specified dilemmas, (credits were awarded on the basis of the previously specified criteria for the observed behavior), the SA performance score is calculated by adding the points obtained for handling of the eleven dilemmata. Additionally, the Situation Awareness Rating

Technique (SART), is used to permit the subjects to evaluate their own situation awareness [10]. Contained within this validated questionnaire are ten items about Demand from Attentional Resources (D), Supply of Attentional Resources (S) and Understanding of the Situation (U). The total score is obtained using the following formula:

SARTtotal score = U + S – D [14]

To develop a common understanding of certain safety-relevant situations and scenarios, it can be useful to replicate them under real conditions. This first step of the investigation ensures that all possible influencing factors can be assessed by experts and considered into the future experiments in a proportional way. Such an exploration in real-time allows for a performance through the accordingly case step by step attended by experts.

Figure 3: Exploration of a case study under real conditions attended by experts to identify a common baseline. All the relevant influencing factors can be analyzed in a detailed way and must be configured correctly for use in future experiments on the simulator.

After a detailed analysis under real conditions, the cases will be described using formal methods such as Petri Net or class diagram. Based on the specific model of the situation asked for, a screenplay for the future experiments using simulators is developed. This script contains the needed configuration of the simulator as well as service instructions for the operator of the simulator. Furthermore, the proper and necessary questionnaires will be prepared with the self-rating scores (SART) as well as all the needed documents for the future subjects.

During the next step, the experiments with the test persons on the simulator will be organized and conducted. During the performance of each experiment, a large data sample is logged and compiled by the simulator, containing every state of the drivers cab and the infrastructure (signals, switches, level crossing, other safety equipment, environment, etc.). After the test ride, the subjects are invited to the collection of qualitative data and filling in the questionnaires.

All the collected data will be made anonymous to protect the privacy of the subjects. Finally, this data can be evaluated according to problem statements, hypothesis and research questions. Based on the data evaluation, new conclusions about special safety-relevant situations in railway operation can be drawn which can be useful to develop measures to reduce risks or to maintain a desired safety level.

In the DESM-laboratory, the behavior of train drivers has been investigated and evaluated by several passes on the simulator instrument. While SA performance (evaluated by the expert based on the previously specified criteria for the observed behavior) and SART self-rating score are the dependent variables, semi-automated train operated (STO) is added as a stress factor, taking into account that all the test persons may not be familiar with driving a train in this new mode.

Figure 4: The operator of the simulator (above, right) is accompanied by an expert, who is observing and critiquing the performance of the subjects according to the screenplay. This way of qualitative data collection serves two purposes; to calculate the SA performance score and to verify the evaluation of data in certain cases based on the results of the expert's opinion

3. CASE STUDIES ABOUT REACTION TIMES

For the investigation and the evaluation of complex issues such as the handling and operation in cases of emergency, for example, the application of both qualitative and quantitative methods are needed. Formal methods are used to describe the system and the concerning situations. Based on this formal description, simulators serve this purpose for human-machine investigations. With the increasing automation in the railway sector, more studies about the impact of human factors in the system of the residual staff will be required as the areas of responsibility become increasingly greater.

One important idea to think about is whether or not reaction times were increasing when train drivers no longer drive themselves because the trains work automatically. Is it reasonable to assume that drivers of trains in the STO mode (Semi-automated Train Operation) in cases of need, can intervene with the same speed like they would drive manually?

In the DESM-laboratory, new case studies were conducted regarding train driver's reaction times under different conditions and comparing the STO mode with manual driving. The test persons had received the task to lead a passenger train on the Swiss route close to the lake of Geneva between Cossonay – Lausanne – Palézieux – Châtillens. During this ride, several issues were observed and evaluated. In the first part up to Lausanne, all the subjects were required to drive manually. During this sequence, an incident already occurred by an unexpected signal at danger demanded a quick reaction from the test persons. In a second part of the tour, some of the subjects had to lead the train in the STO mode, in which the train was driving automatically while the responsibility of the drivers was the same as today: the subject had to observe the route without driving themselves. After passing some stressful events as the machine showed another way of driving like the drivers normally would have done, an obstacle appeared on the track before the train. This occurrence required an immediate intervention by the drivers. The logged data made it possible to compare the reaction behavior between subjects operating in the STO mode with test persons driving in the traditional, manual way.

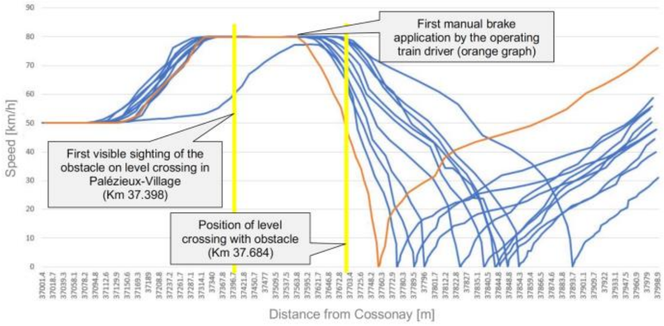

Figure 6: Example of an evaluation of data of 10 test persons operating in semi-automated train operation STO (blue graphs) comparing with a reference train driver (orange graph) working manually as usual. In this situation, the drivers came upon an obstacle on the track before the train. All the subjects in the STO mode showed a higher reaction time as the reference driver. Use of simulators is the only way to collect and evaluate such type of data to benefit new conclusions about human behavior in safety-relevant situations.

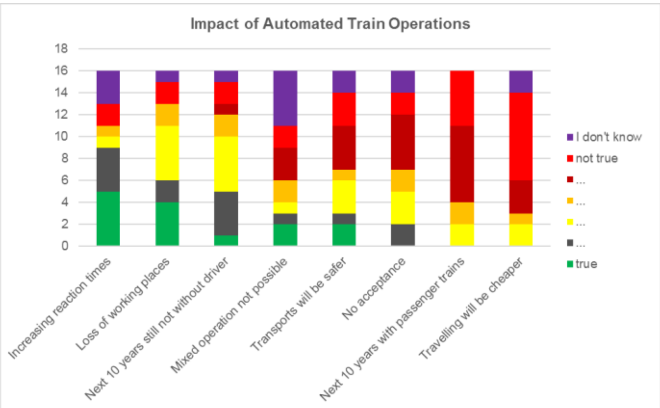

Figure 7: Example of the evaluation of qualitative data regarding the impact of Automated Train Operation ATO, according to the opinion of the subjects. Most of the subjects thought that reaction times of train drivers will increase, when they no longer drive themselves anymore. There is a fear of loss of work places with the development of ATO. While transport will not be safer according to the opinion of the test persons, they do not believe neither that acceptance could be a problem of ATO, nor that travelling will be cheaper in future.

4. RESULTS AND CONCLUSIONS

A laboratory for human-in-the-loop testing with train drivers and a complete configurable and adjustable simulator has been built. It consists of locomotive cabs, driving and track environment animation on 3D screens and signaling and interlocking equipment, coupled via interfaces. The simulation environment can be implemented by using different track and signaling conditions, different operational and environmental conditions, according to the needs of investigation. The train operations can be simulated close to reality. The simulator is equipped with a motion base to replicate the driving dynamics of the train, which allows the test persons to feel like they are driving a real train.

By using this advanced methodology, risk analysis of incidents and known weaknesses can be conducted. Furthermore, the existing and possible accidents analyses benefit to explain the reasons or chains of causes, which leads to the dangerous events. Human reliability and factors can be qualified and quantified considering safety and security risks of management systems as well as human and process performances.

Finally, according to Emery, one of the most important challenges in the future regarding semi-automated Train Operation (STO) is how to find motivated and skilled train drivers if their tasks are reduced when initiating the driving system, to observe the journey and to trigger the emergency brake in some rare incident. A possible solution could be to keep the driver "in the loop", by driving their trains at times when the traffic flow is low. Another possible solution is that drivers take part in more training sessions using simulators to learn skills necessary for driving properly under exceptional conditions. [1].

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