# A New Method for Human Reliability Assessment in Railway Transport

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**Abstract:** Even though human factors have a great influence on railway safety, the assessment still follows traditional and inadequate approaches. In railway engineering practice, the error probability of every human action, regardless of its complexity, is often rated with the fixed value $10^{-3}$. Improving this reductionist approach, e.g. the in Germany well-established method by Hinzen distinguishes three classes of human behavior. However, this method incorporates the contested statement that skill-based actions are generally less error-prone than rule-based ones and rule-based actions are less error-prone than knowledge-based ones. Moreover in classic approaches the human being is considered as a weak point despite its flexibility to react on unspecified system conditions.

In the project SMSmod funded by the German Research Foundation (DFG) a new method for an adequate human reliability assessment is being developed. The internal human processing is modeled by a cognitive processing loop together with cognitive couplings classifying the cognitive demands associated with a particular task. Thereby the focus is on the human's ability to adapt to and recover from hazardous situations (resilience) instead of human errors.

This paper gives an overview of the project so far and focuses on the importance of performing shaping factors (PSFs). The approaches of a CAHR analysis and a detailed PSF analysis which are pursued in parallel are presented and their expected importance for the project is shown.

**Keywords:** Human Reliability, Railway, Ergonomics, Cognition.

## 1. INTRODUCTION

### 1.1. Motivation

Traveling by train is relatively safe compared e. g. to traveling by car. The main reason why every safety-critical component of the railway system has to meet high safety standards is the low risk acceptance of the system which is due to the fact that a passenger's influence on the driving train is minimal (risk aversion). In addition, he most often does not understand how train operation works either.

As a consequence, technical systems and humans must work particularly reliably. For technical systems this can be ensured much easier than for humans as those can be designed to meet a certain failure rate. In contrast, human reliability seems to be more difficult to assure as it is influenced by many factors which are often difficult to assess. This has led to the – in the railway domain widely used – approach to control human actions again by technical systems. Besides that principle for system development the maturity of railways contributes to its safety: many improvements have been made as consequences of critical events or accidents in the past.

So why do we need a new method to assess human reliability in the railway domain? As it will be explained next, (1) there are major ongoing changes to the (European) railway systems which reinforce interest in human reliability and (2) existing methods are not satisfactory.

### 1.2. Trends in Railways

As in many other areas, there is an ongoing process of automation in the railway domain. Work places are equipped with computers, there is a shift from physical work to cognitive tasks and from active work to supervision tasks. For example, written instructions and outside signals for train drivers are being replaced by in-cabin displays. The change is even more drastic for dispatchers: whereas they once set signals and switches mechanically using levers and had to watch trains from the window of their interlocking tower, they nowadays often do their work using computers and sitting in control centers hundreds of kilometers away from the trains they control. As long as normal operation is possible, this saves much personnel and time. But operation on the fallback level is very laborious. Additionally, since this does not happen often, the tasks are not as familiar as the ones for normal operation which makes them slower and probably more error-prone.

In the long run, the human as a supervisor of technical systems might become even more important for a system's safety in the automated environment than he used to be in the traditional system – this automation paradox was described by Bainbridge (1987), who also recognized that the risk for the human to be "out of the loop" when unusual situations occur increases. Consequently human reliability becomes more and more difficult to ensure and thus it is an important research topic.

The cognitive modeling of the human was limited, since he was sufficiently controlled by technical systems. Not much attention has been given to ergonomic design and usability aspects. The situation for the latter has already started to change as railway ergonomics norms like (DIN 5566-1) show.

Finally, the European Union's endeavors to open the European railway market and to facilitate Trans-European railway operation result in major ongoing structural and technical changes. This implies an accumulation of new and challenging situations for humans in the railway system. In order to keep up the current high level of railway safety through these changes it is important to thoroughly assess human reliability.

### 1.3. Existing Methods for the Assessment of Human Reliability

A number of methods from different technical domains such as nuclear engineering, chemical industry, aviation, air traffic and rail traffic exist for human reliability assessment (HRA). Especially in recent years, there was a mind shift in the way that newer methods have been established to better model human behavior in complex situations.

Every method first models human behavior in a given safety-relevant scenario. Human behavior is regarded as being triggered by the context and the factors influencing the performance (Performance Shaping Factors - PSFs). Scenario and context are the prerequisites that the person has to manage with his behavior. To properly cope with it, the information processing capacities of people are essential to transform the demands into appropriate actions.

Two assessment approaches can be distinguished: the task-related and the situation related approach. The leading question for the former is whether an operator will properly perform the task required for coping with a particular scenario; the latter asks which actions an operator will take in a particular scenario where specific contextual conditions are given.

Compared to the task-related processes, which focuses on the specific task necessary to be accomplished in a scenario, situation-related methods describe systematically the entire situation and examine possible errors in the context of the scenario, including a situational analysis and the analysis of all possible procedures in that situation (Cooper et al. 1996). The context is defined as the set of all scenarios in which a person must act to achieve safety. Situation-related methods need to model the human information processing accurately in order to come to an assessment of the situation. Methods developments are e.g.:

- ATHEANA – A Technique for Human Error Analysis (NUREG-1624 2000)
- CAHR – Connectionism Assessment of Human Reliability (Sträter 2000)
- CESA – Commission Errors Search and Assessment (Reer 2004)
- CREAM – Cognitive Reliability and Error Analysis Method (Hollnagel 1998)
- MERMOS – Méthode d'Evaluation de la Réalisations des Missions Opérateur pour la Sûreté (LeBot 2004)

In contrast to the task-oriented methods these are often referred to as the second generation HRA methods in literature. According to Sträter (2005) there are situational factors regarding the timing of the situation and the system states in the situation that affect the application and thus the choice of methods. Second generation HRA methods should be made mandatory if there is e. g. a lack of transparency of dependencies in the system or ambivalent symptoms that have multiple conclusions which is often true in the railway domain. More details can be found in the paper (Sträter et al. 2012).

However, in railway practice often fixed values for human reliability are assumed. This clearly does not do justice to the many factors that influence human reliability and to all the different tasks in the railway domain. Slightly more differentiated methods exist and are used in practice like the in Germany well-established method by Hinzen (1993). This method is based on the distinction of skill-based, knowledge-based and rule-based tasks following Rasmussen (1983) and provides different sets of constant values for these cases. But this method builds upon contested statements as well (Sträter 2005). Furthermore, it is based on the experience in the nuclear industries in the 1960's which is probably not comparable with today's railway systems.

A new attempt has been made by the British Rail Standards and Safety Board (Gilroy & Grimes 2007), based on the generic HRA method HEART (Williams 1985) which was adapted for the railway domain to obtain a method we shall call "Rail-HRA". However, HEART is a first generation method and not as thorough as e. g. THERP (Swain & Guttmann 1983); moreover Rail-HRA was developed on the basis of the British railway philosophy and operation which differs in several respects from other European railway systems.

Feldmann et al. (2008) conclude that there exists no satisfactory method that could be used for human error estimation in German railways.

### 1.4. The SMSmod Project

There is an ongoing research project by the Institute of Railway Systems Engineering and Traffic Safety of the TU Braunschweig, the Institute of Transportation Systems of the German Aerospace Center in Braunschweig and the Fachgebiet Arbeits- und Organisationspsychologie of the University of Kassel called SMSmod *System Mensch-Sicherheit modellieren* which aims at developing a new and thorough method for the assessment of the human reliability for German railways.

Experience shows that the current approach used in Germany is not satisfactory as was explained above. The new approach of SMSmod has started with a very detailed task analysis for train drivers and train operators which was presented in (Lindner & Milius 2012). The tasks were further analyzed and categorized e.g. according to accident classes and cognitive coupling. Currently the team is working in parallel to get more detailed results about the performance of train drivers. Using the CAHR method event data obtained from the German Railways is analyzed to obtain very detailed information about the human reliability in practice taking into consideration different cognitive profiles and obtaining performance shaping factors. Performance shaping factors (PSFs) are a common concept in many HRA methods. Factors like stress, training, working hours, working environment and personal factors have to be assessed and result in some correction value for a base human reliability for a particular task.

Parallel to the application of CAHR, performance shaping factors for railways are collected using own experiences, interviews with train drivers and an extensive literature analysis.

### 1.5. Structure of the Paper

The paper focuses on the importance of performance shaping factors for an assessment of human reliability in railways.

In the next chapter we will give a short overview about what has happened so far in the SMSmod project. This is necessary as the information gathered in that chapter is to be used in the steps discussed in the paper. In chapter three the CAHR analysis is presented and the steps to be taken are explained. Besides information about how the event data is treated we will discuss which and how performance shaping factors are taken into account. In chapter four another approach to the derivation of performance shaping factors is shown.

In the final chapter we summarize the approach presented in the paper and highlight some advantages.

## 2. HIERARCHICAL TASK ANALYSIS: RESULTS FOR THE TRAIN DRIVER

The tasks of a train driver vary considerably between different countries and even within one country. This is due to national railway philosophies and developments and the long life cycles in the railway domain. The latter result in many different on-board and trackside systems and equipments that are in use at the same time. In order to restrict the HRA performed within the project to a manageable amount of clearly defined tasks, a typical German scenario was chosen for the project. It was focused on normal operation on a track which is equipped with an Automatic Train Protection system. We did not take into account operation in fallback mode or shunting. Based on the described scenario, a hierarchical task analysis (HTA) has been carried out in the project SMSmod. However, as the hierarchical task analysis (Annett 2003) requires a decomposed notation of the train driver tasks by definition, the fluid and flexible nature of the tasks may be obscured. Therefore the HTA was supplemented by the cognitive couplings, which attempt to preserve these characteristics of the tasks by classifying the type of cognitive demands imposed on the system operator (Arenius et al. 2011, Lindner & Milius 2012).

In Figure 1, an extract of the resulting cognitive task analysis for the task of a train driver containing the function “passing distant signal” is shown. In railway operation, a distant signal announces the aspect of the following main signal. In many cases, it is located in the braking distance of the following main signal: in case of a stopping aspect at the main signal, the driver recognizes this when passing the distant signal and has to use the braking distance for decelerating speed and stopping at the main signal.

In this case, there are two different possibilities of signal aspects: the signal can show a driving aspect (green light) or a stopping aspect (red light). Thus in Figure 1, the main function is sectioned into the subfunctions “train driver realizes signal aspect” which represents the driving permission, and “approach to main signal and stop in front of the main signal”. The latter function is further divided into the realization of the signal aspect, as well as the pressing of the vigilance button (that has to be done by the driver in the German PZB safety system) and the slowdown to standstill in front of the main signal. The extracted figure also shows the cognitive couplings connected with the different subfunctions. For example, the subfunction “train driver realizes signal aspect” depends on the couplings “monitory” (processing the information from the working environment) and “compensatory” (the human has to infer the relation between the current and the desired system state). For further information about the different cognitive couplings see Arenius et al. (2011), for detailed information especially about the consideration of cognitive couplings for modeling railway operational functions also see Lindner & Milius (2012).

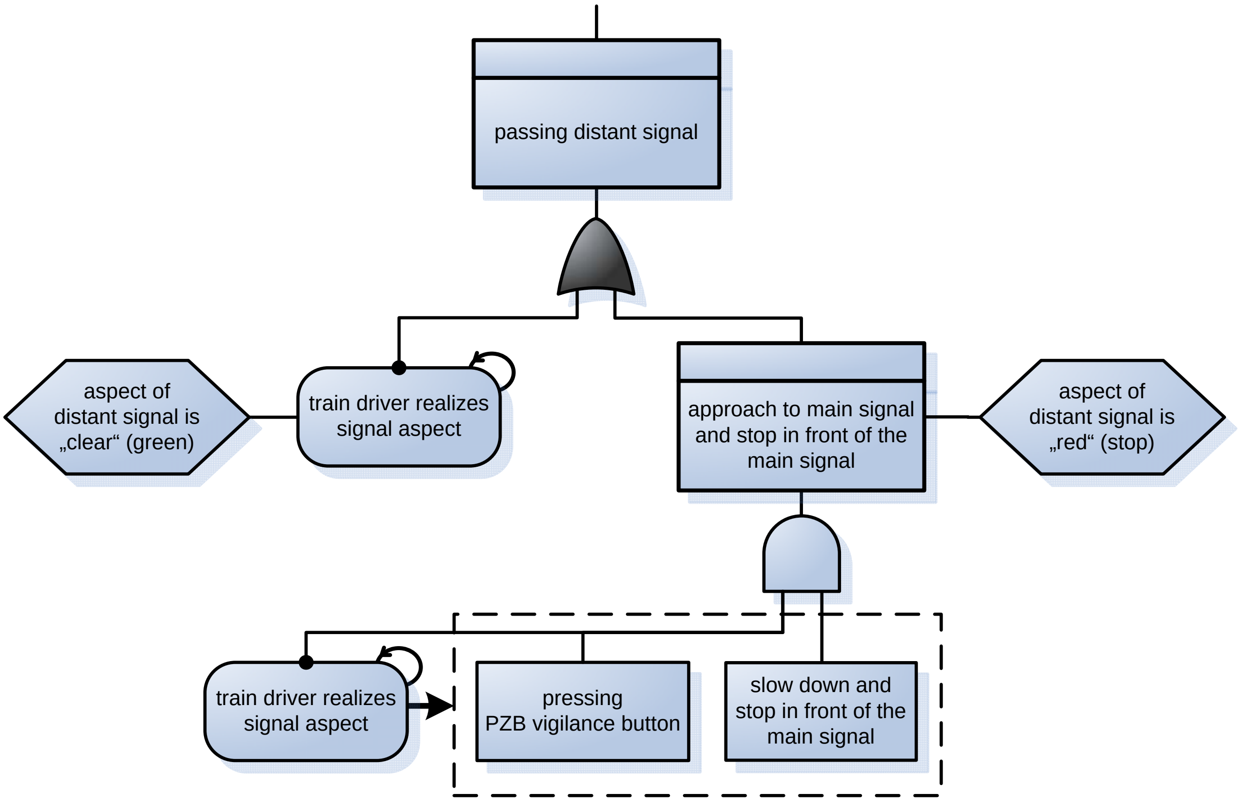

Figure 1. Extract of hierarchical task analysis “train driver”, function “passing distant signal”

## 3. COGNITIVE MODELING

Addressing cognitive aspects of performance can provide valuable insights and inputs to human reliability assessment (HRA) in the railway domain, see e.g. Arenius & Sträter (2012). Our overall approach to cognitive modeling, the *Adaptive Cognitive System*, and its relation to the cognitive task analysis have been presented on last year’s ESREL conference (Arenius et al. 2011).

A critical phase in HRA consists in selecting the appropriate notation, representation and formalization of the accident data for further analysis. The event data in this project, obtained by the German railways, will be structured according to the man-machine-system proposed in VDI 4006 (1999, 2002, 2010).

As stated before, for the purpose of HRA, situation-related methods need to model the human information processing accurately in order to link human performance to the context in which it occurs and which renders a particular course of human action feasible (particularly for accurate assessment and prediction of errors of commission). Therefore, the structured data is evaluated according to the model on human information processing described in Sträter (2005), which ties performance in context to the demands and the coping strategies of the associated individuals and teams.

An extended version of the second generation method “Connectionism Assessment of Human Reliability” (CAHR) will be used as computational method for the HRA, in order to compare the extensive accident data in the railway domain with analyzed events from other technical domains (e.g. nuclear, aviation, shipping, car industry).

PSFs are an important tool for conceptualizing the contextual factors at work in events and accidents, and are therefore highly relevant for the qualitative description of the data. Although PSFs are used extensively in a wide range of HRA methods, their usefulness and scientific value has been under discussion. In particular, the interdependencies between PSFs and the dynamic nature of PSFs have been considered as problematic (Hollnagel 1998).

The CAHR method does not presuppose a fixed taxonomy of PSFs and in the course of this research project, the human adaptive goal-oriented behavior will be related to the affecting PSFs in a systematic manner. To this end, a comparison will be made between what is considered as “fixed” PSFs in current HRA (see below) and the PSFs resulting when considering performance in context of proactive human behavior. The results of this comparison will yield further insights on the factors behind system resilience (Hollnagel 2009).

## 4. PERFORMANCE SHAPING FACTORS

### 4.1. A Different Approach

Parallel to the application of CAHR a PSF-focused approach was taken which is somewhat different from the existing HRA methods: listing PSFs, we tried to break down the identified factors into measurable units whenever possible. This way the influence of the PSFs can be judged in two steps: first, they are assigned a value which is inherent to the actual circumstances in which a task is performed. Second, it can be assessed which values indicate a positive or negative influence on human reliability (Sträter 2005) which also reflects that human have the ability to react upon unspecified system conditions (resilience). In some cases as for “situation awareness”, it would be difficult to assign values. However, such PSFs are included in the cognitive modeling. Our measurable PSFs approach makes the list of PSFs relatively detailed, but in contrast to some general HRA methods, we limit ourselves to PSFs which are relevant for the train driver. The measurable PSFs have one more advantage since they immediately give rise to concrete system improvements. Further information about our approach w.r.t. PSFs can be found in the paper (Schwencke et al. 2012).

### 4.2. Concrete PSFs for the Train Driver

Following the approach explained above, more than 150 concrete PSFs for the train driver have been identified and structured. In order to achieve a list which is as complete as possible, several sources were examined: several HRA methods have been inspected, in particular the British rail-specific method Rail-HRA (Gilroy & Grimes 2007). Norms have given valuable input for in-cabin ergonomic factors (DIN 5566-1) and for usability factors (DIN EN ISO 9241 110). Additionally, an ergonomics expert was consulted.

The many PSFs have been structured in four groups and 22 subgroups as shown in Table 1.

Table 1. Structure of the PSF list

| PSFs Group I: Systems Design | PSFs Group II: Tasks Design | PSFs Group III: Environment |
|---|---|---|
| Ergonomic design | Process design | Conditions inside cabin |
| Usability | Time critical task | Workload and stress |
| Haptic feedback | Monotone task | Weather conditions |
| | | Vegetation |
| | | Buildings near track |
| **PSFs Group IV: Individual Factors** | | |
| Familiarity with track | Working hours | Social ties |
| Familiarity with cabin | Communication | Situation awareness |
| Familiarity with train behavior | Psychological/physiologic factors | Fixation at workplace |
| Education and training | Motivation | |

As the reliability of the train driver is considered w.r.t. his tasks, the identified PSFs had to be related to the tasks identified in the train driver HTA (see Section 2). However, this would have been very laborious because of the many tasks and PSFs and would have led to repetition of PSFs for similar tasks. Instead, categories containing several similar train driver tasks were formed. It was then determined in a matrix which of the 22 subgroups of PSFs from Table 1 influence which task category.

### 4.3. Impact of the PSFs

Clearly not all of the many PSFs have the same relevance for human actions: for example, the complexity of the operational situation has more impact on the train driver than the heat conductivity of the surface of his desk. In the project, own experience and estimates were complemented by an interview with a train driver and event data. From the latter, particularly relevant PSFs were identified in three ways: for some PSFs, it was possible to extract statistical results from the data. The relevance of some PSFs could be shown by inputting events in the CAHR method (see Section 3). Finally, evidence of some PSFs could be drawn from Why-Because-Analyses (Ladkin 2001) of selected events.

We shall briefly describe the latter method: using facts from the event description, a WBA-graph is constructed in a top-down manner. The top event is broken down into a complete set of necessary causes, i.e. all causes from the set taken together imply the top event and if one cause was removed from the set, the top event had not happened. This is done recursively as long as possible and reasonable. The nice property of this rigorous method is that the leaves of the resulting graph form again a complete set of necessary causes for the top event.

In the following, the example graph presented as Figure 2 is described. The graph summarizes the facts of one specific practical linking of events that led to a derailment. In the situation at hand, the train driver has to decelerate the speed of his train: the train will pass the switch no. 101 on its diverging track. In normal case, the diverging track can be passed with less speed than the non-diverging track and the line outside the switch area. In our example, it is allowed to pass the diverging track of switch 101 with a maximum speed of 60 km/h. The derailment speed, which describes the point of speed that leads to a derailment of the train (centrifugal force too high) is 100 km/h. While driving on the previous line outside the switch area, the maximum speed is 120 km/h. In our example, the train drives with this maximum value. Approaching the switch area, there are different speed restriction signals that announce the driver to decelerate speed. The driver overlooks those signals. In addition to this fact, there does not exist any automatic speed control system on this specific line. Thus, the speed of the train is not regulated. Reaching switch 101, the train passes it with the previous maximum line speed of 120 km/h – and exceeds the derailment speed. This leads to the derailment of the train.

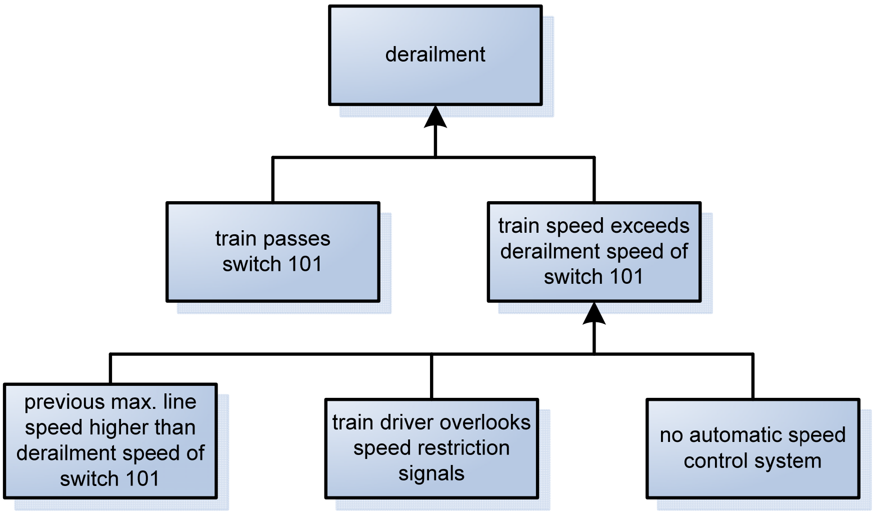

Figure 2. An example Why-Because-Graph

The main benefit of a WBA is that this very formal method shifts away from the question of guilt, often helping to identify causes which may be otherwise overlooked, e.g. because the search for causes is too much focused on the human. In Figure 2, not only the obvious cause that the train driver has overlooked a signal is identified, but also the involvement of (present and absent) technical systems that influenced what happened. PSFs that may have influenced the train driver can now be identified, not only his (missing) attention, but also (in this imaginary example) the possibly poor ergonomic design of speed restriction signals inside and outside the cabin as well as the problem that no automatic train control system was there to brake down the train. Of course the outcome of a WBA heavily depends on the number of facts available about the event.

We found that our WBAs of (real) railway events underpin the importance of some PSFs like "unusual operational situation" or factors which influence the train driver's sight conditions.

From the "relevant PSFs viewpoint" critical tasks may be e.g. braking to standstill at a certain point (PSF "familiarity with inertia of train"), driving into a station (PSF "complex operational situation") or the operation on fallback level (PSF "unusual situation").

### 4.4. Ergonomic Design and Usability

An important group of PSFs is the ergonomic design and usability factors. Whereas other PSFs like personal factors are inaccessible to the designer of a railway system, these factors provide a good starting point to improve human reliability. Our measurable PSFs approach explained above supports the transition from the PSF assessment to concrete suggestions for changes towards an ergonomic design and better usability.

We give examples of PSFs from the ergonomic design and usability subgroups (cf. Table 1). The ergonomics design PSFs refer either to element design, arrangement, embedding in the environment or surface properties. For example, the element design PSFs include the color and shape of elements as well as their unambiguousness of handling.

Finally we shall show on some examples that we see in fact several possibilities for improvement in ergonomic design and usability in the train driver environment: to control the line speed is much more difficult with a classical tachometer than with an ETCS[1] level 2 display: in the first case, the train driver must also collect additional information about his position on the track and the permitted speed; in the second case, the tachometer needle turns orange or red whenever he exceeds the line speed. Another problematic system is the so-called dead man's device, a foot switch or hand button which must be released or pressed in short interval (at least once in 60 seconds). It was shown that due to the customization train drivers manage to do this even when they fall asleep, which runs counter the device's purpose. Other examples include similar signs or signals with different meanings which may confuse a train driver.

## 5. CONCLUSION

In this paper, we have motivated the need for a new method for human reliability assessment in railways and presented developments towards such a method within the project SMSmod. The holistic approach that was taken includes the cognitive modeling of the human as well as an ergonomic evaluation of the technical systems the human interacts with. The interaction between human and technical system is also part of the approach but was not presented in this paper.

In the project, emphasis is put on the ability of humans to cope with unfamiliar situations and disturbances (resilience). This is done by addressing the proactive, goal-oriented way in which humans adapt to and shape their work context (and therefore the performance shaping factors). PSFs are not only taken from the literature, existing methods and expert evaluation, but are also extracted from event data with an explicit focus on the dynamic nature of the PSFs. Furthermore, the ergonomic investigations offer concrete starting points for the improvement of human reliability by adapting the system's design to optimally support the human in his actions. Here the focus is no longer only on minimizing the impact of human error, but on actively utilizing human abilities in order to reduce human error.

As the project progresses, the different pieces in the project will complement each other and our approach will give a new perspective on human reliability in the railway domain.

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[1] European Train Control System – for an implementation of the system in different existing settings several "levels" have been defined

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