HUMAN FACTORS IN THE RAILWAY SYSTEM SAFETY ANALYSIS PROCESS: 3RD INTERNATIONAL RAIL HUMAN FACTORS CONFERENCE

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Abstract

Current European railway standards highlight the influence of human factors into railway system's safety. In spite of this precept the integration is less frequent in engineering practice. The paper proposes the consideration of human factors in several life-cycle phases and in different risk perspectives in railway design and operation. Even for the classic method of integrating human error in quantitative risk analysis, the study for railway applications shows that data for error probabilities and existing techniques involve significant drawbacks. A straight-forward model of working systems is developed to structure influence factors on human performance and to provide a practicable cause-and-effects diagram. Additionally, current safety mechanisms in railways should be studied concerning their efficiency in terms of human-barrier-interaction. By providing this technique and basis for further development, the paper contributes to the integration of human performance into safety assessments and railway engineering practice.

Keywords: Risk analysis, Railway systems, Human error, Barriers, Safety

1. Introduction

In continental Europe, the consideration of human factors does not have a long tradition. Although a high percentage of accidents are accounted to human error, the integration of human contribution into the system's safety is often rudimentarily analyzed in railway engineering. Unfortunately, outdated approaches of continuous automation or usage of fixed human error probabilities for quantitative risk analyses can still be found. Therefore, this article takes a point of view quite close to railway engineering practice and tries to give some answers on the need for human factors integration.

2. Current situation for human factors and railway system safety

2.1 Human factors in the railway system's life-cycle

The focus of this paper is set to dependability understood as reliability, availability and maintainability and particularly safety (RAMS). The most important and well-known standard for the system design of railway technical components EN 50126-1 (CENELEC, 1999; section 4.4.2) requires integration of human factors. In spite of emphasizing the importance of consideration of human factors of railway system's staff, the standard provides sparse information on the way of integration.

The principal model of RAMS that can be found in the standard was retrofitted by Anders (2004). Figure 1 shows that human factors particularly appear in the *design and construction*, *operation and maintenance* phases. Note that in our contribution the strict division of correct and incorrect human actions from Anders (2004) is abandoned. It is important to mention that systematic (human) failures in the design phase appear in the set of internal disturbances in the operational period.

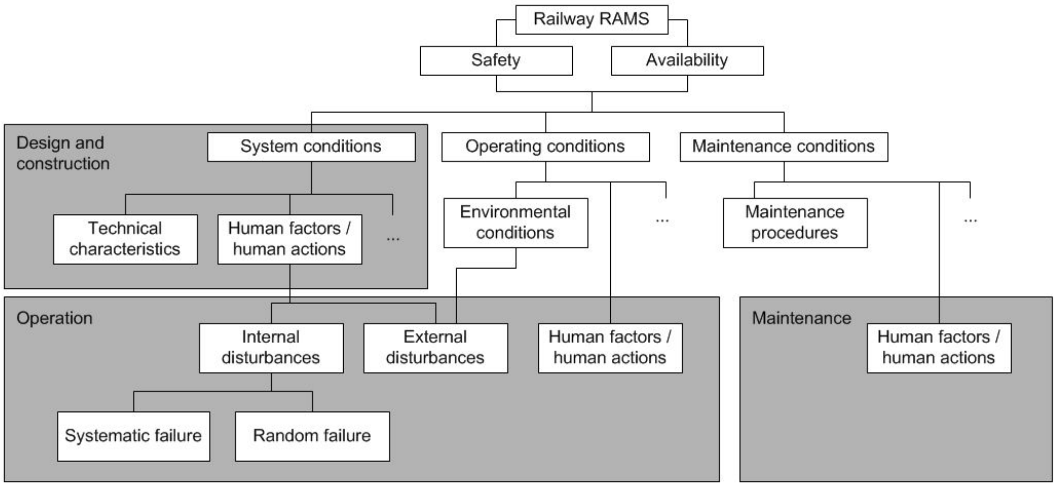

Figure 1: Human factors in the railway system safety life-cycle (adopted from Anders, 2004)

The workplace of humans at the sharp end, i.e. the railway system in operation, and corresponding safety-related risks is shaped by design engineers, the employer and the operator himself. Hereby, the designer is not necessarily only located at the manufacturer as the operating company (i.e. the employer) often sets up the requirements very closely, in the railway industry.

If safety assessments consider human factors, the scope is frequently limited to the designer's evaluation of the risk that evolves from the operator's task (see table 1). Thereby firstly, the designer neither estimates divergences to the user's risk perception in the moment of operation nor takes his own error into account. Though, systematic errors are to be controlled by requirements determined by safety integrity levels and new safety management systems. The design engineer has an external and stable perspective to evaluate risk for a human-machine-system, though the operator has a very flexible point of view for his risk control (Vanderhaegen, 2004). Secondly, the employer and his risk assessment and safety-related measures are cut out of these considerations. We argue that future risk assessments have to integrate not only the human factors of the operator, but also the employer's measures and the risk of human error in the design phase.

Risk evaluation		Workplace under consideration Party performing the task		
		Designer	Employer	Operator
Party conceiving the risk	Designer	Limited	Limited	Most common
	Employer	Only indirect	Limited	Common
	Operator	Only indirect	Only indirect	Limited

Table 1: Risk perception by designer, employer and operator for the different parties

In the remainder of this paper, we focus on the design for human operators in the *operation and maintenance* phase due to the long duration and the comparatively high risks this phase involves. In addition, we limit the scope to train drivers –

meaning staff of the railway operating company, undertaking the task of driving trains – and signallers – meaning staff of the infrastructure managing company undertaking the task of authorizing the movement of trains (definitions taken from the Technical Specifications for Interoperability). These two work stations influence railway performance and safety *directly* and *on-line* in the *moment of operation*.

2.3 Quantitative risk analysis

The European standard EN 50129 (CENELEC, 2003) requires a quantitative risk analysis for safety-related railway systems. Hazards are to be identified and the corresponding risk is estimated. If the risk is not negligible, it has to be proven that the final product fulfils the safety requirements. The actual hazard rate of a safety-related function must not be higher than the associated tolerable hazard rate. The reliability of functions implemented by technical components can in most cases be estimated sufficiently. The human reliability is usually characterized by an estimation of a human error probability. Bringing together technical reliability and human performance is vital for railway transport because most safety-related functions are implemented by a combination of technical systems and human actions.

2.4 Résumé and proposals

The safety assessment and approval processes still vary in many European countries. During the harmonization (see e.g. Cassir, 2008), there is the chance to integrate human contribution to system safety and performance, in order to not only establish technical but also *human interoperability*.

The most important standard for railway dependability engineering proposes the integration of human factors without providing approaches. Anyhow, EN 50126-1 recommends the use of cause-and-effect-diagrams for the consideration of human factors. In order to fulfil this need, we propose a model for work systems later in this paper. This approach may serve as a basis to address human influence factors for the railway engineering practitioner. Besides, we stress that the scope of human factors considerations should exceed engineering for the operator's workplace.

Quantitative risk analyses are required by EN 50129. So, an often-used, but not sufficient way to assess human contribution to dependability is to integrate human error in classic risk analysis techniques. By using this approach, there is a risk to degrade the human operator to a simple brick in the wall, error-prone and undesirable. However, the broad acknowledgement of the standards in the railway sector creates a significant need in practice to bring together human and technical performances in a quantitative way. Some of the classic ways of human reliability assessment and their drawbacks are discussed in the following section.

3. Discussion of existing approaches

3.1 Human error in quantitative risk analysis

When pursuing a classic risk assessment, the railway practitioner has difficulties in integrating the human reliability into the analysis methods: this is due to the lack of valid data for human error probabilities in the railway domain.

In German railway engineering practice, sometimes the constant human error probability of 10^{-3} is chosen in spite of the high variability of human performance. More sophisticated risk analyses refer to the values for human error in railway transport published by Hinzen (1993). 18 fixed probabilities are presented in dependence of stress level, surrounding conditions and Rasmussen's three levels of behaviour: knowledge-based, rule-based and skill-based (Rasmussen, 1983). Feldmann et al. (2008) show that neither Hinzen's values are fully proven to be valid for the railway transport, nor do accident statistics provide comprehensive data to derive human error probabilities. In order to obtain probabilities for certain working conditions, the classic approach is to use human reliability assessment (HRA) methods.

3.2 Existing techniques for human reliability assessment

The steps of the most HRA approaches are to perform a qualitative analysis of the task by conducting a task analysis together with an assessment of possible human errors. Subsequently, human error quantification (HEQ) methods can be applied.

The technique Analysis of Consequences of Human Unreliability (ACIH) (Vanderhaegen, 2001) represents a non-probabilistic technique for human reliability assessment. The non-quantitative method can be used when a qualitative integration of human error into risk assessment is sufficient. One of the most common HEQ methods is called THERP (Technique of Human Error Rate Prediction) (Swain & Guttmann, 1983). First, the task under consideration is decomposed into several individual tasks. The corresponding nominal probability from the handbook is to be adjusted by a set of so called performance shaping factors (PSF) and the calculation by prescribed rules. The nominal probabilities in THERP were recorded in the nuclear power industry. Not only does railway transport differ from that application, also the values reflect a technology and control system design that is actually no more applicable. THERP was already initially applied to the railway driving task (Chaali-Djelassi et al. 2007), but without the adaptation of the probabilities by influencing factors. Another technique, HEART (Human Error Assessment and Reduction Technique) (Williams, 1986) is also based on nominal probabilities that are adjusted by so called error producing conditions. Also, to adapt this technique to railway work places is challenging and possibly exposed to discussions due to the original estimations of the probabilities with different workplaces in mind.

Some of the latter drawbacks of existing techniques were motivation for the British rail safety and standards board to develop a first railway-specific HRA method (RSSB, 2005). A review exposed the high complexity and some disadvantages of the new technique (Hickling, 2007). Analyzing the 29 factors that influence the human performance, a high degree of overlapping and interdependence between the PSF can be observed. Consider for example the set of factors *unfamiliarity*, *driver experience* and *technique learning*. In rail-HEQ – like in several HRA methods – performance shaping factors represent a complex set and are neither well-separated nor visualized. PSF like *concentration* and *fatigue* can themselves be influenced by other factors before. Here, we propose a clarification, i.e. a differentiation between cause and effects, in order to avoid faulty double-representation of influence factors.

At least since the human error taxonomy by Reason (1990) it has been known that human malfunctions appear in several shapes. Some classic risk analysis techniques are capable of modelling errors of omission (leaving out an action) and errors of commission (performing an action in a wrong manner); i.e. slips or lapses. The following three types make human error even more difficult to predict and are not yet fully covered by analysis techniques: intentional human errors, known as violations (though see Polet et al., 2002), unexpected human actions not necessary from a system point of view and finally human recovery of errors.

3.3 Human variability and resilience

The drawbacks of existing approaches and the great variability of human error have led to new ideas to bring human factors and safety together. Understanding human variability as a capability and not as a threat, understanding safety as the presence of adaptability instead of the absence of weaknesses or human errors has become known as resilience engineering (Hollnagel et al., 2006). See Quéva (2008) for an approach of adaptability and reactivity to describe human variability when driving an urban train. The accident analysis method FRAM developed by Hollnagel (2004) has also been applied to the railway domain (Belmonte, 2009). Needless to say that – due to their distance to the classical analysis of human error – these publications do not exactly respond to the need of the CENELEC railway standards.

3.4 Discussion and approach

Summing up the considerations of the last three subsections, neither fixed values for human error probabilities nor one of the existing HRA techniques can fully meet the requirements of the standards. There is a demand for the development of a serviceable tool applicable in railway engineering practice. The method's components have to be less fine-grained to stay practicable and however should provide at least semi-quantitative assessments of human error and performance. Without limiting the scope to non-intentional errors, the paper proposes a clarification and railway applicable structuring of performance shaping factors with a work system model.

4. Structure for performance shaping factors

4.1 Introduction to the work system model

In this section, we propose a somewhat simplified structure for performance shaping factors, applicable to the railway system. The approach is based on a model on working environments in Hammerl et al. (2008). The structure is secondly brought forward to provide a cause and effects diagram that is required by EN 50126-1. The model attempts to visualise engineering and psychologists perspectives in a straightforward manner. Human factors influences and phenomena in a working system are separated into set variables the railway engineer can modify and rather dependent variables, i.e. the behaviour of the human in certain surroundings.

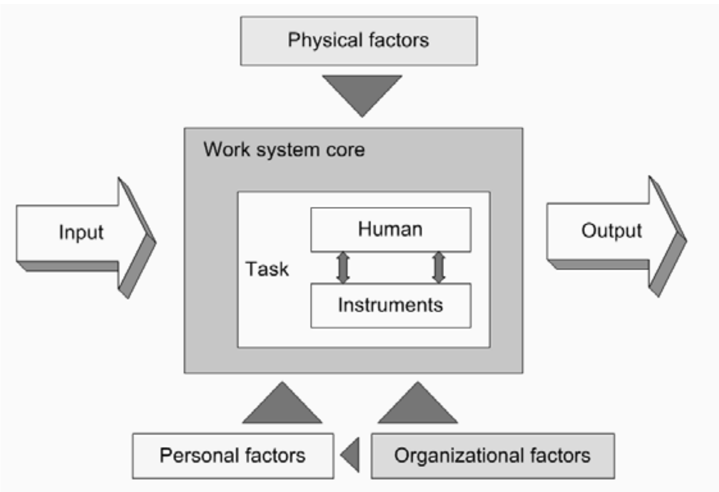

Figure 2: Model of working systems and performing shaping factors

The model of working systems defines the work system core as an interaction of a human, his task, and his instruments (see the center of figure 2). The set variables are represented by physical, personal and organizational factors, i.e. performance shaping factors. It is clear that some of the organizational measures have an impact on personal factors, see the small arrow at the bottom of figure 2. For example, the training has an influence on the employee's skills. All the influencing factors at the top and the bottom have a continuous influence on the work system core and are less dynamic, i.e. at least constant for a shift. In contrary, the horizontal axis represents the work system in the moment of operation: inputs of information change dynamically. Via the work system core, influencing factors as well as input factors have an impact on the work result (output; e.g. controlling the movement of the train).

A zoom on the human reaction in these surroundings was added to the core of the work system in order to take the high mental part of the train driver's and the signaller's work into account. Consider figure 3 as a new center in figure 2. Phenomena like workload, stress and vigilance shall here – with a certain simplification – be understood as passive, i.e. dependent variables, and as subjective human reaction on the influencing factors. For example, vigilance (in the center) depends on the tiredness (personal factor), the roster planning (organizational factor), and in a way on the design of the human-machine-interaction as well – think of the dead-man's device for train drivers. Rather the influence factors offer the chance for modifications by redesign. So, a change of the independent variables (*causes*) results in *effects* in the human-machine-system.

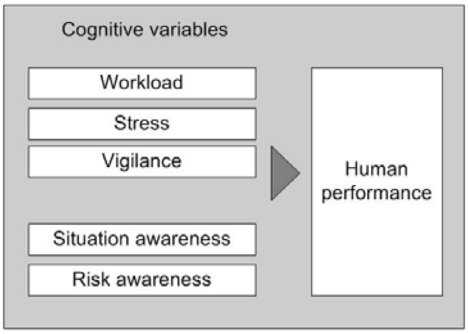

Figure 3: Layer of cognitive reactions

4.2 Performance shaping factors

Table 2 represents a detailing of the model. The items were derived and restructured on the basis of the performance shaping factors in THERP and rail-HEQ. For the application on railway working environments, a certain set of factors of THERP was not relevant; some factors of rail-HEQ have been revised. The table provides a straightforward structure that a railway engineering practitioner can apply and complement to the working situation under consideration.

Physical factors		
Anthropometry	Working conditions	Design of HMI
• Basic layout of the working environment	• Physical conditions as temperature, humidity, light, noise	• Positioning and layout of HMI • Usability • Quality of feedback

Personal factors	
Individual factors	Dependent factors
• Health • Emotional tension • Age, Gender	• Tiredness • Skills (rule, track and vehicle knowledge) • Experience • Motivation • Safety awareness

Organizational factors	
Employee related factors	Standard factors
• Roster planning • Leadership • Education • Training • Social aspects • Safety culture	• Standards • Rules and guidelines • Task design

Table 2: Performance shaping factors

The inputs (figure 2) are changing dynamically and can therefore not be understood as performance shaping factors. For the train driver, inputs are information gathered by track observation, signal aspects, transmitted by cab instruments or radio communication. Weather conditions and the local state of the track vary too frequently for being included in an assessment of human performance. Delay and degraded modes cannot be directly visualized in the model due to its general approach. The task related factors from other techniques were included in the task design as an organizational factor. Task complexity, frequency, criticality and the corresponding time frame represent important affiliated performance shaping factors.

4.3 Influences on human performance

The influence of factors from the outside on human performance can be visualized in chains of actions (see figure 4 for some examples). In line with table 2, personal factors (boxes without hatching on the left hand side) can be with or without influence by organizational factors. Note that PSF are constant for one work period while the cognitive reaction changes with the situation and corresponding inputs. Consider safety culture as an organizational factor, safety awareness as the permanent attitude of the operator and risk awareness as situation dependent consciousness. High subjective workload, less vigilance, incomplete situation awareness and reduced risk awareness are examples for error favouring conditions. So, the diagram offers a practicable tool to qualitatively illustrate influences on performance (causes and effects) of a human-machine-system situated in railway operation as is proposed by EN 50126-1.

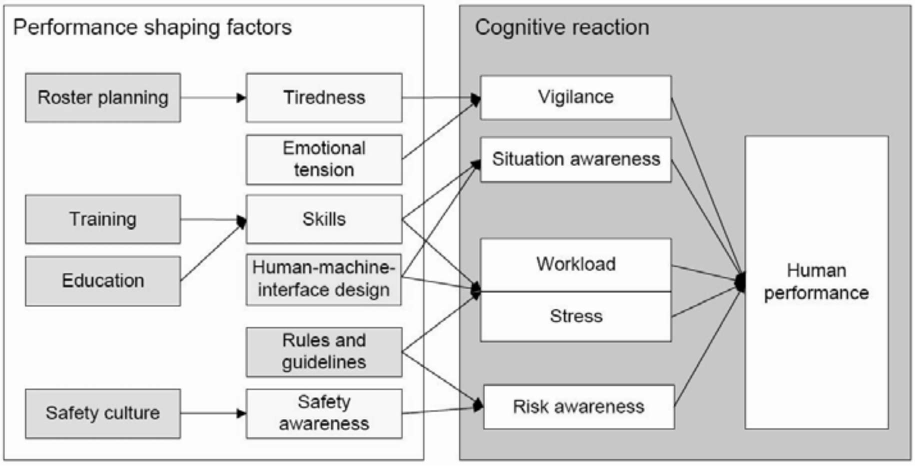

Figure 4: Examples for influence chains on human performance

A following weighting of connections represents first the assessment of the degree of influence of particular performance shaping factors and second the appearance and severity of error favouring conditions. The semi-quantitative assessment should be undertaken either by both railway and human factors expert judgement or with the support of simulations and human factors studies in corresponding environments. The domain-specific analysis facilitates quantification useable for railway engineering practice; by intermediate-term research being made suitable for EN 50129.

5 Human-barrier-interaction in railway systems

In the preceding section, the influences on the human, on so-called cognitive reaction, were analyzed. In order to study organizational and physical influence factors in a better way and to take consequences of human performance into account, the utilisation of safety barriers is proposed as a another approach to human error.

Barriers represent safety mechanisms that are installed to prevent undesired events from taking place or to protect against its consequences. The most common taxonomy of barriers distinguishes between material barriers being physically in the system, functional barriers creating dependencies, symbolic and immaterial barriers, the latter both being for example signs or rules (Hollnagel, 2004). For the classification of safety barriers in terms of a process model, a three step structure was proposed: *barriers of prevention* that prevent an undesired initial event from taking place, *barriers of correction* that recover the situation and *barriers of containment* that lessen the severity of the consequences. See Sklet (2006) for a deeper study.

While a physical and a functional *barrier system* executes the *barrier function* itself, symbolic and immaterial barriers request an action and its performance represents the barrier function. Due to the dependency on human actions, these barrier systems can generally be estimated as being medium or less efficient (Hollnagel, 2008).

The efficiency of barriers in terms of *human-barrier-interaction* should be analyzed in a more profound manner. Thereby, the approach should not be limited to violations – interpreted as barrier removal in Polet et al. (2002) and Chaali-Djelassi et al. (2007) – but to human performance in general. The following barrier properties are proposed as exemplary detail criteria for a well-functioning of human-barrier-interaction: ability, benefit and ease to deactivate; temporal presence (continuous or *on-demand* functioning), perceptibility of the barrier and its status and finally temporal and spatial distance between barrier system and barrier function.

In order to apply this idea to the railway system, there is a necessity for barrier identification. Up to now, two initial approaches can be found in literature (Schwartz and Pelz, 2008; Radbo et al., 2008). Consider the protection against overspeed in the train-driving task as an example. A *symbolic barrier of prevention* is the speed indicator which is continuously visible to the driver. The high perceptibility certainly has a positive effect on the probability of well-functioning of this particular human-barrier-system. In contrary, an advance speed limit sign appears only punctually and involves a certain delay to execution of the barrier function. The train control system (preventing overspeed in a technical way) is a *functional barrier of correction* that can be deactivated under circumstances and whose state is disadvantageously not always well perceivable for the operator.

Regard the link to performance shaping factors: while the design of the speed indicator instrument is a physical factor (design of human-machine-interface), the actual information represents a dynamically changing input. Rules against overspeed constitute *immaterial barriers of prevention* and are organizational factors.

So, the approach of human-barrier-interaction supports the analysis of performance shaping factors and their influence degree. Furthermore, barriers also permit the study of consequences of malfunctioning as barriers can overlap or secure each other. Last, the analysis of barrier regimes also gives hints for redesign and error reduction.

6 Conclusion and outlook

The paper pointed out the need for human factors integration in several phases of the railway system's life cycle, supported by European standards. The actual limit of only considering the human performance of the operator must be overcome. The harmonization processes in European railway transport offer a possibility to open RAMS considerations for human factors.

Unfavourably the strict requirement of quantitative risk analysis narrows down the perspective to the calculation of human unreliability. The drawbacks of this approach, related to railway transport have been described.

This paper has presented a straight-forward model of working system to structure performing shaping factors. The approach practicably gives an overview on human factors for the railway engineer dealing with EN 50126-1. The assessment of efficiency of barriers in terms of human-barrier-interaction has been brought forward. These contributions and on-going research will support the future railway-specific and at least semi-quantitative substantiation and further analysis of the influencing factors.

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