Identification of Training Topics for the Improvement of the Relevant Cognitive Skills of Technical Operators in the Railway Domain

Giulio Nisoli, Jonas Brüngger, Karin Hostettler, Nicole Stoller, Katrin Fischer

***Abstract*—**Technical operators in the railway domain are experts responsible for the supervisory control of the railway power grid as well as of the railway tunnels. The technical systems used to master these demanding tasks are constantly increasing in their degree of automation. It becomes therefore difficult for technical operators to maintain the control over the technical systems and the processes of their job. In particular, the operators must have the necessary experience and knowledge in dealing with a malfunction situation or unexpected event. For this reason, it is of growing importance that the skills relevant for the execution of the job are maintained and further developed beyond the basic training they receive, where they are educated in respect of technical knowledge and the work with guidelines. Training methods aimed at improving the cognitive skills needed by technical operators are still missing and must be developed. Goals of the present study were to identify which are the relevant cognitive skills of technical operators in the railway domain and to define which topics should be addressed by the training of these skills. Observational interviews were conducted in order to identify the main tasks and the organization of the work of technical operators as well as the technical systems used for the execution of their job. Based on this analysis, the most demanding tasks of technical operators could be identified and described. The cognitive skills involved in the execution of these tasks are those, which need to be trained. In order to identify and analyze these cognitive skills a cognitive task analysis (CTA) was developed. CTA specifically aims at identifying the cognitive skills that employees implement when performing their own tasks. The identified cognitive skills of technical operators were summarized and grouped in training topics. For every training topic, specific goals were defined. The goals regard the three main categories; knowledge, skills and attitude to be trained in every training topic. Based on the results of this study, it is possible to develop specific training methods to train the relevant cognitive skills of the technical operators.

***Keywords*—**Cognitive skills, cognitive task analysis, technical operators in the railway domain, training topics.

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I. Introduction and Theoretical Background

IN Switzerland the railway power grid as well as the railway tunnels are supervised and managed by the same experts, so called *technical operators*. Errors in the execution of the job of technical operators can lead to severe consequences for safety and reliability of railway traffic. Since unreliable, variable human performance can lead to errors, it is often considered as a major issue in the safety domain. To avoid errors, the human scope of action and therefore variability in human performance is often reduced through standardization of processes execution. Standardization occurs typically through the introduction of detailed guidelines of task execution to be followed very thoroughly and through the introduction of highly automated technical systems [1], [2]. Most of the tasks within the job of technical operators are repetitive. Because of this, most of the tasks of technical operators are standardized. In this respect, Schulman argues that tasks with low variability resp. high repetitiveness should be regulated through standardization [3]. It seems therefore appropriate to standardize the execution of the routine tasks of technical operators. As a consequence, these experts are confronted with the challenge of working with technical systems constantly increasing in their degree of automation and with detailed guidelines that prescribe how the job should be executed. Against this background, it becomes clear why the basic education of technical operators strongly focuses on work with guidelines and on technical knowledge, two areas that are strictly necessary to master this job. Nevertheless, in order to guarantee a successful cooperation with the technical systems, Wäfler et al. consider it crucial that the human maintains the control over the task executed [4]. A typical negative effect of the introduction of technical systems to support the execution of a task is the so called *deskilling*. Regarding this topic, Manzey describes how the introduction of technologies that set the human in a passive role can lead to the loss of relevant skills to master the task [5]. Without the relevant skills to master the task, it is not conceivable that the technical operators maintain the control over their tasks. This is why it is crucial to find a way to maintain and further develop the relevant skills, especially when the job must be executed in collaboration with extremely automated technical systems. Furthermore, even in the most repetitive and predictable activities unexpected events can always occur. This means that a minimal amount of variability is always present in every activity [6]. Humans are considered to be superior to technology in their capacity to adapt to changing conditions [5]. This capacity of adaptation is essential in order to achieve stable outcomes under varying conditions but requires a certain amount of variability in performance execution. In this regard, Smith et al. describe many examples in different domains of how variability in human performance is needed to adapt to variability in performance conditions to achieve stable outcomes – for example in the sport domain where athletes constantly have to vary their performance according to the present conditions in order to achieve the same goal [7]. In a similar way, the technical operators must be able to guarantee the correct supervision and management of the railway power grid as well as the railway tunnels also when technical systems fail and the operation must be done manually (without the support of technical systems) in a different manner than usual. The same objective must be achieved but different operations must be performed.

Reducing the scope of action through standardization – having to work with standardized guidelines and technical systems – reduces the possibility for technical operators to variate their performance. This can have the advantage of reducing the risk of errors, but it can also lead to a loss of skills and knowledge of experts, especially their ability to adapt to varying conditions such as unexpected events [2], [5]. In order to maintain these abilities, it is crucial that technical operators maintain and further develop the cognitive skills needed to understand and execute their job – especially important in unexpected events. With this in mind, the main goals of this research were to identify which are the relevant cognitive skills needed for the execution of the job of technical operators in the railway domain and to define which topics should be addressed by the training of these cognitive skills.

II. Identification of the Relevant Tasks and Cognitive Skills

A. Identification of the Most Demanding Tasks

Design and procedure: In order to identify the cognitive skills necessary to execute the job of technical operators a qualitative method aiming at analyzing the main tasks of the job has been applied. For this purpose, two observational interviews were conducted. Through this step, it was possible to identify the most demanding tasks in the job of technical operators. It is in fact for the execution of these tasks that the core cognitive skills of technical operators are especially relevant, therefore it is in the most demanding tasks that they can be identified.

Participants: The two observational interviews were conducted with two technical operators (n = 2), one with an expert and one with a novice. The sample has been chosen based on the reasoning that the difficulty of the tasks can be perceived differently depending on the experience of the interviewee.

Measures: In the observational interviews, first, the main tasks of the technical operators have been identified. Then they have been analyzed. For this purpose, main goals and steps of the tasks have been identified. The most demanding steps have been picked out and further described. The information flow – where the information comes from (*inputs*), how it is processed (*transformations*), what effects the processed information has (*outputs*) – has been analyzed for the human, the technical and the organizational components of the system. For a comprehensive analysis of a socio-technical system, it is crucial to consider all three elements [8]. Last, based on the guideline for the analysis of socio-technical systems of Wäfler et al., possible variations and disturbances – such as failures of technical systems – have been identified [4]. The questions asked to analyze the main tasks of technical operators are described in Table I.

TABLE I
Questions of the Observational Interviews

Elements to be identified	Questions asked to identify the intended elements
Goals of the task	What are the goals of the task?
Steps of the task	Which steps does this task involve?
Demanding steps	- In your experience, which task steps are particularly difficult? - What are the most difficult task steps for a technical operator? - Why are these task steps difficult?
Inputs	- Which information relevant for the execution of the task comes from other persons? (*Human*) - Which from technical systems? (*Technique*) - Which from other tools (e.g. Checklists)? (*Organisation*)
Transformations	- What do you do with the information together with other persons? Which persons? (*Human*) - With technical systems? Which technical systems? (*Technique*) - With other tools? Which tools? (*Organisation*)
Outputs	- Where does the information go? To which persons? (*Human*) - To which technical systems? (*Technique*) - Somewhere else? (*Organisation*)
Variations and disturbances	What are possible variations and disturbances in this task?

Note: The questions of the observational interviews aimed at identifying the most demanding tasks for technical operators.

Results: The main tasks of technical operators can be categorized into two core domains, the *railway power grid* and the *railway tunnel*.

Within the domain of the railway power grid the main tasks are:

- The supervision of the power grid;
- Managing the power grid, which is divided in:
  - o Normal operations: Switching power lines on and off for construction sites;
  - o Managing malfunction situations, which involves:
    - Assessing and minimizing the operational influence of the malfunctions (safeguarding the area where the malfunctions occur and isolating the malfunctions);
    - Commissioning repairs by summoning and informing the appropriate service specialists.

In the task of managing the power grid, the following step has been identified as especially demanding: *Localizing malfunctions in the railway power grid*.

Within the domain of the railway tunnel the main tasks are:

- The supervision of the railway tunnel;
- Managing the railway tunnel, which involves:

- Normal operations: Controlling the tunnel access;
- Managing malfunction situations, which involves – in addition to the two tasks described for managing malfunction situations in the power grid – assessing the operational relevance of the malfunction and identification of interdependencies of different malfunctions;
- Managing emergency events: Mobilizing emergency services and management of the tunnel ventilation.

In the task of managing the railway tunnel, the technical operators consider the following three steps as especially demanding:

- Identifying interdependencies of different tunnel infrastructure's malfunctions;
- Working manually (without the support of technical systems) with checklists;
- Managing (without the support of technical systems) the tunnel ventilation manually.

All taken together, four tasks were assessed as the most demanding ones:

(a) Localizing malfunctions in the railway power grid;
(b) Identifying interdependencies of different tunnel infrastructure's malfunctions;
(c) Working manually (without the support of technical systems) with checklists;
(d) Managing (without the support of technical systems) the tunnel ventilation manually.

B. Identification of the Relevant Cognitive Skills

Design and procedure: For the identification of the cognitive skills needed for the execution of the most demanding tasks of technical operators, a qualitative analysis method has been applied. For this purpose, a CTA has been developed and applied within two focus group interviews. CTA specifically aims at identifying the cognitive skills implemented for the execution of a task [9]. In the focus group interviews the described four most demanding tasks have been analyzed. The first focus group interview aimed at identifying the cognitive skills necessary for the execution of the tasks related to work with the support of technical systems:

(a) Localizing malfunctions in the railway power grid;
(b) Identifying interdependencies of different tunnel infrastructure's malfunctions.

The second focus group interview aimed at identifying the cognitive skills necessary for the execution of the tasks related to the work without the support of technical systems:

(c) Working manually (without the support of technical systems) with checklists;
(d) Managing manually (without the support of technical systems) the tunnel ventilation.

Each focus group interview had a duration of half a day and they were conducted over two weeks.

Participants: Each of the two focus group interviews were conducted with three technical operators with several years of experience (n = 6).

Measures: Based on the *applied* CTA, the *critical decision method* and the *situation awareness model*, a CTA appropriate to identify eight core types of cognitive skills relevant to master the most demanding tasks of the technical operators has been developed [10]-[12]. The eight core types of cognitive skills are: (1) perception, (2) comprehension and anticipation, (3) decision-making and performance of action, (4) development and implementation of tricks, (5) self-monitoring, (6) improvisation, (7) knowledge of equipment's limits and (8) usage of tools. For each type of cognitive skills, three general questions have been asked:

- What is essential for the execution of the task?
- What is difficult in the task?
- What can be helpful to overcome the difficulties in the task?

These general questions have been specified for each of the eight core types of cognitive skills and related to the four most demanding tasks of technical operators. Examples of questions asked to identify (1) *perception* and (2) *comprehension and anticipation* can be found in Table II.

TABLE II
EXAMPLES OF QUESTIONS OF THE CTA

Core types of cognitive skills	Questions of the CTA
(1) Perception	Which information in this task needs absolutely to be perceived? Which information is hard to find in this task? Why? What is helpful to perceive an information for this task that is difficult to find?
(2) Comprehension and anticipation	What needs absolutely to be understood for the successful execution of this task? Which development of events and consequences must be anticipated in this task? Why is understanding sometimes difficult and other times easier? What makes the anticipation of the development of events and of consequences especially difficult? What would be helpful: - To understand the situation in difficult instances? - To anticipate the development of events and consequences in difficult instances?

Note: The questions of the CTA aimed at identifying the cognitive skills necessary to master the most demanding tasks of technical operators.

TABLE III
EXAMPLES OF COGNITIVE SKILLS

Core types of cognitive skills	Cognitive skills	Related demanding tasks
(1) Perception	Finding out whether a goods train or a passenger train is travelling in the tunnel in order to decide how the tunnel ventilation should be managed.	(d) Managing manually (without the support of technical systems) the tunnel ventilation
	Requesting relevant information verbally.	(c) Working manually (without the support of technical systems) with checklists
(2) Comprehension and anticipation	Collaborating with the other team member to get a better picture of a situation.	(a) Localizing malfunctions in the railway power grid
	Knowing the actual condition of redundancies (e.g. is a support water pump available?).	(b) Identifying interdependencies of different tunnel infrastructure's malfunctions

Note: The first main goal of the present study was to identify the cognitive skills relevant to master the most demanding tasks of technical operators.

Results: The application of the CTA has allowed to identify the cognitive skills relevant for the execution of the four most demanding tasks. Examples of the cognitive skills identified for (1) *perception* and (2) *comprehension and anticipation* are listed in Table III.

III. Definition of Training Topics and Goals

A. Definition of Training Topics

The second goal of the present study was – based on the identified cognitive skills – to define training topics in which the cognitive skills can be trained. For this purpose, cognitive skills concerning the same topic were clustered together, resulting in six main training topics: (I) establishing mental models, (II) communication, (III) teamwork, (IV) practical execution (this topic regards the training of rare events' management), (V) interaction with technology and (VI) stress management. Table IV describes some examples of the cognitive skills clustered in the training topics for (I) establishing mental models, (II) communication and (III) teamwork.

TABLE IV
EXAMPLES OF COGNITIVE SKILLS CLUSTERED IN THE TRAINING TOPICS

Training Topics	Cognitive skills
(I) Establishing mental models	Knowing the actual condition of redundancies (e.g. is a support water pump available?) (*comprehension and anticipation).* Knowing of geographical / regional borders: - At which tunnel exit the fire fighters/police must be called up, - Where goes the watercourse – to which region / tunnel exit (*comprehension and anticipation*). Relevant when technical systems fail and the information about the geographical / regional borders is no longer available. Activating alternative electrical feeding points (*improvisation*).
(II) Communication	Requesting relevant information verbally (*perception*). Finding out whether a goods train or a passenger train is travelling in the tunnel in order to decide how the tunnel ventilation should be managed (*perception*). Communicating with other railway organizations to have a better understanding of the situation (*comprehension and anticipation*).
(III) Teamwork	Collaborating with the other team member to find the information needed when technical systems fail and the information is no longer available (*perception*). Collaborating with the other team member to get a better picture of a situation (*comprehension and anticipation*).

Note: The cognitive skills relevant for the execution of demanding tasks of technical operators were clustered in training topics.

B. Definition of Training Goals

In order to make the training topics accessible for the development of concrete trainings, goals to be achieved have been set. The goals regard three main categories: *knowledge*, *skills* and *attitude*. Considering all three categories will allow to develop trainings that can lead to effective improvement in the participants' behavior on the job. To implement a specific behavior, the training participants do not only need to theoretically know how a specific behavior should be (knowledge), they also need to be able to implement it (skills) and to be convinced of its utility and importance (attitude). Since the final goal of the trainings should be to specifically train the relevant cognitive skills of technical operators, the goals were formulated based on the identified cognitive skills. Examples of training goals for the six training topics formulated are described in Table V.

TABLE V
EXAMPLES OF TRAINING GOALS

Training Topics	Training goals	Goals' category
(I) Establishing mental models	Having theoretical knowledge about electrical feeding points, voltage differences, geography (where are forests, etc.) and tunnel ventilation.	*Knowledge*
(II) Communication	Being able to communicate effectively.	*Skills*
(III) Teamwork	Having a good and open communication culture (e.g. sharing of malfunctions' experiences).	*Attitude*
(IV) Practical execution	Having theoretical knowledge about how to behave in unexpected situations (e.g. knowing standardized procedures that can be used in unexpected situations).	*Knowledge*
(V) Interaction with technology	Being able to operate technical systems in everyday working situations and in unexpected ones.	*Skills*
(VI) Stress management	Not feeling ashamed to talk about personally experienced stress episodes.	*Attitude*

Note: Training goals for each training topic were defined for the categories knowledge, skills and attitude.

IV. Discussion

Main goal of this study was to identify which topics should be addressed by the training of cognitive skills of technical operators in the railway domain. This is of crucial importance since the training of the experts' relevant cognitive skills in the safety domain should not be neglected. Technical operators in the railway domain are very well prepared for working with standardized checklists and technical systems. This is appropriate since it reflects the typology of their (routinized) job [8]. On the other side, the cognitive skills necessary to understand and master the processes of their job – especially of the most demanding job's tasks – and necessary for being able to adapt to unexpected situations, should also be constantly trained and improved. For this reason, trainings that go beyond the basic preparation that technical operators receive are strictly necessary. In most safety related domains – such as aviation, nuclear plants and medicine – the ability of the human to adapt to changing conditions is often neglected and not enough trained or even impaired through excessive standardization of the job execution with the introduction of detailed guidelines and highly automated technical systems [1], [2], [6], [11], [13].

This study shows how to identify which cognitive skills should be trained in order to allow experts continuing to improve the expertise and the capacity to adapt to changing conditions in their job, especially important to deal with unexpected events. Furthermore, the study shows how the identification of the relevant cognitive skills can lead to the formulation of training topics with specific goals. This step allows to define concretely how the trainings within the training topics should be developed. Setting comprehensive goals including all the relevant aspects that affect the actual implementation of a desired behavior is crucial for the development of successful trainings. A training that develops knowledge, but not the skills necessary to practically implement an aimed behavior has no chance to lead to the implementation of the wished behavior in the real world of the work setting. In the same way, a training that develops knowledge and skills of a desired behavior, but does not lead to the development of a positive attitude toward the training topic will not lead to a real change in the training attendees' behavior. If the training attendees are not convinced about the importance of the training topic, even if they were able to implement the aimed behavior after the training (because they have acquired the necessary knowledge and skills), they will not do it because they do not consider it as necessary or even as appropriate.

V. Limitations and Future Directions

This study bases on data within the railway domain. Cognitive skills relevant to master the tasks of the job, maintaining the control over the processes even when working with highly automated technical systems, and adapting to changing conditions – especially important to react appropriately to unexpected situations – should be trained not only in the railway domain but in all safety domains. It would be interesting to apply the methodology presented in this study to other safety relevant domains in order to research which of the training topics and relevant cognitive skills identified in this study are common to other jobs within the safety domain.

VI. Conclusion

The current study identifies the cognitive skills of technical operators in the railway sector necessary to understand the job, master the most demanding tasks, adapt to varying conditions and appropriately react to unexpected events. The cognitive skills are clustered in training topics with specific goals. Based on these results, it is possible to develop specific trainings appropriate to train the relevant cognitive skills of the technical operators or to apply this procedure in other safety relevant domains other than the railway.

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