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A Human Factor and Rail Transport Safety - a Comparative Criterion of Selected Assessment Methods

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ABSTRACT

Modern safety management in rail transport determines new and interesting directions for its scientific exploration. As a railway system is dynamic, relationships between its individual components become particularly important. A component approach, however, has a complex dimension, due to the different categories of components that constitute this system. The interrelations between an operator, an object and a work environment determine the safety of this system. The operator understood as a Human Factor becomes increasingly important, even strategic in this relationship. The purpose of the paper is to present crucial human factor assessment and management methods and determine their comparative criteria. The paper also presents the selected possibilities of applying the given methods to specific technical, operational and organizational solutions within the framework of the functioning safety management system in rail transport. The paper describes an attempt to conceptualize and operationalize human factor management in rail transport in relation to selected methods presented.

KEYWORDS: Human factor, safety management system, human error assessment methods

1. Introduction

The issue of safety in rail transport requires constant search in the sphere of new and effective solutions. Undoubtedly, a comprehensive approach to ensuring the expected level of safety is important, by showing creative investment directions that aim to protect the railway system against human errors. It should be noted that railway undertakings are obliged to implement and maintain safety management systems for which risk management is obligatory. The issues of rail transport safety, risk management and technical development issues were broadly discussed in the works [1, 2, 3, 4, 5]. The application of risk management principles in rail transport is not easy due to the complexity of transport and maintenance processes in rail transport. It is a complex and demanding process that demands a holistic approach based on a very good knowledge of technical processes [2].

Nevertheless, as regards a risk management process, railway undertakings in the current phase of development do not fully take into account risks resulting from human error, which often have a repetitive nature. These activities should be a key determinant for entities operating in the railway sector, striving to reduce risks related to human errors in rail transport. This process should be part of the operation of railway undertakings and their safety management systems and be analyzed in terms of all aspects related to railway traffic safety. A need to implement innovative system solutions results from the number of railway occurrences caused by the human factor. Human errors appear very often in safety reports as key reasons for railway accidents. Polish experience, due to a relatively new view of the risk management process related to the occurrence of the human factor, indicates significant needs for the implementation of innovative investments aimed at eliminating hazards related to the human factor. These occurrences result not only from the failure of technical systems, but also due to the poor psychophysical condition of an engine driver. The aim of the paper is to present the selected methods of human factor assessment in the context of railway traffic safety management.

2. Safety Management Systems in rail transport and a human factor

The indication of the importance of management processes in rail transport results in a slightly different view of this sector than before. It is a sector that is currently characterized by modernity, including a range of technical innovative solutions [6], whose operation requires the application of knowledge of management in relation to all kinds of technical and organizational interfaces occurring at the level of cooperation of the above systems.

The development of management issues in rail transport can be considered as a new development of the Polish railways. System solutions introduce order and shape an unambiguous way of communication between various participants of railway traffic. A uniform system of definitions, understood and used in the same way, is developed. One can hope that the indicated regulations and standards, as well as the increasing management culture will strengthen and stabilize the rail transport sector in Poland.

A modern look at the problems of rail transport requires a multidimensional approach that takes into account technological as well as organizational and management aspects. Until now, many solutions used in rail transport have not been strongly focused on exposing management issues. At present, such management methods gain special importance that take into consideration technological aspects examined in systemic terms.

Modern safety management mechanisms in rail transport are primarily focused on a system approach. Within the framework of the system approach, there are relationships between particular factors that can result in safe railway traffic. If there are no deviations from the effective implementation of the system approach, they may result in uncontrolled rail occurrences. As a consequence, this can lead to railway disasters with numerous fatalities.

Within the framework of the uncontrolled system approach, the sources of rail accidents may include SPADs.

Such occurrences and their elimination thus require a holistic look at the railway system. It should be noted that the railway system is a vibrating dynamic system of an open nature. According to [7], a new approach to the openness of systems means that the system behavior can only be understood in the context of its environment. The world consists of interactions: "everything depends on everything." Everything can be divided into what can be controlled and what cannot. This distinction enables the operationalization of the system, its environment and boundaries. The consequences of this principle are as follows:

1. A system is a set of interactive variables that can be controlled by participating actors.
2. An environment is a set of variables affecting the system that cannot be controlled.
3. System boundaries are an arbitrary, subjective construct, determined by the interests and level of ability and/or power, which enables (or does not) to control interactions in it.
4. System behavior in its environment may be more or less predictable [7].

Pluralism in systemic thinking concerns the freedom of choice of various systemic theories, methodologies and methods, and the creation of various combinations thereof.

Holism in systemic thinking makes it possible to use various approaches to solving problems in a creative way in the sense that the combinations of different system methodologies are created, adapted to the scale and range of difficulties faced by managers in problem- solving situations. The selection of these methodologies and ways they are used depend on the creativity of managers. Holistic systemic thinking seems to be what can facilitate the work of managers [7].

A holistic view allows for anticipating and developing strategic scenarios that will help subdue the risk of making wrong decisions. Systemic thinking results in building a management system in the company. A management system together with business processes, a business model and strategy creates a certain coherent whole, which results in an effective management platform determining company development and growth.

Systemic thinking is related to the complexity theory, which can be described by recalling the model of a complex adaptive system developed by [8], in which the interrelationships between the evolutionary approach, organization internal mechanisms and the environment are defined [8].

In this concept, it is important to link internal mechanisms with the business environment in relation to the assessment of cooperation between individual entities associated with the company [9].

The conducted system analysis should ensure that railway occurrences are not only supervised, but also multiple decisions of a cause and effect nature are made. Thus, it is important to define the primary causes of railway occurrences. Undoubtedly, the links between an operator, a technical object and the work environment determine the positive and negative effects of railway traffic. It should be assumed in this approach that an operator having the character of a human factor is of strategic and fundamental importance in this relationship. A technical system can be controlled, a human factor, however, with its complex nature, is difficult in terms of the implementation of control mechanisms, which also determines the strengths and weaknesses of the railway system.

When conducting a multidimensional analysis of primary causes, the majority of them result from human errors. Thus, a key question is how to effectively manage rail transport safety, analyzing the behavior in the dynamic system of railway system operators, which include engine drivers on the side of the railway carrier and the train dispatcher on the side of the infrastructure manager.

The correlation relates, inter alia, to the time of railway occurrences, i.e. month, day, hour and finally, they may also concern the mechanisms of drivers' work, taking into account the driver's professional life cycle, age (age range) and seniority.

The engine driver's rest management is also of particular importance. One of the crucial recommendations is to define and examine driver's rest in a 24-hour cycle. It is surprising that on the basis of data from the Office of Rail Transport, engine drivers that participated in railway occurrences did not include engine drivers who exceeded the allowable rest period between work periods.

The key conclusions defined by the Office of Rail Transport became the source of the following recommendations:

1. Deepening the analysis of the participation of a human factor in the SPADs,
2. Using simulators in the training of engine drivers,
3. Verifying, in the control mode, the effectiveness of the implementation of the Safety Management System,
4. Paying attention to the issue of the theoretical and practical training of engine drivers,
5. Implementing additional organizational and technical resources.

3. The comparative criterion of the selected methods of human factor assessment in the context of rail transport safety

When conducting a multidimensional factor analysis, attention should be paid to the fact that the driver's work is influenced by numerous internal and external stimuli. Internal stimuli are focused on stress mechanisms and work under pressure.

Human factors traditionally focus on ensuring that employees have safe equipment easy to use and a place where they are and where they can work efficiently.

However, the term "human factor" may also be used in a much broader sense. The above aspect has became necessary due to the following interrelated trends:

- Technical systems are becoming wider and more complex, which makes it necessary to consider their impact on a much larger working group as well as the entire organization.
- Work requires increased human knowledge and skills.
- Organizations increasingly consider employees as well as technology as valuable investments.

Instead of focusing only on individual factors such as man-equipment-work environment, it should be ensured that there is the right balance of the organization as a whole. If the organization effectively focuses on all human factors, both the organization and employees benefit from this relationship. The railway sector works best if all human factors are taken into account that can affect its operation, that is, its safety and profitability.

Taking into account human factors in the context of knowledge and technology:

- reduces the possibility of an error
- increases a safety margin
- reduces the potential for costly redesign
- increases the efficiency and effectiveness of training
- reduces the potential of costly staff turnover
- increases the productivity of the entire organization.

The following is a list of various methods for human factor assessment that may be useful in rail transport.

Table 1. List of methods for human factor assessment [own study based on [10]]

No.	Methods
TASK ANALYSIS METHODS	
1.	(HTA) Hierarchical Task Analysis
2.	(GOMS) Goals, operators, methods and selection rules
3.	(VPA) Verbal Protocal Analysis
4.	Task Decomposition
5.	(SGT) The Sub –Goal Template Method
6.	(TTA) Tabular Task Analysis
COGNITIVE TASK ANALYSIS METHODS	
7.	(CWA) Cognitive Work Analysis
8.	(ACTA) Applied Cognitive Task Analysis
9.	Cognitive Walkthrough
10.	(CDM) Critical Decision Method
11.	(CIT) Critical Incident Technique
PROCESS CHARTING METHODS	
12.	Process Charts
13.	(OSD) Operation Sequence Diagrams
14.	(ETA) Event Tree Analysis
15.	(DAD) Decision Action Diagrams
16.	Fault Trees
17.	Murphy Diagrams
HUMAN ERROR IDENTIFICATION METHODS	
18.	(SHERPA) The Systematic Human Error Reduction and Prediction Approach
19.	(HET) Human Error Template
20.	(TRACEr) Technique for the Retrospective and Predictive Analysis of Cognitive Errors
21.	(TAFEI) Task Analysis For Error Identification
22.	(HAZOP) Human Error
23.	(THEA) The Technique for Human Error Assessment
24.	(HEIST) Human Error Identification in Systems tool
25.	(HERA) The Human Error and Recovery Assessment Framework
26.	(SPEAR) System for Predictive Error Analysis and Reduction
27.	(HEART) Human Error Assessment and Reduction Technique
28.	(CREAM) Cognitive Reliability and Error Analysis Method
29.	(SPAR-H) Human reliability analysis method
SITUATION AWARENESS ASSESSMENT METHODS	
30.	(SA) Requirements Analysis
31.	(SAGAT) Situation Awareness Global Assessment Technique
32.	(SART) Situation Awareness Rating Technique
33.	(SA-SWORD) Situation Awareness Subjective Workload Dominance
34.	SALSA
35.	(SACRI) Situation Awareness Control Room Inventory
36.	(SARS) Situation Awareness Rating Scales
37.	(SPAM) Situation Present Assessment Method

38.	(MARS) Mission Awareness Rating Scale
39.	(SABARS) Situation Awareness Behavioral Rating Scale
40.	(CARS) Crew Awareness Rating Scale
41.	(C-SAS) Cranfield Situation Awareness Scale
42.	Propositional Networks
MENTAL WORKLOAD ASSESSMENT METHODS	
43.	Primary and Secondary Task Performance Measures
44.	Physiological Measures
45.	(NASA TLX) NASA Task Load Index
46.	(MCH) Modified Cooper Harper Scales
47.	(SWAT) Subjective Workload Assessment Technique
48.	(SWORD) Subjective Workload Dominance Technique
49.	(DRAWS) DRA Workload Scales
50.	(MACE) Malvern Capacity Estimate
51.	Workload Profile Technique
52.	Bedford Scales
53.	(ISA) Instantaneous Self-Assessment
54.	(CTLA) Cognitive Task Load Analysis
55.	(SWAT) Subjective Workload Assessment Technique
56.	Pro-SWORD – Subjective Workload Dominance Technique
TEAM ASSESSMENT METHODS	
57.	(BOS) Behavioral Observation Scales
58.	(CUD) Comms Usage Diagram
59.	(CDA) Co-ordination Demands Analysis
60.	(DRX) Decision Requirements Exercise
61.	(GTA) Groupware Task Analysis
62.	HTA(T) Hierarchical Task Analysis for Teams:
63.	TCTA) Team Cognitive Task Analysis
64.	(SNA) Social Network Analysis
65.	Questionnaires for Distributed Assessment of Team Mutual Awareness
66.	(TTA) Team Task Analysis
67.	Team Workload Assessment
68.	Task and Training
INTERFACE ANALYSIS METHODS	
69.	Checklists
70.	Heuristic Analysis
71.	Interface Surveys
72.	Link Analysis
73.	Layout Analysis
74.	Repertory Grid Analysis
75.	(SUMI) Software Usability Measurement Inventory
76.	(SUS) System Usability Scale
77.	User Trials
78.	Walkthrough Analysis
DESIGN METHODS	
79.	Allocation of Function Analysis
80.	Focus Groups
81.	Mission Analysis
82.	Scenario Based Design
83.	Task-Centred System Design
PERFORMANCE TIME PREDICTION METHODS	
84.	(CPA) Multimodal Critical Path Analysis
85.	(KLM) Keystroke Level Model
86.	Timeline Analysis

4. The assessment of human errors by means of selected methods and safety management in rail transport

Human error is a complex construct to which considerable attention should be paid in terms of a human factor. Human error has been consistently identified as a factor contributing to a large number of railway occurrences in complex, dynamic systems. In the area of rail transport, human error was identified as the cause of nearly half of all collisions taking place in the UK rail network in 2002-2003 [11]. Although human error has been analyzed since the appearance of this discipline, research into this construct only increased in the late 1970s and early 1980s in response to a number of high profile disasters, in which human error occurred. Human error is formally defined as " *all* those occasions in which a *planned sequence* of *mental* or *physical* activities fails to *achieve* its *intended* outcome, and when *these failures cannot* be *attributed* to the intervention of some chance agency" [12].

Twelve main causes of human errors were identified Within the framework of the human factor assessment. The "Dirty Dozen" contains a number of factors that are the subject of a thorough analysis of the "human factor" [13].

Table 2. "Dirty Dozen" – a list of 12 basic human errors leading to incidents or accidents [13]

No.	Problem	Solution
1.	Lack of communication - errors and interference in the information flow.	• Use logs, spreadsheets, etc. to communicate and remove doubts • Talk about what has been left to do or what has been completed
2.	Complacency - certainty resulting from long-term experience combined with the loss of awareness of existing threats, often caused by repetitive activities and tedious work.	• Never assume anything
3.	Lack of knowledge - lack of clarity or certainty in understanding something	• Get the appropriate training • Use current manuals • Ask a competent person
4.	Distraction - caused, for example, by distraction, confusion, mental chaos.	• Stay focused at the end of work • Mark where you finished your work • Check twice • After returning to work, always commence three steps back • Use a detailed control card

No.	Problem	Solution
5.	Lack of teamwork - inconsistent effort of a group of people caused, for example, by a lack of a sense of shared purpose, fear of showing managers mistakes made by others, an inappropriate leadership style or an inappropriate way of communicating	• Discuss how to do the job • Make sure everyone understands and agrees
6.	Fatigue - it is ignored, because until it is excessive, man does not realize it.	• Be aware of the symptoms and look for them in yourself • Plan to avoid complex tasks when you are tired, e.g. at the end of a shift • Ask others to check your work
7.	Lack of resources - no tools or materials; outdated documentation, improper conditions	• Check suspicious areas at the beginning of the inspection and check the availability of parts • Know all sources available
8.	Pressure - caused by the pressure of superiors or colleagues, lack of time, incorrect setting of tasks	• Express your fears • Ask for additional help • Just say „no"
9.	Lack of assertiveness - lack of the ability to refuse to perform a task resulting, for example, from lack of confidence, anxiety or complexes.	• Deny compromise
10.	Stress - nervousness caused by e.g.: time pressure, a new methodology, change in the scope of tasks, competition or private factors.	• Be aware of how stress can affect your work • Determine a rational course of action • Take time off or at least rest. Discuss your problem with someone • Ask colleagues to monitor your work
11.	Lack of awareness - the incorrect assessment of possible consequences of action caused by e.g.: pressure, lack of experience or lack of knowledge	• Think about what can happen in case of emergency • Check if your work will interfere with an existing modification or repair • Ask others if they see any problem with their work
12.	Norms –most people's acceptance of deviations from instructions as norms facilitating work.	• Always follow the instructions or change the instructions • Be aware that „norms" are not always right

5. The HFCAS model - the Human Factors Analysis and Classification System

In many cases, human factors were the main causes of railway accidents. The Human Factors Analysis and Classification System (HFACS) is the core of the classification modified based on the Swiss cheese model by [17]. Initially, the analysis and classification of pilot errors in maritime aviation accidents and incidents was proposed. The HFACS structure sheds new light on the definition of "holes" in cheese slices, specifying in detail the classification of hazardous activities, preliminary conditions for dangerous activities, dangerous behavior and organizational influences, so that they can be conveniently applied in practice. Clear hierarchies that contain supervisory and management factors make the HFACS framework available to fully deal with human problems in accidents. In addition, the HFACS framework is able to investigate the possible causes of accidents of varying complexity. In recent years, the HFACS framework has been extensively introduced into civil aviation and other areas to investigate human error in accidents due to their high reliability [14].

The HFACS has been developed to provide a structure based on theory to analyze and classify errors made by the operator in accidents. As mentioned above, the "Swiss cheese model" presents errors resulting from holes at four levels of the organization, starting with the operator, through the system to organizational conditions. According to the model, operator's failures combine with hidden factors in the organization that lead to an accident. Active factors include operator actions and decisions taken just before the accident/incident and have traditionally been most frequently cited as the cause of the accident/incident. Hidden factors (decisions or conditions) have often existed for years and are not often directly associated with an accident/incident. They are not often identified as a safety issue, unless they are thoroughly examined [15].

Four levels of the HFACS are dangerous activities, preliminary conditions for dangerous activities, dangerous supervision and organizational influences.

Historically, the HFACS was mainly used to analyze the data available during the investigation of accidents/ incidents. However, the HFACS was designed to also conduct investigations of accidents/ incidents to support the collection of information related to human factors in the first place. The use of the theoretically controlled system of human error classification to investigate accidents /incidents has many potential benefits [15]:

- it provides a coherent and formal structure for collecting and analyzing accident/incident data.
- it ensures that reaching the outcome is systematic and accurate, ensuring that all levels of the system are examined.
- it counteracts the heuristics and deviations that researchers can contribute to the investigation.
- it enables the comparison of the causes of accidents/incidents in various industries that use the HFACS to support their research and analysis.

The HFACS method can be used to collect and analyze accident/incident data due to the fact that it is diagnostic, reliable and comprehensive, based on the widely accepted model (GEMS) of human error in work systems. The method has been successfully applied in other domains (e.g. air traffic control [16] and military operations) [17] and can also be used in rail transport due to the general nature of terminology.

More importantly, the HFACS structure seems to be a useful tool to capture all relevant data on human rail factors. Failures have been identified at all levels of the framework, providing strong support for a systemic approach to a cause and effect relationship [18].

5.1. The SHELL model

The SHELL model is a tool used to analyze relationships between people and other elements of the workplace. The SHELL model contains the following four components:

- Software (S) - procedures, training, support, etc.,

- Hardware (H) - machinery and equipment,
- Environment (E) - work environment,
- Liveware (L) - people in the workplace.

In the center of the SHELL model there is "Liveware", meaning people directly involved in activities. They show, despite their adaptation skills, considerable variation in their activities. Cooperation between various environmental factors functions at different levels. It is necessary to analyze the effects of disturbances in relationships between different SHELL structures in this method and the main factor of "Liveware". It allows for avoiding tensions that could adversely affect human activities. The other factors of the model must be carefully adjusted to people. The mismatch between man and the other four contributes to human error.

5.2. Eye tracking

Eye tracking is a research method in which a device called an eye tracker is used to track the eye movement of the person examined. Even small eye tracking data are collected using a remote or head-mounted "eye tracker" connected to a computer. There are many different types of non-invasive eye trackers, but they usually contain two common elements: a light source and a camera. The camera tracks the reflection of the light source with visible eye features, such as the pupil. These data are used to extrapolate the rotation of the eye and ultimately the direction of the gaze. Additional information, such as the blink rate and changes in the pupil diameter, are also detected by the eye tracking device. Analyzing the movement of the eye, eye tracking allows for determining information about the position of the eyeball at a given moment and to indicate the point of fixation (focus) of the eyesight. This study allows us to determine how people react to a given object, what the recipient focuses on and what information goes unnoticed.

5.3. Pointing and Calling

Pointing and Calling is a method that aims to improve activities ensuring work safety. It improves the state of mind and concentration through the coordination of the sense organs, including vision, brain and consciousness, body movements, inducing and hearing. Pointing and Calling was developed in Japan to strengthen employees' concentration, their awareness and accuracy at work, thus reducing the number of negligence, errors or misunderstandings related to accidents. In the pointing and calling method there is interaction and co-reaction between the operator's brain, eyes, hands, mouth and ears. Not only seeing, but also pointing, and sometimes observing, allow for avoiding negligence and help stay focused. In the case of simple tasks (and most of these tasks are relatively simple), this technique reduces errors by almost 85%. The number of accidents in Japanese rail transport has decreased by 30%, making train travel in Japan the most reliable and safest train journey in the world.

6. Conclusion

The dynamic development of rail transport in Poland requires a holistic look based on the use of many good and tested patterns of conduct from other, more developed economies of the world. This applies to both technological and management aspects. It is particularly important, however, when defining the prognostic and planning assumptions resulting from ensuring an acceptable level of safety and risk in rail transport. In Polish conditions, many decisions are taken in the context of neutralizing the adverse effects of railway accidents or disasters. The complexity of the issue is important, as the human factor functions in the context of a dynamic environment. Thus, the interaction between these components determines rail traffic safety or its lack. It is important to look for cause and effect relationships and correlation between these components using the methods of human factor assessment in rail transport.

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