

Impact of automated systems on reducing the human factor in rail transport

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ABSTRACT

In the last 5 years, the role of rail transport has grown a lot within the European Union. It is the most environmentally friendly and safest transport, transports a huge amount of cargo and passengers over short and long distances, and employs thousands of people. There is a shortage of trained personnel in all European countries. The human factor is still leading in all activities in railway transport. This leads to wrong ones that are the result of accumulated fatigue, distraction, delayed reactions, incorrect reading of signals, etc. Digitalization in rail transport aims to increase its safety and reliability. This article reviews the impact of automated systems to reduce human error. The advantages and disadvantages of modern technologies used for this purpose are analyzed. Different types of process automations are presented - semi-automatic and automatic. The challenges accompanying the implementation process are considered, such as high cost, infrastructure modernization and cybersecurity. Automated systems are not aimed at completely replacing people, but at supporting and controlling processes. The future of rail transport is impossible without the deployment of intelligent and automated systems.

KEYWORDS

Railway transport, Human factor, Automation, ERTMS, ETCS, ATO, Safety, Cybersecurity.

1. INTRODUCTION

In the context of increasing mobility and the need for safe, sustainable and environmentally friendly transport, the role of railways in passenger and freight transport is increasing. High capacity, energy efficiency and minimal environmental impact define rail transport as key. For the effective functioning and public trust of rail transport, it is important to ensure its reliability and safety. Digitalization in rail transport is a process in which modern technologies support, replace and fully realize the connection between people, systems and rolling stock. It includes intelligent signaling, continuous communication, automated infrastructure monitoring, maintenance and real-time data integration between all dependent actors – trains, infrastructure and control centers [1]. (Commission E. , 2026)

Through the digitalization of railway transport, the issue of the shortage of physical infrastructure can be solved by increasing the capacity of the existing ones. Some operational types of human error are significantly reduced, while at the same time emerging new risks such as cyber threats, problems with monitoring and verification of systems. Automation affects the frequency of operational human errors occurring in routine tasks. Automated systems are very reliable in performing repetitive operations and in reducing risk in high-risk activities. On the other hand, digitalization is changing the type of human errors that result from the use of automated systems [2]. (Vanderhaegen, 2021, 189–192)

2. HUMAN FACTOR IN RAIL TRANSPORT

The human factor in railway transport includes knowledge, experience, attention, communication skills, decisions under pressure. The operation of the rail system depends not only on technique and procedures, but also on the way in which employees apply them in practice [3]. (EUAF, 2016). The human factor is one of the most significant elements influencing railway safety. Most accidents occur not due to a single technical error, but as a result of errors in monitoring, communication, decision, or reaction. Rail traffic is high-speed, highly coordinated, and dependent on strict adherence to rules and

signals, and any mistake can have serious consequences [4]. (Human-Centered Systems Approach in a Social-Technical System, 2019)

Human errors in rail transport are divided into three main groups – operational, cognitive and organizational. The first group includes incorrect reading of signals, inappropriate estimation of distance or speed and omission of important information from the environment. The second group includes errors that are the result of an incorrect choice of action in a situation of risk, and the third - a delayed or inaccurate operational reaction [5]. (Melissa T. Baysari, 2008)

Table 1: Types of human errors in railway transport

Types of errors	Manifestation
Operational	Incorrect submission or interpretation of signals. Errors in arrow and route settings. Increasing the permissible speed. Failure to comply with the permissible speed. Failure to follow instructions and procedures.
Cognitive	Incorrect assessment of the situation. Delayed reaction. Loss of concentration. Information overload.
Organizational	Insufficient training. Lack of clear procedures. Ineffective communication. Insufficient safety control. Insufficient risk management.

In the report, human error is seen not only as a personal omission, but as a result of the organizational environment, workload, communication, and process design. It is recommended that when analyzing incidents, look not only for "who made a mistake", but also "why it was possible to make a mistake". The aim is to build more reliable working practices and reduce risks. Clear instructions, good training, fatigue, working hours, coordination between teams and the quality of information directly affect the safety and quality of services [3].(EUAF, 2016)

Causes of Human Errors

The main causes of human errors are fatigue and monotony, stress and lack of timely information. A study was conducted on 1391 high-speed train drivers in China. Its conclusions show that fatigue and stress increase human error by worsening situational awareness. The error is not an isolated personal omission. It is the result of the interaction between man, technology, environment and organization [6].(Wenil Dong, 2024)

Human errors can be caused by faulty equipment and technology, by designers, manufacturers, operators or maintenance persons, excessive speed or load. Human errors related to skills are observed at all times, as part of a series of events that caused an accident. Such events may involve negligent inspection and maintenance and are part of organizational and system errors [7].(Zhuru Wang, 2016)

Fatigue affects the working capacity of all people; it is normal to affect railway personnel as well. Shift work, night work and the need to concentrate lead to reduced alertness, slower reactions, difficulty making decisions, increased risk of mistakes. This identifies fatigue as a factor that increases the likelihood of operational disruptions and incidents in transport systems. Fatigue affects the perception of the situation, signals, the environment, and affects problem-solving abilities [8]. (Yaser Haj Yousef, 2014)

Insufficient or incorrectly submitted information between drivers, dispatchers, signaling and technical personnel can be the cause of serious traffic management violations. Research shows that poor communication is among the most common factors in the occurrence of accidents in complex transport systems. According to the analysis of railway accidents, communication gaps are often accompanied by organizational and technical weaknesses. The lack of data on the spatial and temporal characteristics of the operational situation creates a risk, as the operator is forced to act on the basis of intuition or incomplete knowledge. It is important to note that with all the training, serious experience and good education of the operator, there may be a different way of performing a procedure [9]. (RAIB, 2015). Mistakes resulting from an incorrect decision are the result of a bad choice or wrong procedure. These errors are the result of a deliberate act or omission on the part of the operators, where the plan proves to be inappropriate for the situation [10]. (Ndaru)

Impact on Safety

Human errors have a serious impact on railway safety and are the cause of collisions, derailments, accidents at level crossings, traffic schedule problems. As a result of them, significant material damage, victims and injured occur. The main directions for ensuring the safety of the transport process include the reliability of technical means, the human factor and the legislative framework. The human factor is the most vulnerable link in the safety system, as they work in an area of uncertainty and subjective decision-making [11]. (Зоя Хубенова, 2016)

3. AUTOMATED SYSTEMS IN RAIL TRANSPORT

Automation and computers increase reliability and safety by performing some of the control and computational functions in complex technical systems. In rail transport, they support monitoring, signaling and failure, speed control, which reduces dependence on momentary human reactions. Modern automated systems do not eliminate risk, but transform it, as they create new dependencies on software, interface and data quality, which require constant human supervision and a high level of cybersecurity. Automated systems in railway transport are a complex of technical solutions that support or partially replace humans in management, control, signaling, diagnostics and support. Their use reduces subjective judgment in critical situations and ensures standardized and safe train movement [12]. (Dekker, 2001)

The European Rail Traffic Management System (ERTMS) was developed to create a single railway area and bridge the gaps between more than 30 national and incompatible systems. It can be implemented as a supplement to the existing system or as a main one when building new infrastructure. Table 2 summarizes the advantages of ERTMS [13].(ECII, 2017)

Table 2: Advantages of ERTMS

Advantage of ERTMS	Influence
Increased safety	Reduces the risk of collisions and speeding.
Reducing human error	Standardized procedures and automatic intervention reduce the possibility of human decisions.
Compatibility	Uniform protocols allow seamless passage between different operators and networks.
Capacity Increase	Tight intervals and automated operations.
Improved service	Improved traffic and quality management.
Safe crossing	Higher safety at level crossings.

ERTMS allows for automatic monitoring and control of speed, signaling and traffic safety, limiting the risk of human error. It includes three subsystems. ETCS for speed control and traffic protection and GSM-R for safe radio communication between the dispatcher, infrastructure and train. The third ATQ system helps trains run automatically. In this way, the need for manual protective actions and subjective decisions of staff through automatic monitoring and intervention is reduced. Automatic intervention ETCS can stop or penalize the train if the observed parameters are exceeded and thus limits the possibility of human error.

The European Train Control System (ETCS) provides cab signalling and automatic train protection. The system receives information about the movement of the train from balises, radio block centers or other communication channels. If the driver does not react when speeding or approaching danger, the system automatically triggers a braking.

Level 0 and level NTS (National Train Control) are related to the compatibility status of the borders. Level 0 describes the mode of operation in which the locomotive is equipped with ETCS but runs on an unequipped railway. At Level 0, there is no exchange of information between the train and the infrastructure via ETCS and traffic control is carried out through the national signalling system. On-board equipment monitors only the maximum permissible speed, and the driver relies on roadside signals.

In ETCS Level 1, the information is transmitted automatically via balises located along the route. Eurobalise electronic devices mounted on the tracks, which send information to the passing train about the permitted speed, the status of the signals, specific characteristics of the section, the traffic permit. The transmission of information is known as stop transmission or point data transmission. Switching to Level 1 leads to an increase in traffic safety, controls speed, allows the use of existing national signaling, prevents crossing at a prohibitory signal, lower cost than ETCS Level 2.

In ETCS Level 2, there is continuous communication using a radio connection, which allows dynamic motion control. There is a continuous exchange of data between the train and the infrastructure via radio communication. Eurobalises continue to be used, but to determine the exact location of the train on the track. ETCS Level 2 continuously monitors the speed, location, section, condition of the switches, distance to the transition train. In the event of any deviation from the permissible parameters, the system immediately warns the driver or automatically triggers the emergency braking. All this leads to a reduction in human error, increased safety and higher line throughput.

ETCS Level 3 is the carrier of the concept of a mobile unit and efficient use of infrastructure. At the transition levels, the railway is divided into block sections. One block can only be occupied by one train.

Table 3: Comparison of different levels

Level	ETCS Infrastructure	Speed control	Data transmission
Level 0	Nope, I don't	Limited	None
Level 1	Yes (close)	Yes	Tochkovo
Level 2	Yes	Yes	Continuously
Level 3	Yes	Full	Continuous and dynamic

Table 3 shows a summary of the data on how the degree of automation and control of train traffic changes at different levels of ETCS. With the transition from Level 0 to Level 3, the role of the driver gradually decreases, and the role of automated systems increases [14]. (Commission E. , 2026)

4. IMPACT OF AUTOMATION

Automation in rail transport leads to a reduction in human error, because it transfers critical functions such as speed monitoring, traffic control and part of operational solutions to systems with continuous automatic control. This is extremely important in conditions where fatigue, stress or lack of information can slow down the driver's response and increase the risk of an accident (P). Automation reduces the likelihood of accidents, since the driver's attention and reaction are not leading.

Cab signaling provides the driver with information about the permissible speed, subsequent limits, braking curve and thus reduces the interpretation of external signals in case of poor visibility, high speed or complex infrastructure. With proper implementation of automation in railways, compliance with traffic schedules can be improved, energy consumption can be reduced and operational errors can be reduced.

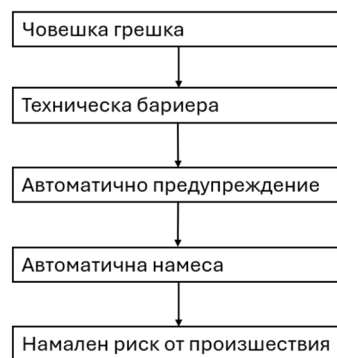


Figure 1: Impact of automation on the human factor

As a disadvantage of automation, the possibility of reducing the practical skills of staff can be considered, since it is rarely switched to manual control. In emergency situations, the operator must quickly regain knowledge, skills and make a decision, which can be difficult after a long period of passive observation. To maintain this knowledge and skills, periodic trainings, simulations and competence checks are carried out, as they are a mandatory element of safe automation.

5. CYBERSECURITY IN RAIL TRANSPORT

Cybersecurity

Digitalization is an inevitable process that also affects rail transport, bringing with it positive and negative consequences. Due to the increased number of connected systems and interactions between digital and physical components, the risk of cyberattacks increases. This necessitates the development of new approaches and architectures to improve cyber resilience, as there are problems with outdated security systems. The study shows that there is a lot of research in the field, but there is a need for a cybersecurity strategy in the railways that incorporates the new challenges. Most developments are theoretical and without the application of artificial intelligence [15]. (Ravdeep Koar, 2022) The problems, threats, and applications of artificial intelligence in cybersecurity are discussed in detail in [16]. (G. Hristov, 2023)

ERTMS works through a constant volume of data between trains, infrastructure and dispatch headquarters. Such exchanges must be protected from external attacks, disruptions and unauthorized access. The security of communication channels is very important, because even a small problem in them can affect the movement and safety of trains. The system should allow future upgrades to introduce new features, communication protocols without disrupting the operation and [17] (C).

The future development of rail transport will be related to the use of artificial intelligence, sensor systems, digital twins, predictive maintenance and autonomous train control. Through the new technologies, it will be possible to detect anomalies in real time, optimize schedules, manage energy consumption and predict possible failures. The aim is to achieve preventive safety, with the system identifying dangerous trends before they turn into incidents [18] (T).

The application of autonomous trains in railways is more complex than an automated metro. The reason is that metro systems operate in a closed and controlled environment, while rail operations include level crossings, a variety of rolling stock, open infrastructure, interaction with outsiders, weathering and higher speeds. To ensure the safety of passengers, an autonomous train must recognize obstacles, assess the condition of the infrastructure, communicate with dispatch systems and, in case of refusal, pass into a safe state. The reduction of the human factor does not mean its complete exclusion, but the redistribution of functions between man and machine. Automation takes over routine and critical defense functions, and the human remains responsible for supervision, ethical judgment, emergency management, and strategic decisions [19], [20], [1]. (U), (F).

Summary of the Study

The more the human factor is reduced through automation, the greater the dependence on cybersecurity increases. Table 4 summarizes the data from the survey.

Table 4: Major cyber risks

ETCS Level	Automation	Influence of the human factor	Main cyber risks
Level 0	Very low	Very high	Limited risks; Local unauthorized access to on-board systems; Lack of centralized protection.
Level 1	Low	High	Manipulation of balize data; Unauthorized access to on-board equipment; Vulnerability in data exchange between infrastructure and train.
Level 2	High	Average	Attacks on the GSM-R network; Refusal to communicate; Falsification of messages; DoS attacks; Compromise of the Radio Block Centre (RBC).
Level 3	Very high	Low	Cyber attacks on traffic management systems; Compromising train location data; Attacks on train integrity control systems; Attacks on cloud and artificial intelligence-based platforms; GPS/ GNSS spoofing.

Table 4 clearly shows the upward trend towards the level of automation from ETCS Level 0 to ETCS Level 3, the influence of the human factor is decreasing, but the dependence on digital technologies and the associated cyber risks is increasing. At Level 0, safety depends entirely on driver actions and traditional signalling, which is why cyber risks are limited. With the transition to Level 1, the use of Eurobalise devices begins, introducing the first potential vulnerabilities related to the exchange of digital data.

At Level 2, rail transport relies on continuous communication via GSM-R and Radio Block Centre, which significantly reduces human error, but creates opportunities for attacks on communication infrastructure and control centers.

At Level 3, cybersecurity becomes a key factor for the safe operation of railway infrastructure.

CONCLUSION

The study shows that rail automation reduces the risk of human error, but increases dependence on digital technologies and serious cyber protection is needed to ensure safe operation. The future development of ERTMS needs to be accompanied by measures to increase automation and cybersecurity solutions.

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