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STATUS AND PROSPECTIVE DIRECTIONS FOR IMPROVING SAFETY OF TRAIN TRAFFIC

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Train safety is a key element of the stable operation of railway transport, which plays a critical role in ensuring the mobility of the country's population and economy. This is especially relevant for Ukraine, where the share of rail traffic is more than 60% of freight traffic and a significant portion of passenger transportation. In the context of the growing load on the infrastructure, depreciation of fixed assets, and the challenges caused by military operations, the issue of safety has become particularly important.

The railway safety system covers a range of technical, organisational, regulatory and personnel measures [1]. However, an analysis of the current state points to a number of systemic problems: outdated traffic management technologies, high levels of wear and tear on rolling stock and infrastructure, insufficient automation, and a lag in the implementation of international risk management standards. According to statistics from the European Railways Agency (ERA), the main causes of railway accidents include technical malfunctions (38% of cases), human factors (up to 30%), external interference (including vandalism and interference with systems), as well as natural disasters and climatic factors [2, 3, 4].

In recent years, damage to infrastructure elements as a result of hostilities has been a particular threat. The destruction of railway bridges, junctions, power supply and signalling equipment leads to unpredictable disruptions in train traffic and makes it impossible for transport corridors to function properly. In these circumstances, there is an urgent need to modernise the safety management system, which should include not only technical upgrades but also the introduction of modern methods of risk forecasting and prevention.

The key technical equipment that plays a crucial role in ensuring traffic safety includes signalling, centralisation and interlocking systems, automatic locomotive signalling (ALS), as well as rail circles and other devices for detecting the presence of trains on the section. Microprocessor-based control systems play a special role, allowing for centralised real-time traffic management and rapid response to changing situations. Video surveillance systems, axle box condition monitoring sensors, and integrated IoT systems are also being increasingly implemented to monitor the technical condition of infrastructure and rolling stock, which allow for the implementation of Predictive Maintenance principles, i.e., to prevent malfunctions before they occur [5].

The human factor remains one of the most critical issues in the security system. Insufficient staff training, violations of instructions, overwork and stressful situations all lead to an increase in accidents. In view of this, it is becoming increasingly important to introduce automated systems for monitoring driver attention, digital simulators for modelling non-standard situations, and platforms for remote testing of personnel knowledge and skills. According to international experience, the introduction of biometric systems for monitoring the psycho-physiological state of employees is also effective, allowing for timely detection of risks of disability. Higher education institutions, including the UkrSURT, are implementing updated curricula focused on modelling real-life risk scenarios and integrating IT tools into the training process.

Safety management is impossible without effective regulatory and legal provision. In Ukraine, the basic documents are the Rules for the Technical Operation of Ukrainian Railways, the Signalling Instruction, and the Law of Ukraine On Railway Transport. At the same time, the issue of harmonising the regulatory framework with the European Union directives, in particular, the implementation of a safety management system (SMS) in accordance with ISO 45001 and the ISO 31000 principles of risk management, is becoming increasingly relevant [4, 6]. Such a system allows identifying, analysing and eliminating risks at all stages of infrastructure and transportation management.

In view of the above, the strategic priorities in the field of train safety should be deep technical modernisation, digital transformation of management processes, human capital development and institutional reform. It is advisable to actively implement the ERTMS/ETCS system, the European Train Management System, which has already proven its effectiveness in EU countries. In addition, strengthening international cooperation with organisations such as UIC and ERA and active participation in projects of integration into the TEN-T transport system should be an important component. Considerable attention in modern practice is paid to the concept of Smart Railway, which involves the comprehensive digitalisation of infrastructure. As part of this concept, solutions based on the Internet of Things (IoT) are being implemented to enable real-time monitoring of the condition of tracks, bridges, tunnels, signalling equipment and rolling stock. Sensor data is processed using analytical platforms with artificial intelligence elements, which allows not only to record deviations but also to predict the likelihood of malfunctions. Such technologies are already being implemented on pilot sections of the Ukrainian railway with the participation of international partners [7].

Another promising technology is the use of satellite systems (GNSS) in combination with telematics for precise train positioning. This allows for more flexible traffic management, especially on sections without classic relay systems or where infrastructure is partially destroyed. In combination with cloud services, this creates the basis for building new logistics models that take into account the real conditions in a war zone or emergency. Such solutions have already been

implemented in some European countries as part of the development of ERTMS Level 3 [8].

An important component of improving traffic safety is the development of diagnostic and automated fault detection systems. In particular, we are talking about the introduction of Wayside Monitoring Systems - stationary systems for monitoring the condition of wheel sets, braking systems, overheating of axles and load parameters. They are installed along the track and transmit data in real time to diagnostic servers. This allows for the localisation of defective cars before an incident occurs and the formation of a database for decision-making at the fleet management level [9].

In today's environment, cyber-security of railway systems is also of particular importance. Microprocessor-based control devices, automated workstations for dispatchers, transportation databases, ticketing systems and logistics platforms are all critical infrastructure that can be targeted by cyber-attacks. According to ENISA recommendations, the railway industry should implement IEC 62443 standards, use VPNs and data encryption, multi-level authentication, and create backup data centres and recovery systems. Ukraine already has positive experience in implementing such solutions at the level of UZ in cooperation with European IT companies.

So, ensuring train safety is a multi-factorial process that requires coordinated action at all levels – from technical equipment to regulatory regulation and staff training. With an integrated approach and the introduction of innovative technologies, the Ukrainian railway is able to ensure not only an adequate level of safety but also competitiveness in the European transport space.

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