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A model for determining employee compliance with professional requirements in human–machine systems of railway transport

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Abstract: The article discusses the issues of minimizing the influence of the human factor on train traffic safety and occupational safety in railway transport. An analysis of statistical data on occupational injuries and violations of labor protection requirements at the enterprises of JSC "Uzbekiston Temir Yollari" was carried out. It was established that a significant part of safety violations is associated with an insufficient level of professional training, non-compliance with technological processes, and inadequate control over personnel activities. A methodology for determining the professional profile and assessing the degree of compliance of an employee's individual profile with the requirements of a specific professional activity is proposed. The methodology is based on comparing the reference professional profile and the individual characteristics of an employee using normalized indicators and weight coefficients of significance. A compliance assessment coefficient was developed, making it possible to determine the level of professional suitability of personnel, identify risk groups, and formulate recommendations for training, rotation, and restriction of access to certain operations.

Keywords: railway transport, human factor, train traffic safety, labor protection, professional profile, profession profile, personnel assessment, occupational injuries, professional suitability, risk of errors, modeling, personnel management

1. Introduction

According to international and industry studies, a significant proportion of transport accidents, incidents, and train traffic safety violations in railway transport are caused by the human factor. Errors made by locomotive drivers, station duty officers, train dispatchers, and signaling and communication personnel often become the triggering mechanism for emergency situations even when the technical equipment is in proper operating condition. This indicates that ensuring a high level of reliability of technical facilities alone does not guarantee the safe functioning of the transport system without considering the human component [1].

Railway transport is a complex multi-level human–machine system in which the reliability and safety of operation depend not only on the technical condition of infrastructure and rolling stock, but also largely on the actions of operating personnel. Despite the high level of regulation, automation, and standardization of processes, the human factor remains one of the key sources of risks affecting train traffic safety and the stability of the transportation process [2].

2. Research methodology

The results of the analysis of safety violations among transportation service employees showed that about 82% of cases occur during station operations and 18% during freight operations. The main subjects violating labor safety requirements in transportation operations are station duty officers, yard duty officers, shunters, chief conductors, and train inspectors [3].

At the enterprises of JSC "UTY", analyses were carried out regarding compliance with occupational safety requirements (Figures 1–2 and Table 1).

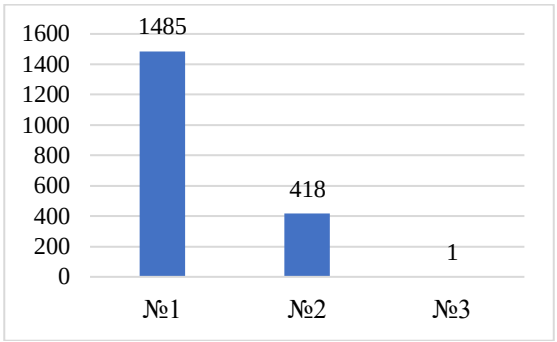

Fig. 1. Chart of warning tickets withdrawn by occupational safety service employees in 2024

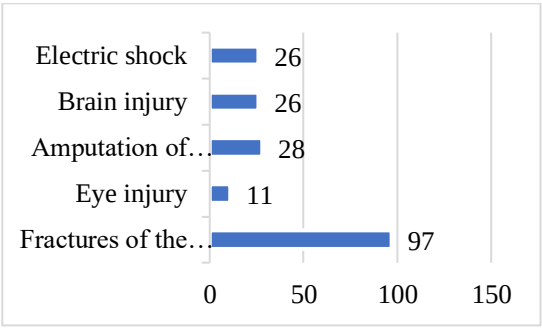

Fig. 2. Recorded types of injuries sustained by employees of JSC "UTY" at the workplace

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Table 1

Types of occupational accidents recorded at the enterprises of JSC "UTY" during the period 2019–2025

№	Occupational accidents (year)	Total number of occupational accidents	Including: Fatal accidents	Accidents with severe injuries	Accidents with minor injuries
1	2019	34	6	19	9
2	2020	21	5	10	6
3	2021	30	5	18	7
4	2022	23	5	13	5
5	2023	23	6	14	3
6	2024	30	7	17	6
7	2025	27	9	11	7
	Total:	**188**			

A measure to improve the current situation is the modernization of equipment. In recent years, Uzbekistan has actively begun modernizing its railway infrastructure. At major railway hubs, mechanized unloading systems such as wagon tipplers are being introduced, which makes it possible to reduce human involvement in hazardous processes. The Ministry of Employment and Poverty Reduction, together with JSC "Uzbekiston Temir Yullari", has launched training programs for workers at industrial enterprises, particularly in the field of compliance with safety regulations and operation of modern equipment. The introduction of stricter occupational safety requirements, as well as the implementation of control and audit systems on industrial access tracks, also contributes to reducing occupational injuries [3].

It has been established that the following deficiencies in the field of occupational, technical, and industrial safety are repeatedly observed at the enterprises of JSC "UTY":

non-compliance with technological processes;

failure of enterprise managers and chief engineers to comply with the fundamental provisions of occupational safety and insufficient consideration of labor protection issues;

insufficient attention of middle-level managers to violations of occupational safety requirements during working hours;

low level of occupational safety knowledge among enterprise management and middle-level managers;

poor quality of initial supervision and professional training of newly hired employees;

newly employed workers are assigned to unqualified specialists, and the work process remains uncontrolled;

employees involved in train operations continue working despite not having passed mandatory periodic medical examinations within the established time limits;

failure to conduct three-stage occupational safety control in accordance with the requirements of Regulation NBT-313, or superficial implementation of such control without participation of enterprise managers, chief engineers, and occupational safety representatives;

various occupational safety briefings for middle-level managers are conducted in violation of the requirements of Regulation NBT-312.

The presented statistical data on occupational injuries in the Republic of Uzbekistan for the period 2020–2024 indicate a persistently high level of risks in the transport industry, which is traditionally considered one of the most hazardous sectors of the economy. Of particular concern is the increase in the number of severe injuries and fatal accidents, indicating systemic problems in ensuring occupational safety and the reliability of production processes.

The analysis of occupational accidents shows that the transport industry occupies a leading position in terms of the number of severe occupational injuries, which is directly related to the high complexity of technological operations, the increased responsibility of personnel, and the significant share of manual labor. These circumstances create conditions in which the human factor becomes one of the key risk elements affecting both the level of occupational injuries and train traffic safety.

3. Results and discussion

Minimizing the impact of human errors in railway transport requires a comprehensive approach focused not only on control and punishment for violations but also on the prevention of erroneous actions at early stages of their occurrence. Modern scientific and practical approaches consider a human as an element of a human–machine system, whose behavior is shaped by technical, organizational, and social environments. In this regard, error minimization strategies should be aimed at improving all components of the system.

1) Improvement of organizational and managerial mechanisms

A key direction is the transition from formal control to proactive safety management. This includes:

implementation of risk-oriented approaches in planning and organizing the transportation process;

regular analysis of incidents and near-miss situations;

development of a safety culture in which employees are not afraid to report risks and errors;

clear distribution of responsibilities across management levels.

2) Improvement of personnel training quality

An effective system of training and retraining is one of the most efficient ways to reduce the likelihood of errors. Important elements include:

simulator-based training with modeling of emergency situations;

regular certification of employees involved in train operations;

training in decision-making under time constraints;

development of teamwork and communication skills.

3) Optimization of working conditions and work-rest schedules

The physiological and psycho-emotional state of employees directly affects the probability of errors. Therefore, the following are required:

rational shift schedules;

monitoring of fatigue and stress levels;

compliance with rest time requirements;

improvement of workplace ergonomics.

4) Improvement of interfaces and automated systems

Modern automated control systems should be designed with a human-centered approach. This includes:

simplification of control logic;

reduction of information overload;

visualization of critical parameters;

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implementation of decision support systems and automated prompts.

5) Formation of a professional profile and personnel selection

One of the promising directions is the use of methods for assessing the compliance of personal and professional characteristics of an employee with the requirements of a specific profession. This allows:

reducing the risk of assigning unqualified personnel;

predicting the likelihood of erroneous actions;

individualizing training and development programs.

6) Technical and technological modernization

Reducing the share of manual operations, introducing mechanized and automated tools, as well as digital process management platforms, makes it possible to decrease the influence of the subjective factor and improve overall system stability.

The methodology is based on comparing two vectors [4]:

the reference professional profile;

$$P = \{K, C, P, F, E, R\} \quad (1)$$

the individual employee profile [5].

$$P_w = \{K_w, C_w, P_w, F_w, E_w, R_w\} \quad (2)$$

The comparison is performed using normalized indicators (0…1), taking into account significance weight coefficients w_i. Stage 1. Collection of Initial Data

Two sets of data are formed:

professional requirements;

employee data: testing results, medical indicators, simulator results, certification outcomes, indicators of errors and violations. Stage 2. Normalization of Indicators

All parameters are converted into the range from 0 to 1 [6].

$$p_i = \frac{x_i - x_i^{min}}{x_i^{max} - x_i^{min}} \quad (3)$$

Stage 3. Calculation of Integral Indices

$$I^* = \sum_{i=1}^{n} w_i \cdot p_i^*, \; I_w = \sum_{i=1}^{n} w_i \cdot p_{i,w} \quad (4)$$

Stage 4. Assessment of the Degree of Compliance Using the Similarity Coefficient

$$S = 1 - \sum_{i=1}^{n} w_i \left| p_{i,w} - p_i^* \right| \quad (5)$$

Integral indices are calculated on the basis of normalized indicators and significance coefficients $S \in [0; 1]$.

Interpretation:

S≥0,85S≥0,85 – full compliance;

0,70≤S<0,850,70≤S<0,85 – acceptable compliance (moderate risk);

S<0,70S<0,70 – non-compliance (high risk of errors) [7].

Stage 5. Development of Recommendations

Based on the components with the greatest deviations, the following are developed:

training programs;

restrictions on access to operations;

recommendations for rotation or changes in working conditions

The value of S is used as an input parameter in the probabilistic simulation model for:

adjusting the probability of errors;

assessing the effectiveness of management measures;

selecting optimal personnel allocation scenarios.

4. Conclusion

The analysis of statistical data on occupational injuries at the enterprises of JSC "Uzbekiston Temir Yullari" showed that the human factor remains one of the main causes of train traffic safety violations and production process failures. It was established that the most common causes of accidents and hazardous situations are non-compliance with technological processes, insufficient professional training of employees, weak managerial control, and violations of occupational safety requirements. A methodology for determining the professional profile and assessing the compliance of an employee's profile with professional activity requirements was developed based on the comparison of normalized indicators with significance coefficients. The proposed compliance coefficient makes it possible to quantitatively assess the level of professional suitability of employees, identify potential risks of errors, and make management decisions aimed at improving personnel reliability. It was established that the use of an integrated assessment of professional compliance contributes to improving the effectiveness of personnel management systems, reducing the probability of employee errors, and increasing train traffic safety.

The developed methodology can be integrated into digital personnel management systems and used for professional selection, certification, training, and allocation of railway transport personnel.

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