Risk Management in Transportation Safety System

T A Finochenko¹, L V Dergacheva², I A Yaitskov³

¹Rostov State Transport University (RSTU), Research and Production Center «Labor Protection», Candidate of Engineering Sciences, Associated Professor, 2, Rostovskogo Strelkovogo Polka Narodnogo Opolcheniya sg., Rostov-on-Don, 344038, Russia
²Rostov State Transport University (RSTU) 2, Rostovskogo Strelkovogo Polka Narodnogo Opolcheniya sg., Rostov-on-Don, 344038, Russia
³Ph.D. (candidate of technical Sciences), Associate Professor, Chair «Life Safety»
³Rostov State Transport University
Doctor of Engineering Sciences, Associate Professor, 2, Rostovskogo Strelkovogo Polka Narodnogo Opolcheniya sg., Rostov-on-Don, 344038, Russia

E-mail: l.v.gromova@mail.ru

Abstract. This article presents a conceptualized analysis of technology-related risks for a transportation safety system. It also considers its subsystems that impact safety. The scheme developed allowed defining the key factor influencing transport safety through accounting various destabilizing impacts. The authors claim that the human factor is the key one, which is especially true for locomotive crews responsible for transportation. Locomotive crew working conditions are described in a visualized combination of negative effects people suffer in an engine cab. Based on the statistics collected and analyzed, the article presents specific occupational diseases of transportation workers. The dynamics of mental capacity and the state of the cardiovascular system of locomotive crews were analyzed using the WAIS test. The research results can be used in the practices of the Russian Railways to facilitate the efficiency and coherence in decision making related to labor safety.
Keywords: Transportation safety, locomotive crews, risk management, occupational diseases, injury factors.

1. Introduction
The Human-Machine-Environment systems are fundamental for the business processes of the railroads. They perform the basic workflows and operations and comprise both personnel, technologies, and equipment implementing the main purpose of the railroads, i.e. transportation and rolling-stock operation.

Solving the problems of occupational safety and employee health preservation must be carried out using a systematic approach based on the fundamental prevention principles at all levels from corporate to governmental. One of the key features of the safe labor concept is the reduction of workplace injury risks and occupational disease rates, as well as the improvement of working conditions and
preservation and improvement of employees’ health. The safe labor concept is based on labor-management that would not ignore safety requirements or undermine the economic feasibility of the organization, which is the firm basis for a sustainable development strategy [1, 2].

The analysis of numerous research papers [2, 4, 6, 7, 9, 11-13, 15, 23, 24] confirms that occupational diseases occur due to the poor working conditions and employees’ health largely depends on the duration and intensity of the exposure to occupational hazards. Adverse working conditions lead to early aging, the reduction of life expectancy, employee health deterioration, and the resulting increase in social relief costs [5].

2. Rationale
Our civilization follows the sustainable development path as defined by the goals formulated by the UN in 2015. One of them is good health and well-being. The World Health Organization defines health as “the state of complete physical, spiritual, and social well-being and not just the absence of diseases of physical deficiencies” [1]. Therefore, the introduction of a risk-oriented approach to labor safety is the next possible option for society to solve the problem of employee health preservation and workplace injury reduction.

The problems of labor safety are pressing due to the rates and severity of occupational diseases and injuries, as well as the number of accidents in various industries, which influences business process safety. Rail transport is an industrial transportation system, which means that apart from the high degree of responsibility due to train safety requirements, employees are also exposed to occupational hazards. The majority of all transport employees (over 34%) work under harmful conditions in their jobs. According to the official reports of the Russian Railroads Department of Labor Protection, Industrial Safety, and Environmental Control, the company employs about 336 thousand people, of which 84 thousand are associated with harmful working conditions. These conditions increase the risk of occupational disease occurrence, as well as incident risk due to employee’s tiredness. To define the risks, one needs a comprehensive understanding of the sources and causes of the respective hazards, as well as qualitative and quantitative assessment criteria for specific hazards and their combination [9, 11-13].

Global trends in introducing a risk-oriented approach to labor protection are quite complicated. Most developed countries already use and continuously improve their risk management practices. This is due to the on-going increase in the number of risks and their diversity: work status changes, workplace reconfiguration, increasing the proportion of senior employees, defining psychosocial factors as occupational hazards, etc. [16-19].

That is why safety factor detection is becoming more and more relevant. This is especially true for the transportation industry because disturbances in this area lead to disasters with huge casualties and environmental damages. As of today, there are no recommendations to detect and eliminate occupational hazards and injuries that would form the backbone of risk management and increase the safety of railroad facilities.

3. Problem statement and theory
Any potentially dangerous object has two states: workable and unworkable. The unworkable state always stipulates that the object is broken. The workable state, on the contrary, can imply the object is either operational or broken. Manufacturing faults are the main causes of dangerous equipment malfunctioning arising due to the development mistakes or insufficient durability of come components. That is why the authors have to conduct taxonometry of destabilizing factors for transportation processes and find the factors with the biggest impact on their safety. Use the systemic approach to represent the safety system structure and view it as a three-fold composite of Supersystem - System - Subsystem. This approach to detecting parameters with the biggest impact on process safety has not been properly used before, although some authors tried to apply it [3, 4].

The authors will represent the Safety System as a three-fold composite of Supersystem - System - Subsystem. The notion of a system and its position are quite relative. Every system has its hierarchy,
and the systemic approach research shows that the object under study is relative. When working with the three-fold composite, it is necessary to consider the configurator [3]: this knowledge subsystem includes an integral picture of all objects in the system and its implementation aspects.

There is a certain core system (hereinafter the Wheel-Rail), and a number of subsystems are located around this core, which defines its functioning. Transportation safety is one of such subsystems. The Wheel-Rail is the configurator for these subsystems, and the subsystems of the Infrastructure and the Train directly implement the transportation and the functioning of the traffic safety system. The network structure with a poor hierarchy is the basis of the safety subsystem (Fig. 1). The conceptualized structure of the system described above is presented in Figure 1 and it can be expanded, complemented and elaborated. This will allow adapting it to a specific enterprise without changing the basic layout because not all components are indicated for the supersystem elements, as well as the Train and Infrastructure subsystem elements, i.e., they are open.

| Supersystems: |
| - regulatory |
| - organizational distributional |
| - organizational technological |
| - technical |

| Incident rate | Consequences |
| --- | --- |
| Yes | No |

| Risk reduction | Risk assessment | Acceptable risk |
| --- | --- | --- |
| No | Yes |

| Wheel-Rail core system |
| --- |

| Train subsystem |
| --- |
| - Rolling Stock with all facilities |
| - Human-Machine |

| Acceptability criterion |
| --- |

| Infrastructure subsystem |
| --- |
| - Railroad Track with all facilities |
| - Overhead line |
| - Companies servicing the transportation processes |

Figure 1. The conceptualized structure of industrial risks for the transportation safety system (see the translation of the legend below).

While analyzing the developed layout (Figure 1, see more details about each of the subsystem and supersystem components in [20]), one can see that the human factor has a huge influence on the transportation safety and the core system of Wheel-Rail since it is a leading one in almost all supersystems and subsystems. The reliability of this human element depends on the qualifications, training, internships, advanced education, and labor conditions.

Consider the destabilizing factors for the transportation process and find those that can switch the core system of Wheel-Rail from the operating condition to a fault. While implementing transportation processes, some adverse effects can occur due to the action of some destabilizing factor that would lead to a dangerous state and open the door to a disaster. These destabilizing factors may include the following:

1. Equipment fails and errors (e.g. critical failures of equipment (hardware) or fatal errors of software);
2. Fatal mistakes of the personnel.
The fundamental causes of dangerous hardware fails due to the human factor include manufacturing flaws and development errors. They result in lower durability of some equipment components and lead to their transition to an inoperable or even dangerous state.

The mistakes of service personnel can be explained by the following:
- their low qualifications;
- professional selection mistakes;
- insufficient production culture and discipline;
- poor labor conditions impacting employees’ health;
- low quality of specialist training.

Every 3rd employee engaged in servicing transport suffers from constant exposure to hazards at their workplace. Those directly implementing the transportation processes suffer from constant, complex, and irreversible effects of occupational hazards.

The ubiquitous professions within the Traction Rolling Stock Directorate are the engine driver and driver’s assistant, i.e., the members of locomotive crews. These jobs have the largest influence on the safe functioning of the core system of Wheel-Rail, as well as the transportation process as a whole. The actions of locomotive crews can neutralize some of the other destabilizing factors in the Train and Infrastructure subsystems if the crews notice them in time. The working conditions for locomotive crews have a decisive impact on the safety of transportation. Demonstrate it by analyzing the aggregate data.

The analysis of occupational disease rates at Russian Railroads performed by the authors shows that the locomotive unit employees (i.e., drivers and their assistants) have the largest disease rates. The distribution of occupational diseases in Russian Railroads for 2015-2018: 43.3% at the locomotive unit; 20.2% at the permanent way service; 3.8% at the rolling stock unit; 8.7% at other Russian Railroads branches; 23.1% at the companies no associated with Russian Railroads; 1% at the plants of Russian Railroads).

Locomotive crews are mostly comprised of specialists up to 45 years because more senior employees (the most experienced ones) often cannot pass their medical checks.

In 2018, labor and rest conditions of the locomotive crews were monitored at 183 operating locomotive depots. The analysis of the statistics (Table 1 and Figures 2, 3) shows that locomotive crew members have higher disease rates as compared to other professional groups due to the prolonged work in adverse labor conditions. This includes cardiovascular diseases (the rate of locomotive crews is 3 times higher than that of depot workers), digestive tract diseases, and central and peripheral nervous system disorders.

Besides, locomotive crew members systematically suffer from the deterioration of central nervous and endocrine systems. This leads to anxiety, fatigue, and reduced concentration, which can cause transport accidents due to the increased number of errors during the run or in the course of decision making. The occupational disease rates increase along with the duration of work under harmful labor conditions. The research concerning locomotive crew members’ health shows that they suffer from accelerated aging, which leads to various disorders and reduces the quality and span of their lives.

| Table 1. Age and experience specification of occupational disease rates for locomotive crews. |
|-----------------------------------------------|-----------------------------------------------|
| Age                           | Duration of work in harmful conditions |
| 1% - 20-29 years             | 1% - up to 5 years                       |
| 2% - 30-39 years             | 6 % - 5-10 years                         |
| 31% - 40-49 years            | 13 % - 11-15 years                       |
| 60% - 50-59 years            | 23 % - 16-20 years                       |
| 6% - 60 or above             | 27 % - 21-25 years                       |
|                               | 30 % - over 25 years                     |
Figure 2. The structure of specific occupational disease of railroad employees:
72% - neurosensory hearing loss;
14% - dust-caused diseases;
6% - vibration disease;
6% - peripheral nervous system disorders; 1% - acute poisoning;
1% - chronic diseases.

Even though it is the human who determines the reliability and safety of the Human-Machine-Environment system, it is also its “weakest link” [21, 22]. During the run, a driver's body is exposed to various harmful occupational factors in the cab. These various and diverse factors can be found in Figure 4 [3].

The results of the special assessment of working conditions (SAWC) for railroad workers and the grading of occupational hazards performed based on the analysis of locomotive crew working conditions [9] show that 57% of their occupational diseases occur due to the noise and vibration (combined), 45.7% due to the load of work, and 24.9% due to the intensity of work.

The analysis of workplace injury shows that 50-75% of the incidents occurred due to the human factor, i.e., the reduced concentration of the employee. According to this data, the most serious factor impacting the driver's working conditions is the informational load. The information received by the driver within a certain period (the data stream) can be acquired, processed, and implemented in certain control actions within various times. If the information acquisition time exceeds its processing time, some of the operative information gets lost, which results in the failures of the driver's control activities (due to the dashboard information overload). Such situations are short-lived but their reoccurrence leads to the reduced control quality and railroad traffic safety. The work of locomotive crews is characterized by intensity (it is a monotonous process with high nervous and emotional strain, high information and analyzing load, and specific operational modes), and physical strain (constrained position leads to a high load on the musculoskeletal system).
During the research, the locomotive crews underwent the WAIS test (Fig. 5). Both overall intelligence and its components (verbal and non-verbal) were assessed. This factor aggravates when working alone in a cab for a long time (without an assistant), see Figure 6. The mental capacity indicators were determined with a correction test using the Anfimov letter table. They help determine the degree of fatigue, concentration, and speed of reaction at any time. The reduction of mental capacity at the end of a workday as compared to the values for the beginning of the day allows making conclusions on the degree of fatigue. Fatigue can be classified according to the degree of its manifestation, which is evaluated based on muscular stamina (MS), short-term memory volume (STMV), the simple and complex hand-eye reaction lag (SHER and CHER respectively), the attention switch index (AS), and the critical flicker frequency (CFF).

**Figure 4.** Adverse impacts affecting the human body in a locomotive cab (see the legend translation next page).

**Figure 5.** The mental capacity dynamics of locomotive crew members (WAIS test). Legend below the diagram (left to right): Working with the assistant – Working without the assistant; Legend above the diagram: 1-4 года: 1-4 years, 5-9 лет: 5-9 years, 10-14 лет: 10-14 years.

**Figure 6.** The reduction of visual analyzer function as a result of a general eye and color fatigue (complete locomotive crews). Legend: start of run, машинисты – engine drivers.
According to the guidelines R 2.2.1766-03, the risk is measured by the labor condition class [14]. The impact of the risks is calculated based on the SAWC results. Each labor condition class corresponds to a specific risk expressed as a qualitative value, i.e., the occupational hazard category (from negligible to ultra-high) and as a quantitative value, i.e., the occupational disease index. The results of the SAWC serve as unique initial data to assess occupational hazards. They can be used to predict occupational environment state, dangerous situations and areas. The workplace risks for specific labor condition classes are calculated as follows:

\[ R = x_{\text{max}} + \sum x_i \cdot \left( \frac{8-x_{\text{max}}}{8(n-1)} \right) \]  

where \( x_{\text{max}} \) is the maximum evaluation grade for the occupational hazard; \( x_i \) is the numeric score for each factor in the SAWC results; \( n \) is the number of dangerous and harmful occupational factors.

The authors calculated the risk associated with the occupational factor impact on locomotive crew members using the results of the SAWC and formula (1).

\[
R = 4 + (4 \cdot \frac{8-4}{8(7-1)}) + (2 \cdot \frac{8-2}{8(7-1)}) + (2 \cdot \frac{8-2}{8(7-1)}) + (3 \cdot \frac{8-3}{8(7-1)}) + (3 \cdot \frac{8-3}{8(7-1)}) + (4 \cdot \frac{8-4}{8(7-1)}) = 5.788
\]

These data (Table 2, Formula (1)) provide the management with the most complete information about occupational hazards for every stage of the business processes in place and the employees that are exposed to the highest risks. Based on the knowledge received and taking into consideration of the significance of the risk for workplaces, a desirable labor protection management is selected.

**Table 2. Risk management strategy.**

| Risk level conservation | Actions to reduce the impact of occupational hazards | Insurance and risk reduction actions | Insurance and strict observance to regulations for works |
|-------------------------|---------------------------------------------------|-------------------------------------|-------------------------------------------------------|
| 0 to 2                  | 2 to 3                                            | 3 to 4                              | 4 to 5                                               |
| Negligible              | Small (moderate risk)                             | Medium (significant)                | High (intolerable)                                  | Very high (intolerable) |
|                         |                                                   |                                     | 5 to 6                                               | 6 to 7                  |
|                         |                                                   |                                     |                                                      | Ultra high risk        |

**4. Applicability**

The recommendations prepared using the results of the research are the practical outcome of this work. They can be applied in the work of Russian Railroads to facilitate the efficiency and justification of decision making in labor protection.

The risk management procedure stipulates for a compulsory identification of harmful and dangerous occupational factors and the evaluation of workplace occupational hazards. The statistics show that 80% of accidents globally happen due to the human factor. This was confirmed, including in the research works presented in this article. The authors demonstrate that the human factor is a crucial one in transportation safety (Fig. 1). This factor directly depends on labor conditions. Dangerous and harmful factors destabilize the system and reduce its operability which inevitably leads to a dangerous situation and the safety loss in the system. That is why it is vital to detect these factors in a timely manner.
The logical diagram for the industrial risk analysis of a transportation system (Fig. 1) can be adjusted to fit any industrial unit to visualize and quickly determine the factors impacting process safety without changing the diagram structure itself. The developed visualization diagram for adverse factors (Fig. 4) can explicate harmful and dangerous factors affecting employees at their workplaces. Using the harmful and dangerous factor rating, it is possible to find the key factor to develop actions to mitigate or eliminate its effects. The SAWC, formula (1), and data from Table 2 can be used to develop a risk management strategy for the organization. Such strategies might help improving transportation safety by taking into account all the data received, such as:

- determining the key factor impacting safety (Fig. 1) - the human factor;
- analyzing labor conditions (Fig. 2-6) – labor intensity and the vibroacoustic factor;
- calculating the risk of occupational factor impact on the locomotive crew members - formula (1),

It is also possible to develop a labor condition improvement strategy for locomotive crews to increase the safety of transportation.

Thus, the key factors for locomotive crews include teamwork (the driver and the assistant), work and rest regulations, high-quality rest, locomotive infrastructure (AC, shock-absorbing seats, personal protection equipment), diagnosing and eliminating psychosomatic disorders. One of the key aspects of transportation safety improvement is the development of a reward and punishment system for complying with labor protection requirements, and the performance of SAWC (including the unannounced ones to monitor the increased factors only) for both legal entities(organizations) and the employees (natural entities). The associated costs shall break even due to the improved company image and competitive edge, as well as the reduction of insurance payments, disability benefits and sick leaves, and damages incurred in accidents and disasters.

5. Conclusions
When developing a risk management strategy, it is necessary to keep in mind that the quantitative cost evaluation for actions aimed at improving labor conditions will eventually break even due to the reduction of losses associated with occupational hazards. The reduction of risks will allow decreasing the number of accidents, which are a prominent source of significant potential losses. Setting up a functional link between the industrial (chemical, physical, psychophysiological) and economic factors will help evaluating the amounts of losses and economies associated with labor protection actions, i.e., get a prospective efficiency forecast. The economic assessment of labor safety and conditions improvement actions is closely related to the social assessment. This is a practical implementation of the UN doctrine targeting the building of such a labor environment that would support staff health and well-being.

6. References
[1] Constitution of the World Health Organization
[2] Finochenko T A and Yaitskov I A 2018 Decent work - safe work RSTU, scientific and technical journal: “Trudy RGUPS” 2 pp 6-7
[3] Kokhanovsky V A, Dergacheva L V and Fedenko A A 2016 System security: monograph - Rostov n / A: Publishing Center RGUPS
[4] Brusyanin D A 2006 Functional safety of structural divisions of railway transport: abstract of dis. for the degree of Candidate of Science, Engineering, Science, specialty 05.02.22 Organization of production (transport) (Yekaterinburg: UrGUPS)
[5] Lysenko A V, Finochenko T A, Mamchenko V A and Kozina L S 2007 Unfavorable working conditions as a factor of premature aging of workers of locomotive crews Bulletin RGUPS 4 pp 104-111
[6] 2009 ILO standards on occupational safety and health Promoting a safe and healthy working environment International Labor Conference (Geneva, Switzerland) 162 p
[7] Kaptsov V A, Mezentsev A P and Pankova V B 2002 Industrial and occupational risk of railway workers (M.: Reinfor)
[8] Finochenko T A, Lysenko A V, Nazimko V A, Chukarin A N and Sheikhova R G 2013 Management of the rate of aging and the effectiveness of adaptation in unfavorable conditions of professional activity (monograph) Publishing Center DSTU (Rostov n / D)
[9] Chukarin A N, Finochenko T A and Yaitskov I A 2017 Identification of production factors affecting the working conditions of workers in locomotive crews of diesel locomotives Engineering Bulletin of Don
[10] Finochenko T A, Pereverzev I G and Finochenko V A 2016 Special assessment of working conditions: a methodological guide for members of commissions of enterprises to conduct a special assessment of working conditions (Rostov n / a)
[11] Chukarin A N, Finochenko T A and Yaitskov I A 2017 Theoretical Research of Noise and Vibration Spectra in Cabins of Locomotive and Diesel Shunting Locomotive International Journal of Applied Engineering Research ISSN 0973-4562 Vol 1 21 pp 10724-10730 Research India Publications
[12] Atkov O Yu 2008 Human cardiovascular system under the influence of intensive technologies Bulletin of the Russian Military Medical Academy Appendix 2 3 pp 8-9
[13] Tsfasman A Z and Gutnikova O V 2006 The effect of antihypertensive drugs on the psychophysiological qualities of locomotive drivers / Bulletin of the Scientific Council Medical and environmental problems of workers 4 pp 68–72
[14] R 2.2.1766-03 Occupational hygiene. Guidelines for the assessment of occupational health risks for workers Organizational and methodological foundations, principles and evaluation criteria Leadership (approved by the Chief State Sanitary Doctor of the Russian Federation on 24.06.2003)
[15] Pushenko S L 2012 Principles of developing an occupational safety risk management strategy Engineering Bulletin of Don 1 (http://ivdon.ru/ru/ magazine / archive / n1y2012 / 634 /)
[16] Toshiaki HIGASHI Trends and Issues of Occupational Safety and Health in Japan http://www.researchgate.net/publication/271608558
[17] Neverova A S The concept and features of US labor protection legislation [Electronic resource] http://cyberleninka.ru
[18] Belyakov S A, Zabudskiy A I and Bayanova E Y Analysis of foreign experience of economic stimulation of safe working conditions Access mode: http://cyberleninka.ru (04.02.2020)
[19] Temirova Z D A brief review of the features of the organization of social insurance against industrial accidents in developed foreign countries. http://cyberleninka.ru
[20] Dergacheva L V 2017 The structure of the transport process safety system and its assessment Nauch. those. journal "Proceedings of the Rostov State University of Railways" 3 FGBOU VO RGUPS (Rostov n / a) pp 42-45
[21] Chura N N 2014 Technogenic risk: a tutorial (M.: KNORUS)
[22] Telemtaev M M Holistic method of system technology and system ecology http://lib.rus.ec/b/199147/
[23] Dergacheva L V 2018 Quantitative assessment of the level of functional safety in railway transport departments: Abstract of the thesis for the master's qualification (degree) (DSTU, Rostov-on-Don)
[24] Pereverzev I G, Finochenko V A and Finochenko T A 2017 Influence of quantitative assessment of working conditions on the value of industrial risk Electronic scientific journal "Engineering Bulletin of the Don"