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Development of Strategies for Analysing the Factors which Influence the Organization of Routine Railway Track Maintenance

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Abstract

It is critical for railway transport management to be able to predict the condition of any railway track that operates in a challenging environment, including high tonnage, magnitude of traffic flow, an increased governed speed, and harsh climate — factors that combine to reduce the life cycle of track superstructure components. The condition of railway track cannot be predicted until after the factors affecting all track elements and their interrelationships have been identified. It is therefore essential to identify the factors that have a bearing impact on the management of routine track maintenance and track work processes. This article discusses the formulation of strategies for reviewing existing methods for track condition assessment followed by assignment of track works and efforts to identify factors that may not have been recognized in previous planning. The studies used both statistical and analytical methods.

Keywords: railway track; organization; routine track maintenance; track works; operating procedures; management.

1. Introduction

Railway track is one of the most important parts of railway transport. Its condition is critical to the entire transportation process, the attractiveness of this type of transport for clients, including passengers, and competitiveness versus other modes of transport.

All elements of the track superstructure are part the railway track. These elements include rails, turnouts, rail seat fasteners, and the ballast section. Railway track also includes subgrade, the drainage, deformation prevention, protective and strengthening structures of the subgrade located within the right-of-way, and engineering structures (Instructions for the current maintenance of the railway way, 2016).

Regulatory documents and state standards govern routine track maintenance, which is performed throughout the life cycle of all track elements and includes systematic monitoring of the condition of the track, structures and track arrangement, plus their maintenance in a state that guarantees safe and uninterrupted train traffic at governed speed (The regulation on the management of the track economy, 2015; The methodology for calculating the indicators of reliability and safety of the functioning of the upper structure of the way, 2020; Methodology for conducting cluster analysis of integral risk factors in the field of traffic safety on the infrastructure of JSC "Russian Railways", 2020).

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Routine track maintenance is provided based on identified problems followed by further work planning. Track works are performed based on standard operating procedures, which must be implemented to a high standard and ensure the safety of the rolling stock.

The relationship between the number and types of malfunctions, the purpose and sequence of repairs, including the extension of track elements' life cycle is of great interest both to the functional units of the track facilities and to researchers in this field (Standard requirements for the formation of a factor analysis of risks in the field of traffic safety on the infrastructure of JSC "Russian Railways", 2018; Beltiukov et al., 2020; Kiryunin, 2021).

2. Problem Definition

Railway transport currently uses multiple methods to capture factors affecting the railway track — something which does not always help with factor selection and complicates decision-making in planning routine track maintenance.

Current practices of organizing routine track maintenance include the following:

- assessment of the state of the geometry of the rail track and non-destructive testing of rail facilities;
- equipment operational failures;
- availability of materials and labour;
- engagement with functional units on capital works, medium repairs and running repairs;
- climatic conditions in the railway line location; and
- railway track operating conditions.

Let us look at some of the strategies employed:

1) Methodology for calculating reliability and safety performance metrics for the track superstructure.

This methodology sets a procedure for calculating the operational actual indicators of reliability and safety of rail superstructure sections and a procedure for calculating the corresponding regulated/permissible indicators of reliability (Beltiukov et al., 2020). In addition, the methodology addresses automated calculation and regulation of operational reliability indicators and calculation of functional safety indicators for the track superstructure.

2) One priority strategy used in organizing routine track maintenance is the URRAN methodology.

Risk assessment in the URRAN methodology is based on the assessment of design, permissible and actual/achieved indicators of reliability and safety of railway infrastructure elements and their subsequent comparison with one other. This methodology focuses on the allocation of available resources based on mitigating functional risks for railway infrastructure systems and facilities within the specified reliability and safety values. As well as assessing the degree of reliability and safety of railway infrastructure facilities, the URRAN methodology is currently used to evaluate the performance of functional units responsible for their maintenance (Kiryunin, 2021, p. 51).

3) The next method recommended for use on railway transport is a technique for cluster analysis of integral risk factors associated with traffic safety on the Russian Railways infrastructure. This methodology defines the rules and procedure for analysing integral risks that may compromise traffic safety on the Russian Railways infrastructure (Gorelik and Zhuravlev, 2017).

One feature of this methodology is that it addresses risks separately for each infrastructure section and links them to factors that increase the likelihood of a risk as identified for all functions that support the operation of infrastructure facilities and rolling stock in the area under study (Gorelik and Zhuravlev, 2017).

This methodology provides a classification of risks and various analysis techniques, with one of those designed to calculate the probability of occurrence of each type of traffic safety violation in infrastructure sections. The probability of a violation is determined by dividing the number of the corresponding type of violations by the total number of all traffic safety violations, which is a non-dimensional quantity (1):

$$P(A_i) = \frac{m_i}{n}, \tag{1}$$

where Ai is the i-type of traffic safety violations from among $A_1, A_2, \ldots, A_N$ — a complete set of all traffic safety violations on the Russian Railways infrastructure;

m_i is the number A_i violations at all sections; and

n is total occurrences of traffic safety violations.

The number of violations at all sections is determined from the following formula (2)

$$\sum_{i=1}^{N} m_i = n \tag{2}$$

Therefore, P(A_i) — the likelihood of an i-type traffic safety violation — is expressed by the following formula (3):

$$P(A_i) = \frac{m_i}{\sum_{i=1}^{N} m_i} \leq 1 \tag{3}$$

To find the probability P (A_{ij}) i-type traffic safety violation at j-section, we will represent the number of corresponding violations m_i in the formula (3) as follows (4)

$$m_i = \sum_{j=1}^{K} q_{ij}. \tag{4}$$

where K is total sections;
q_{ij} is i-type traffic safety violations at j-section.
Substituting expression (4) into formula (2), we obtain formula (5):

$$\sum_{i=1}^{N}\sum_{j=1}^{K} q_{ij} = n. \tag{5}$$

Substitution of expressions (4) and (5) into the formula (3) will make it possible to create a formula for the probability $P(Aij)$ of an i-type event in j-section:

$$P(A_{ij}) = \frac{\sum_{j=1}^{K} q_{ij}}{\sum_{i=1}^{N}\sum_{j=1}^{K} q_{ij}}$$

This methodology notes that the total number of traffic safety violations is the same for all the sections under consideration. Therefore, comparing risks in terms of probability is equivalent to comparing the number of traffic safety violations at the sections under consideration.

4) The next strategy for determining traffic safety factors on railway transport is a factor analysis of traffic safety risks that allows you to analyse and assess how certain factors influence the risk of traffic safety violations in Russian Railways operations. In this case, the level of risk depends on the scale or a set of risks that lead to adverse consequences and their likely occurrence (Katasheva, 2020).

This technique is automated in the corporate infrastructure management system. The proposal is to make a factor analysis in the system once every three months based on a statistical analysis of parameters/measurements that characterize the state of work processes that support traffic safety.

The analysis is broken down into four stages: Stage 1 – The proportion of the impact of the factor in question on the conditions for the occurrence of a given risk event is established using a 5-point expert assessment system; Stage 2 – The degree of risk occurrence is determined using a 5-point system based on statistical analysis of data/measurements for the facility in question during the reporting period; Stage 3 – The risk indicator is calculated as the value of the factor's influence on the risk of a given event for the facility in question during the reporting period; Stage 4 – The risk indicator for the entire facility in question is determined and derived from the arithmetic mean of the risk indicators for all specified events associated with this facility.

Factor analysis follows the Pareto Rule: 80% of problems are identified in 20% of ranked objects/subdivisions.

3. Experiment

The experiment was carried out on track sections of the East Siberian and Krasnoyarsk railways. The selected periods were 2018–2020.

The results of the assessment of the level of exposure to risk factors in subdivisions are provided in table format, including subdivision ranking according to the level of exposure to risk factors from the highest to the lowest (Katasheva, 2020; Ilyashchenko et al., 2020; Pevsner et al., 2021).

Factor analysis allows you to provide up-to-date information, increase information storage reliability, standardize input formats, reduce data entry errors, enhance initial data integrity through direct interaction with information systems that generate such data, and improve the reliability of final data by automating algorithm calculation.

Factor analysis covers factors affecting traffic safety as shown in Fig. 1.

Traffic Safety
Non-Compliance with Track Work Procedures
Rail Facilities Defects
Deviations from Track Superstructure Maintenance Procedures
Ballast
Underrail base
Curved Track Condition
Continuous Welded Rail Track
Inspection Findings
Defective Subgrade and Engineering Structures
Accident Rate at Level Crossings
Personnel Training and Competency Gaps
Equipment and Material Procurement Standards

Fig. 1. Factors covered by factor analysis.

Calculations allow you to map how the analysed factors affect the risk of train traffic safety violation at track facilities (Fig. 2).

№	Types of traffic safety violations included in the risk register	Security of service				Non-Compliance with Track Work Procedures		Rail Facilities Defects			Fault in alignment, level										Ballast	
		The number classification of traffic working security violation	The number of failures of railway equipment	The number of failures of railway technical means of 1 degree and 2 degrees	The number track classification	The number of comments when place of trackwork protecting signa	The number of violations of the terms of replacement of critical faulty rail	The number of cropped rails lying in the MAIN track	The number of PASSES of critical faulty rails	The number of defective metal elements of the transition curve switch	Score assessment of the state of the main track for the quarter	The number of kilometers with an unsatisfactory track state	The number of REPETITIONS of unsatisfactory kilometers	Execution of the inspection plan by track measuring trucks (% of the plan)	Amount of path faults III, IV degree according to results track recording car	The number of REPETITIONS of form of error of position	Amount of tack faults III, IV degree according to results track measuring truck	Length of sections with overdue track renewal and overhauls	The number of excess butt joint clear-ance gauge	Length of kilometers length of kilometers with existing warnings that are not provided	Length of the track sections with a splashes	Length of track sections with insufficient volumes ballast in the
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Crash, accident, collision of a rolling stock with another rolling stock, derailment in an organized train	15	3	4	4	15	15	8	8	20	12	20	4	3	8	3	6	15	20	9	5	4
2	Derailment of motive-coach fleet stock, during maneuvering, equipment or other movements	15	2	4	4	15	10		6	25			2	5	8	2	10	9	15		4	3
3	Flooding, fire, violation of the integrity of infrastructure structures that caused a traffic interruption for 1 hour or more	15	2	4	4	15	20	8	8	15	12	15	3		8	2		12	20	9	4	4
4	Break of the rail fatigue under the railway rolling stock	15	2	4	4		20	10	10	25			2		8	3		12	20	9	4	

Fig. 2. A matrix of analysed factor influence on the risk of train traffic safety violation.

The red and orange boxes of the influence matrix include the number of missed defective rails, the length of curved track sections with a lateral rail wear of 12 mm or more, and the ratio of road accidents at level crossings to the total number of crossings. The yellow zones cover criteria that bring risks closer to traffic safety violations.

General influence of the criteria for deviations in the maintenance of the track superstructure indicates that there is a high risk of a crash, collision or rolling stock derailment. There is a high risk of damage to the integrity of the structure or rail fracture under the rolling stock, which can cause serious issues in train movement, including self-uncoupling of automatic couplings or uncoupling of cars from a passenger train (Methodology for conducting cluster analysis of integral risk factors in the field of traffic safety on the infrastructure of JSC "Russian Railways", 2020).

The level of exposure to risk factors is calculated subject to the Factor Analysis Standard Requirements as approved by the regulatory documents of Russian Railways.

4. Results and discussions

A thorough analysis of methods that capture factors affecting routine track maintenance processes can identify the upsides and downsides that need to be reviewed, with a possible requirement for updating methods and strategies used to determine the influence of those factors on the railway track.

For example, the URRAN methodology leaves out problems of mean time between failures or a multiple-valued definition of the failure rate due to increased track load. The methodology does not reflect any calculations of mean time to restoration of track elements or the track availability factor, nor has a relationship been established between the reliability indicators of railway infrastructure facilities (including tracks) and train-hour losses, since the process does not take account of failures and restoration of railway infrastructure facilities or their use directly for its intended purpose to ensure the movement of trains at governed speed (Gorelik and Zhuravlev, 2017).

The URRAN methodology is still just an additional criterion in planning and assigning repairs and track works, which points to the need to refine and implement this methodology in the field. What we see as a significant disadvantage of URRAN methodology automation is that identification of malfunction risks is associated with personnel untrained for multiple factor data analysis. The automated system of the URRAN methodology remains of secondary importance, since data is transmitted to other information management systems, with planners of repairs and track works then using data from a variety of sources. Further research is needed to improve the methodology to substantiate the factors used as a criterion for the assignment of repairs and track works.

The methodology for calculating the likelihood of each type of traffic safety violations in infrastructure sections does take full account of the complexity behind failures of track elements, something which does not allow us to fully calculate the likelihood of such violations. There is a need for a thorough review of the mathematical tool embedded in both cluster and factor analysis.

Yet another important criterion in the development of cluster and factor analysis is due regard for factors that support the reliability of track elements. Current strategies leave those factors out of account.

5. Conclusions

Existing and proven techniques for identifying factors that have a bearing on the organization of the railway track routine maintenance and analytical materials for improving information support for track management processes allow us to identify the following key strategies:

- perform urgent work based on an assessment of the actual condition of the track at a certain point in time;
- plan track works for the short and medium term based on track superstructure reliability and safety indicators (URRAN methodology); and
- organize repairs and track works for the long term based on cluster and factor analysis.

The philosophy behind the reviewed methods is to process statistical data from a certain period of operation of the facilities under consideration. What merits special notice is the accumulation of historical data and its reliability and completeness. Yet the methods described do not make full use of that data.

However, the planning and assignment of track works cannot be driven by design parameters only, for they must be as close as possible to the specific operating conditions of the railway track. What we see as the main factors affecting the organization of routine track maintenance are track power load indicators, which cover changes in operating conditions associated with increased tonnage and axial loads.

Efficient planning and high-quality execution of track works in the context of routine maintenance have a positive effect on the life cycle of railway track elements.

Reducing the likelihood of risks to the reliability and operability of railway track elements will minimize financial outlays for track facilities, given routine track maintenance.

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