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Premises of the creation of a digital traffic safety management system

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Abstract. Aim. *The digital transformation of the traffic safety management system in JSC RZD involves top-level integration with the operating processes of all business units in terms of integral assessment of the risk of possible events and achievement of specified indicators. The result will be the merger of the traffic safety management system with the processes of all levels of the company's management enabled by an integrated intelligent system for managing processes and services whose functionality includes real-time traffic safety management.* **Methods.** *The paper uses system analysis of existing approaches and methods of processing of large quantities of structured and unstructered data.* **Results.** *The paper examines the development stages of train traffic safety management, as well as automated information and control systems that enable traffic safety management. General trends in the creation of systems for collection and processing of information are analyzed. The applicability of such technologies as Big Data, Data Mining, Data Science as part of advanced control systems is shown. The paper examines the performance of the above technologies by analyzing the effect of various factors on the average daily performance of a locomotive, where, at the first level, such factors as average daily run of a locomotive, average trainload are taken into consideration; at the second level, the focus is on the service speed, locomotive turnover at station, etc.; at the sixth level, the focus is on the type of locomotive, its technical state, etc. It is shown that statistical methods of factor analysis and link analysis combined with such other methods of Data Mining as methods of simulation and prediction, the average daily performance of a locomotive can be planned proactively. The author proposes a procedure of migration towards a digital traffic safety management system that would be based on models of interaction of safety and dependability factors of all railway facilities at all railway levels of hierarchy, as well as in association with other factors that have no direct relation to dependability, yet affect the safety of the transportation process.* **Conclusions.** *The primary benefit of migration towards Big Data consists in the development of a dynamic model of traffic safety, the elimination of human factor in control systems. Most importantly, it enables the creation within the Russian Railways company (JSC RZD) of an integrated intelligent process and service management system that enables real-time traffic safety management. An extensive process of development and deployment within the company of the URRAN Single Corporate Platform (SCP) enabled executive decision support as regards risk-based functional dependability and safety of transportation facilities. Thus, the URRAN SCP sets the stage for the digital transformation of the traffic safety management system in JSC RZD.*

Keyword: *train traffic safety, factor analysis, automated control system, Big Data, Data Mining, human factor, risk prediction.*

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Introduction

Train traffic safety is one of the key concerns of JSC RZD in the context of operation of the railway system, passenger and freight traffic. All the organizational and technical measures in railway transportation must comply with the requirements of safety and faultless train traffic. The development of Russia's railways is aimed at increasing the rate, speed and freight capacity of train traffic. That involves a higher number of vehicles simultaneously operating on railway tracks, as well as significantly more complex infrastructure. Due to that, stricter requirements must be specified for the quality and dependability of traffic safety facilities, as well as the professional qualifications and experience of railway personnel directly involved in traffic management.

JSC RZD's traffic safety policy defines the following main goals: minimization of the consequences of transportation incidents; protection of human life and health; assurance of safety of cargo, rolling stock, infrastructure facilities; assurance of a set level of traffic safety. The wide range of traffic safety tasks, on the one hand, and rapid development Russia's railways, rolling stock and infrastructure, on the other hand, require a major rearrangement of the existing traffic safety management system through its transformation into a digital management platform.

Stages of automation of a traffic safety management system

Today, JSC RZD uses a significant number of automated management systems (AMS) developed in various periods for the purpose of solving specific tasks. Some of them are modern, some require upgrading and updating in accordance with new requirements.

At the early stages, traffic safety management was based on railway stations and depots inspection reports. The development of railway transportation required the automation of traffic safety management. In 2005, the Automated System for Supervision and Analysis of Application of Traffic and Workplace Safety Rules by Station Personnel (AIS DNCh) [1] was created. The system's main purpose consists in organizing – within the train service – of collection and classification of information on the results of inspections of railway stations as regards traffic and work safety, its analysis and definition of preventive measures aimed at eliminating faults in the train and shunting operations, as well as cases of workplace injury in stations. The system's users include safety supervisors of all divisions, management of the commercial service, safety office employees. The system has 800 active users, over **700 000 inspection reports** have been prepared so far. They formed the basis of the corporate non-structured safety data storage using the example of a specific service.

In 2006, the Automated Traffic Safety Management System (AS RB) was created [2]. Today, it performs all the required functions that ensure data input, warning, classification and recording of traffic safety violations, supervision of the observance of the terms or registration, timeliness and quality of investigation of traffic safety violations, analysis of the causes and consequences of violations, generation of network-level and division-level violation reporting documentation. The system has over **5000 users**. It has so far generated **over 40 000 technical inspection reports** by safety inspectors.

The Integrated Automated Systems for Recording, Supervision of Elimination of Failures of Technical Facilities and Dependability Analysis (KASANT) was deployed within JSC RZD in 2007 [2, 3, 4]. The system is a radically new tool for the Company's infrastructure facility and rolling stock condition monitoring. It guarantees a single procedure of registration and investigation of technical facility failures in all operational services, in all divisions of JSC RZD, significantly increases the reliability and speed of data collection through a "paperless" process. Over the last three years, KASANT enabled a staged migration towards a single system for registration and analysis of technical facility failures. It became possible to implement comprehensive method of estimation of operational efficiency, both for specific services, and for the whole company, using a single network-wide database of technical facility failures.

At different moments in time, KASANT was integrated with the Company's following automated systems: GID Ural-VNIIZhT (System for Automated Train Traffic Scheduling), ASU E (Transenergo Automated Management System), AS KMO (Automated System for Documentation of Monthly Commission Inspections of Stations), ASK PS (Automated System for Rolling Stock Technical State Supervision), ASUVOP (Standard Automated System for Issue and Cancellation of Warnings), ASU-P (Automated Systems for Track Facilities Management), ASU-Sh-2 (Integrated Automated System for Signalling, Interlocking and Block Infrastructure Management). Later, the above were integrated with the Single Corporate Automated Infrastructure Management System (EK ASUI) that encompassed the AMSs of the infrastructure services and now provides information support of maintenance and repair process.

KASANT has over **50 000 users**. The daily number of registered warnings is **1400**. **2 367 747 technical facility failures** have so far been detected and analyzed**.**

In 2011, KASAT, or the Integrated Automated System for Recording and Analysis of Process Violations, was developed and deployed for the purpose of analyzing cases of process violations by railway personnel causing traffic safety disturbances. It is a hardware and software system for recording, analysis of cases of process violations in infrastructure facilities of JSC RZD. KASAT has over 50 000 users. The daily number of registered warnings is 960. So far 6 497 274 process violations have been detected and analyzed.

The above systems to some extent automate the process of traffic safety management. They enable condition analysis of individual railway facilities. However, in terms of assessment of processes, the data is not structured. Additionally, the systems have proprietary classifiers, they have different information acquisition periods, most importantly, the data they operate have different levels of detail and formats. There is also quite an important fact that safety management systems must be coordinated with many other automated systems of the transportation industry, including 33 recording systems and 8 planning systems. That indicates that the process of traffic safety management involves processing enormous amounts of raw data. The classical solution is data aggregation (for instance, per hazardous events, indicators of failure rate, damage, etc.), as well as analysis of the properties of the managed system. That, to some extent, enables proactive planning: identification of the direct causes of undesired events and planning targeted measures, confirming the achievement of target values. However, in safety management of railway transportation there are over **250 data names** alone, while the sizes of data arrays are evaluated at **millions of terabytes**. In this context, even aggregated data does not provide the desired effect. A digital traffic safety management system must be created.

Development of systems for collection and processing of information on the actual state of infrastructure and rolling stock

Various areas of human activity share the same trends of collection and processing of information. In the XIX century6 our predecessors obtained management-specific information by means of personal observations, manual measurements, stored it in script books. In the era of steam engines, executive decisions were made on the basis of several megabytes of information (Figure 1).

In the XX century, new computer systems, information systems and automated workstations emerged. Field inspections were complemented with automatic systems for data collection that were based on sensors, relays. The amount of processed information was gigabytes. It was collected, stored, analyzed and used for purposes of forecasting. The beginning of XXI century was marked by explosive technological developments. Now we are talking about exabytes (10^9 gigabytes) of information. The capability of collecting and controlling such enormous amounts of data enables the application of modern technology. Currently available speeds are far beyond human response time. Naturally, the role of people in the operation of systems intended for collection of such amounts of data is progressively declining. An ever-increasing amount of information on the real world is collected with the use of sensors, diagnostic systems, technologies that enable interaction of artificial objects with no human involvement.

A large amount of collected and, most importantly, constantly increasing information inevitably changes our perception of it. Ensuring the safety and reliability of transportation processes relies on the prediction of risks, automation of the decision-making process. In other words, we are talking about tasks that used to be the prerogative of people. Now, most of such tasks are assigned to computer-based systems.

Structured and unstructured data in great amounts and considerably diverse, that are efficiently processed with the use of software tools, are conventionally known as

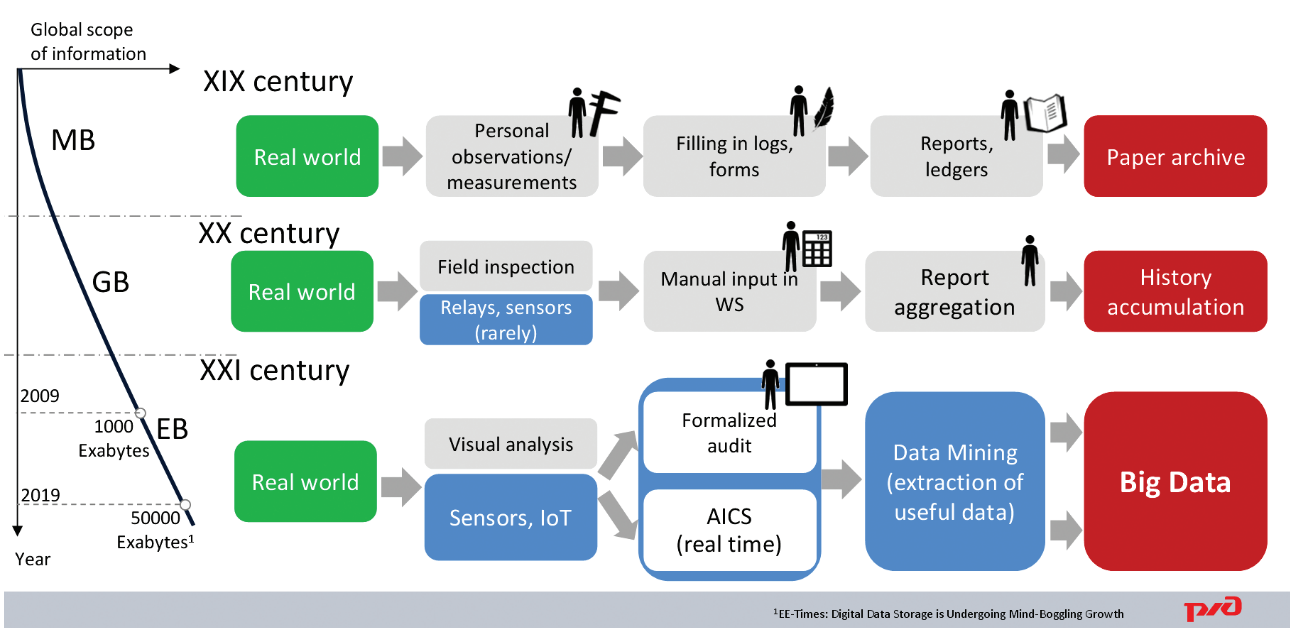

Figure 1. Stages of development of data collection and processing systems

Big Data. This technology of storage and processing of Big Data is an alternative to the conventional database management technology. The defining characteristics of Big Data are the "three Vs": volume in terms of the physical volume, velocity in terms of the speed of growth, and the requirement for high-speed processing and acquisition of results), variety in terms of the capability to simultaneously process various types of structured and semistructured data). Subsequently, some variants and interpretations of the above characteristics came into being.

Not all collected data are useful, that is why today we discuss intelligent approaches to data analysis commonly known as **Data Mining**, a collective name that denotes a set of methods of discovering within data previously unknown, non-trivial, useful and practical interpretations of knowledge required for decision-making in various human activities. Data Mining is based on various methods of classification, simulation and prediction that use decision trees, artificial neural networks, genetic algorithms, evolutionary programming, associative memory, fuzzy logic. According to some experts, methods of Data Mining include the statistical methods (descriptive analysis, correlation and regression analysis, factor analysis, variance analysis, component analysis, discriminatory analysis, time series analysis, survival analysis, link analysis).

Data, whether collected, newly obtained or historical, are at the foundation of the migration towards the digital model of process management in railway transportation. Within JSC RZD, such foundation has been created. The aim of the activities associated with the creation of a top-level digital corporate management platform in JSC RZD consists in the development and deployment of the comprehensive automation model based on control systems integrated within the URRAN Single Corporate Platform (SCP URRAN). That is a set of regulatory and guidance documents, hardware and software systems intended for managing infrastructure facilities, rolling stock and manufacturing processes aimed at assuring guaranteed safety and dependability of the transportation processes performed by JSC RZD [5]. The system is already in use in the track, communications and power supply services and enables automatic assessment of the risks associated with both technical facility failures and traffic safety violations [6]. The analysis of the information it is collecting gives reason to believe that the system, along with the associated solutions, such as KASANT, AS RB, KASAT, KASKOR, EK ASU I, etc., can be designed on the basis of Big Data technology. Data structuring is one of the biggest problems. Large amounts of unstructured information are a typical feature of today's multifunctional AMS. According to international information systems auditors [7], up to 90% of the information we obtain is unstructured. Therefore, the migration towards Big Data must be executed using the foundations of **Data Science**. Up to 80% of time of data mining model generation is spent processing primary data, developing research models, analyzing basic statistics, developing regular calculation models. That requires managers who set goals of strategic analysis, engineers who understand business processes, scientists who develop mathematical models. And only after the data mining model is complete (including connections among all systems, users, factors), Big Data technologies and software solutions set in.

Due to the obvious costs associated with the creation of a digital traffic safety and reliability management system the question arises, whether such efforts are justified. The experience with the creation of similar systems for various industries demonstrates the productivity of such activities. Thus, Gazprom's Cognitive Geologist project [8] enabled the reduction of project development time from 2 years to 2 months. The project also showed that 30% of previously used initial data did not prove to be later useful. In Sweden, Big Data technology is used for managing trackside assets, in particular as part of decision-making regarding infrastructure and rolling stock [9].

Multifactor risk analysis of traffic safety

Big Data management is based on the understanding of business processes. In the context of railway transportation that involves understanding the processes of ensuring safety and reliability of the transportation process. Currently, JSC RZD employs 85 guidelines and regulations in the area of traffic safety and reliability. AMS are used in safety and dependability assessment of elements, railway systems and processes. That is the present. In the future, it is expected that advanced technologies of simulation, risk prediction will allow monitoring unacceptable states, manage assets using the ALARP principle [10, 11], integrating the safety function into business processes. The first step towards such future would be the development of a structure diagram of traffic safety risk management. Such diagram must include *methods of traffic safety risk assessment* (subject to the chosen measures of reduction of the effects of risk factors and prevention scenarios), *methods of factor analysis* (interrelations between factors and risks), *registers of the sources of information* on factor statuses, *registers of factors* that affect risks, service-specific *registers of risks*, *register of corporate risks* of JSC RZD and their classification attributes.

Certainly, the advantage of today's advanced computer-based methods over the conventional ones consists in the capability to handle multivariate data, i.e. consider an object subject to all possible attributes and factors. The methods allow establishing interrelations between indicators in a multidimensional space, which is extremely difficult due to time constraints. Computer-based (normally, intelligent) methods practically eliminate the possibility of calculation errors.

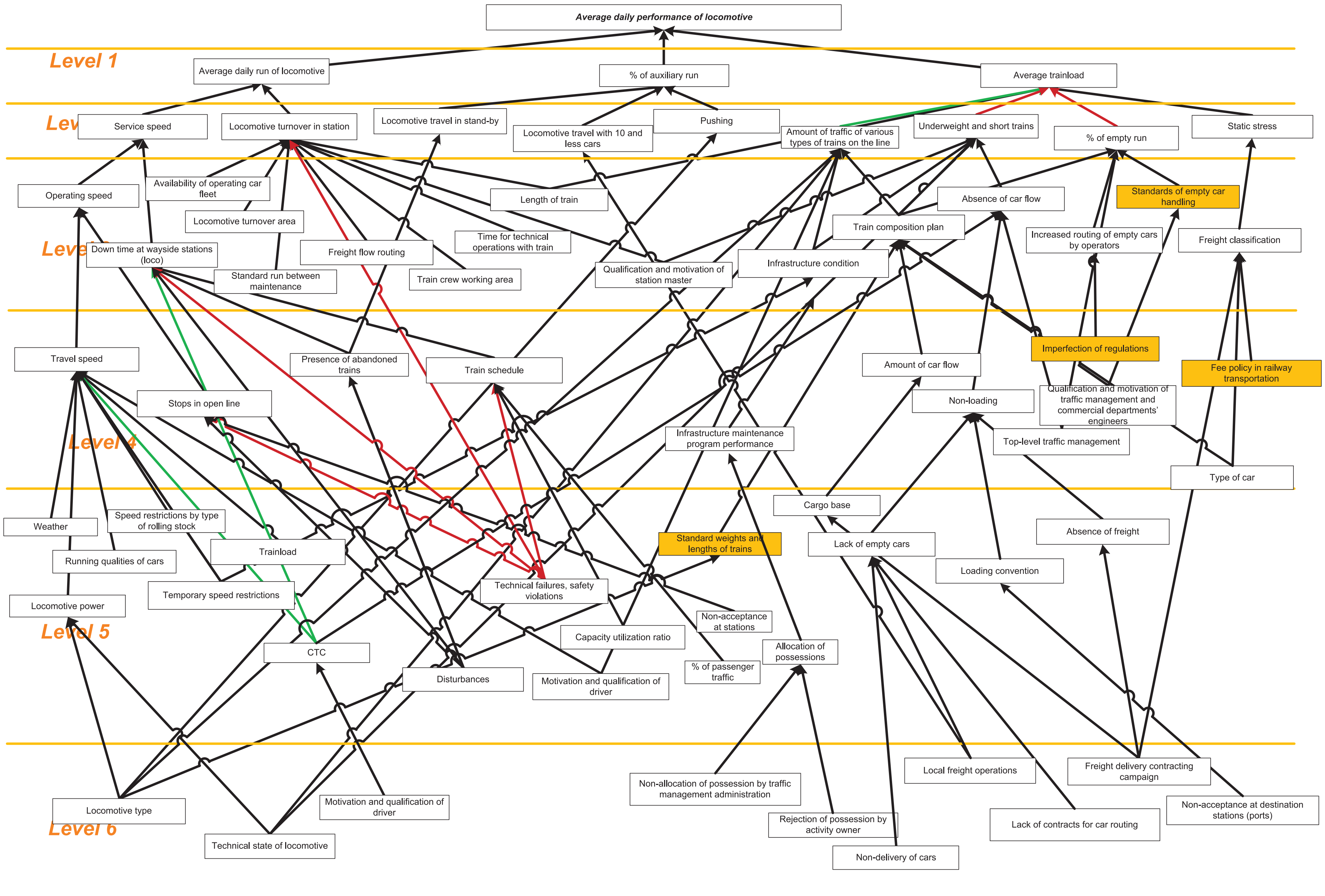

Figure 2. Hierarchical structure of factors' effect on the average daily performance of a locomotive

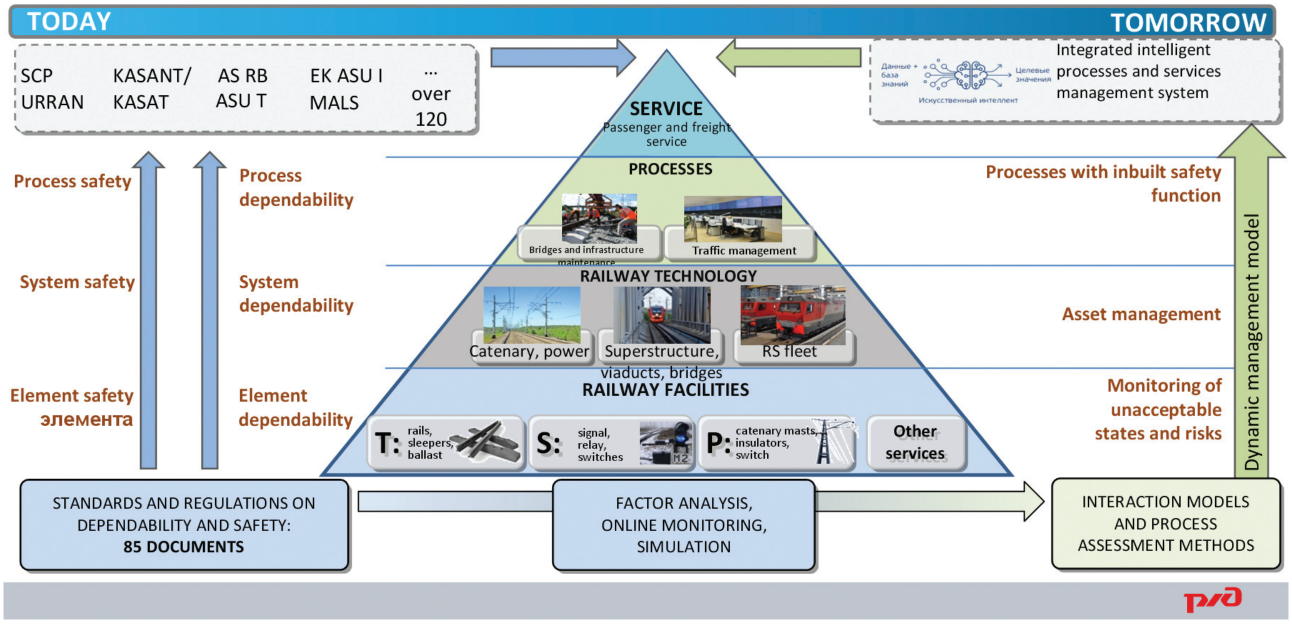

Figure 3. Migration towards a digital intelligent safety management system

Figure 2 shows the six-level hierarchical structure of various factors' contribution to such indicator as average daily performance of a locomotive. At the first level such factors as the locomotive's average daily run, average trainload are taken into consideration. At the second level the service speed, locomotive turnaround in station, etc. are taken into consideration. At the sixth level the locomotive type, its technical state, etc. are taken into consideration. In total, the effects of over 50 factors affecting the average daily performance of a locomotive are taken into consideration. Calculations require statistical data for each factor. Then, using statistical methods of factor analysis and link analysis combined with such other methods of Data Mining as methods of simulation and prediction, the average daily performance of a locomotive can be planned proactively.

Multifactor risk analysis using Big Data analytics and machine learning will enable dynamic risk assessment in railway services, identification of abnormal values in real time and prediction of the probability of hazardous events.

Migration toward the digital traffic safety management system

Currently, given the ongoing deployment of SCP URRAN and associated systems (KASANT, AS RB, KASAT, KASKOR, EK ASU I, ASU T, etc.), traffic safety management consists in current estimation and prediction of the safety and dependability of elements and devices of railway technology (individually for each service), systems separately (e.g. locomotive fleet, catenary, bridges, etc.), then processes (traffic management, service and repair, etc.). Those operations are aggregated at the level of devices, systems, processes and classified by service. The safety of passenger and freight services is based upon the decisions of auditors made according to post-audit statistical and real-time information supplied by automated systems (Figure 3). Such decisions largely depend on the human factor, as the received data mostly are not interrelated neither horizontally service-to-service, not vertically per elements, systems and processes. Due to that there is no comprehensive image of the current status of safety and dependability of infrastructure and rolling stock.

The migration towards a digital traffic safety management system must be based on models of interaction of safety and dependability factors of all railway facilities at all railway levels of hierarchy, as well as in association with other factors that are not directly associated with dependability, yet affect the safety of the transportation process. Such factors include, for instance, line class, service speed, trainload, scheduled and unscheduled track maintenance possessions, condition of ballast, condition of bridges and many more. The large number of factors and exceptional diversity of connections can be formalized and saved with the help of Big Data technology. That will enable real-time comprehensive monitoring of unacceptable states and risks. The monitoring procedure should be based on the methods of management of technical, social and industrial risks of transportation facilities developed as part of the URRAN system [12, 13]. That will allow using comprehensive risk assessment while managing the technical assets of JSC RZD and designing business processes that incorporate the safety function.

Conclusion

The primary benefit of migration towards Big Data consists in the development of a dynamic model of traffic safety, elimination of the human factor in control systems. Most importantly, it enables the creation within

JSC RZD of an integrated intelligent process and service management system that enables real-time traffic safety management. The digital transformation of the traffic safety management system in JSC RZD consists in the top-level integration with the operating processes of all business units in terms of integral assessment of the risk of possible events and achievement of specified indicators. The developed solutions will be deployed using the Big Data and artificial intelligence, IoT-based diagnostics systems, digitization of rolling stock and infrastructure assets manufacture and maintenance, etc. The result will be the integration of the traffic safety management system with the process of all levels of JSC RZD's management in accordance with the three principles of digital business: *Complete coordination*, *Online business* and *Service management*. In the case of the Traffic Safety functional area, that means the analysis of real-time data on the status of the network and rolling stock, online supervision of valuable or dangerous freight by means of collection of sensor data, analysis of data flow regarding the current status of rolling stock and locomotives with assessment of operation, risks, generation or real-time warnings and recommendations for further use and maintenance with minimal risks.

An extensive development and deployment within the company of the URRAN Single Corporate Platform enabled executive decision support as regards risk-based functional dependability and safety of transportation facilities. Thus, the SCP URRAN E (subsystem E responsible for the electrification and power supply) developed and deployed in 2018 enabled comprehensive operations involving over 1 000 users. Over 4.3 mil score cards have so far been filed per Transenergo facilities. Earlier this year, SCP URRAN S was developed and put into revenue operation. It enables real-time calculation of key indicators of dependability and safety, as well as risk assessment within the telecommunications facilities. The functional development of SCP URRAN P in the track service since 2019 allowed improving the reliability of assessment of the activities of the service's business units and objectivity of assignment of standardized dependability indicators. The development and deployment of SCP URRAN Sh in the signalling service and SCP URRAN T in the locomotive service will – as early as 2019 – enable higher efficiency of maintenance through resource and risk management.

Thus, SCP URRAN sets the stage for the digital transformation of the traffic safety management system in the Russian Railways.

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The author's contribution

Zamyshliaev AM has analyzed the stages of automation of the traffic safety management system, established that currently traffic safety management involves processing massive amounts of scattered raw data and suggested developing a four-level (elements, systems, processes, services) digital intelligent safety management system, including safety, dependability, assets and process management.