MODELING OF RELIABILITY AND AVAILABILITY OF DATA TRANSMISSION IN RAILWAY SYSTEM

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Abstract:
The analysis of the reliability and availability of the data transmission system within the integral railway system is realized through the modeling of the system, i.e. its conditions and their connections. According to the defined measure of safety of the International union of railways (UIC), i.e. its committee ORE, defined by recommendations A 158 and A 124/RP, based on previous experience and the achieved level of technical development, we can estimate an acceptable value for the probabilities of certain conditions of the integral railway system and data transmission system. In the paper, the reliability and availability analysis was modeled using the Markov model for data transmission in the railway system with four conditions, for: correct system condition, presence of disturbances in the system, illegal (dangerous) system condition and system blocking condition. The validity for the application of process development modeling the reliability and availability of data transmission in the railway system will contribute to reducing the risk of inadmissible (dangerous) failures, improving maintenance planning and spare parts planning, moving from maintenance by time to maintenance by condition and reducing exploitation costs.

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1. INTRODUCTION

The key goal of the proper functioning of any transport system is to reach the highest level of reliability at any stage of the transport process [1-3]. The main features besides the reliability of these systems is that they must be available, sustainable, safe [4-6] and competitive [7,8]. In order to ensure all this within the railway systems, the reliability of the DCS (data communication system) is of great importance [9].

We are witnessing today that there is on the one hand a continuous increase in speed and specific traffic requirements [10], while on the other hand they are required to operate the control system reliably in railway systems, because in the case that the system fails, the loss of human lives and transported goods is inevitable [11]. In that context, modern railway systems must sutisfy the needs of passengers, be efficient and secure [12] and have as small energy consumption as possible [13].

The development of digitalization significantly influenced the change in equipment and employees in the railway [14], which ultimately led to the improvement of its efficiency. An efficient railway system is an indicator of the development of a country's infrastructure [15]. Today, there are about 16 countries that have developed high-speed railways [16], while China, for example, currently has the longest and most complex high-speed railway system [17]. In recent years, the Republic of Serbia has invested heavily in the modern railway

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system, for example, on the Novi Sad - Beograd route, which was built during 2022, the speed of trains reaches 200 km/h. Also, due to insufficient investments in the past period in the Republic of Serbia, there are a large number of sections where the train speed is 30 - 50 km/h. That led to the loss of human lives, accidents that caused the discharge of polluting materials into the environment, damage to goods, etc. All of this previously stated, among other things, points to the fact of the necessity of justifying the application of the development process modeling of the reliability and availability of data transmission in the railway system.

Basically, the railway system is a very complex stochastic dynamic system [18,19]. Many researchers have used Markov models in their paper because they are suitable for cases of uncertainty and predicting future optimization conditions. These models are used for the purposes of reliability [19,20], maintenance [21-23] delay of arrivals and departures [24], optimal management [25] in research works, etc.

2. MATERIAL AND METHOD

The paper presents research based on statistical analysis of exploitation data and event expertise, as well as valid recommendations and standards in this area. An original computer program was developed for research purposes. In the paper, the reliability and availability analysis was modeled using the Markov model for data transmission in the railway system with four conditions, namely: correct condition of the system, presence of disturbances in the system, illegal (dangerous) condition of the system and blocked condition of the system.

The application of the new model for analyzing the reliability and availability of data transmission was carried out in the Dimitrovgrad and Belgrade railway stations (Republic of Serbia).

3. RESULTS AND DISCUSSIONS

3.1. Reliability modeling of data transmission systems

The reliability analysis of the system was performed according to the Markov model diagram given in Fig.1. in which there is a condition of blocking, a condition of complete failure and a final condition, i.e. there is no recovery of the system by repair or unblocking.

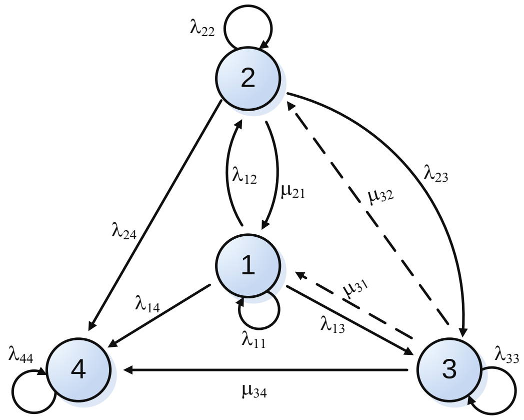

Fig.1. Markov diagram for analyzing the reliability of a data transmission system with four conditions: 1- correct system condition, 2- presence of disturbances in the system, 3- illegal (dangerous) system condition, 4- system blocking condition

In the diagram, in addition to the correct condition (1), we also have a condition with tolerable (permissible) failure, i.e. a condition with the presence of interference (2), a condition with impermissible (non-tolerant, dangerous) failure (3) and a condition of system safety blocking (4).

A tolerable disturbance is a failure that does not directly threaten the development or safety of traffic, condition 2, (Fig.1). As for the condition with tolerating disturbances, first of all we have the so-called "ghost" error, temporary instability or device failure that resolves itself, without operator intervention. In complex systems such as railways, their occurrence is inevitable, primarily for older systems. In other cases, these are failures of devices that are redundant in some way, either on purpose or due to the possibility of adjusting traffic flows. In the balance condition (2), we primarily have an increase in failure from condition (1), characterized by a failure intensity of λ_{12}. Depending on the characteristics of the tolerating interference, it is possible to remove the interference characterized by intensity μ_{21}, which can be on-line or by on-site intervention (which in principle could be separated into two recovery intensity parameters). A tolerant fault may, due to circumstances, develop into a local system lockout and should not develop into a non-tolerant failure, state (3) or a safety system lockout, state (4). It still happens, most often due to negligence, with failure intensity λ_{23} and λ_{24} respectively. The increase in condition (2) is possible by partial (incomplete) repair of dangerous failure (3) characterized by repair intensity μ_{32}. An increase is also possible by eliminating the failure that blocked the system, that is, by unblocking the security system characterized by the intensity of the repair μ_{42}.

In addition to the above, the system can go from a normal condition to a critical failure (3), which directly endangers traffic, with a failure intensity of λ_{13}. The possibility of remote (or direct) removal of a critical failure to a correct condition is characterized by the parameter μ_{31}. In addition, the system can go from a normal state to a system blocking condition (4) with a failure intensity of λ_{14}. The system in the blocking condition (4) most often (by design) comes for safety reasons from the critical state (3) with intensity μ_{34} and returns to conditions (2) and (1) by repair or unblocking characterized by intensities μ_{42} and μ_{41}. From the condition of blocking, the system is returned to its correct condition after testing and repairs according to a strictly prescribed repair procedure.

For the electronic switchboard, based on the recommended values of the parameters with the assumption of an exponential distribution of failures, we have the following: for the dangerous condition $\lambda_{dc}=0.01$ failures/year, we get that the reliability of the data transmission system, i.e. the probability of a correct condition is $P_1=0.99$ after one year of exploitation, i.e. $P_1=0.98$ after two years of exploitation. The unreliability of the system, i.e. the probability of an illegal (dangerous) condition is then $P_3=0.01$ after one year and $P_3=0.02$ after two years of exploitation.

The situation where we have conditions with tolerant failures requires a different approach. Then for the permissible terminations we have, for the failure parameter $\lambda_{fp}=1$ failure/4 months, i.e. λ_{fp}=3/year, after one year of exploitation $P_1=0.05$, i.e. $P_1=0.003$ after 2 years. At first look, an unacceptably low level of probability of a fully correct condition of P_1. It must be borne in mind that even now the maximum allowed unreliability of the system, that is, the probability of a dangerous condition, is $P_3=0.01$, that is, $P_3=0.02$. However, the required level of reliability of the system is achieved as the total probability of the allowed conditions (correct condition, condition with disturbances and condition of blockage), i.e. we can express as $P_1+P_2+P_4 = 0.99$ or $P_2+P_4 =0.98$ for one or two years of exploitation.

The graphical presentation of the probabilities of the state P_1 depending on the parameter λ_{13} is presented in Fig. 2.

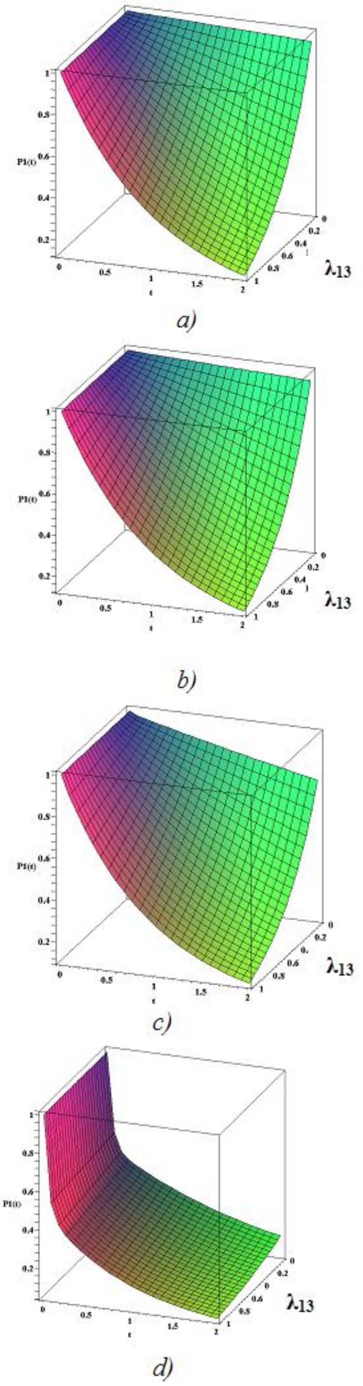

Fig.2. Probability of condition $P_1(t)$ depending on the change of parameter λ_{13}: a) for maximum reliability and maximum repair; b) for maximum reliability and minimum repair; c) for minimum reliability and maximum repair; d) for minimum reliability and minimum repair

The probability of the correct condition $P_1(t)$ depending on the parameter λ_{13}, i.e. depending on the probability of failure of the railway system from the correct condition (1) to the illegal condition (3) is shown in Fig.2. According to Fig.2a and b, it can be seen that, under conditions of maximum reliability of the railway system, there is no significant dependence of the condition $P_1(t)$ on the intensity of the repair from the condition with disturbances (2) to the correct condition and the reliability of the safety system - automatic transition from the dangerous condition (3) to the blocking condition (4). On the other hand, when the reliability of the system is high, including λ_{13}, the probability of the correct state $P_1(t)$ is very high during the exploitation time (time t), but it decreases rapidly with the increase of λ_{13} and over time. According to Fig.2c and d, it can be concluded that in the case of low reliability of the system, intensive repair can contribute to a relatively high probability of a correct condition. According to Fig.2d, a large decrease in the probability of a correct condition with time can be seen for the case of low system reliability and low repair intensity.

3.2. Modeling the availability of data transmission systems

The Markov model diagram for system availability analysis is presented in Fig.3. In relation to the reliability of the system, we have the additional recovery of the system from the condition of blocking both to the state of complete correctness and to the condition with tolerating malfunctions. System availability can be obtained as the sum of conditions 1 and 2, that is, as the probability that the system is in a condition acceptable for traffic.

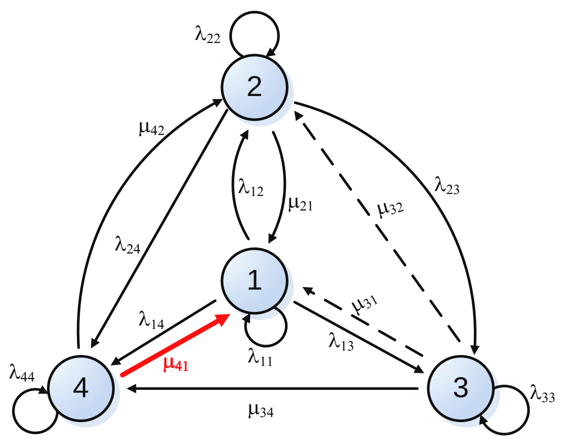

Fig.3. Markov diagram for the analysis of system availability for data transmission with four conditions: 1-correct system state, 2-presence of disturbances in the system, 3-illegal (dangerous) system condition, 4-system blocking condition [19,26]

The graphical representation of the probabilities of condition P_1 depending on the change of parameter λ_{13} is presented in Fig.4

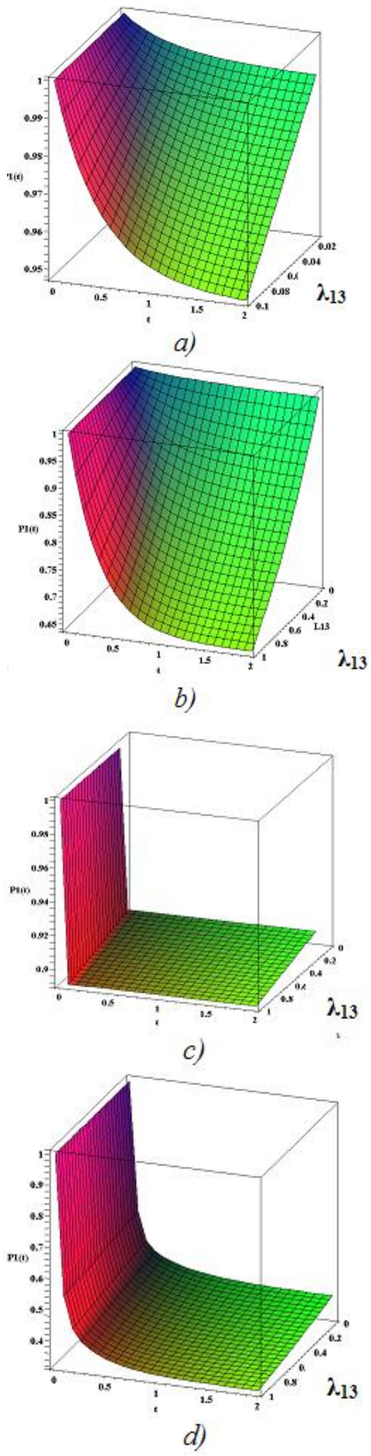

Fig. 4. Probability of condition $P_1(t)$ depending on the change of parameter λ_{13}, a) for maximum reliability and maximum repair, b) for maximum reliability and minimum repair, c) for minimum reliability and maximum repair, d) for minimum reliability and minimum repair

The probability of the correct condition $P_1(t)$ depending on the parameter λ_{13}, ie depending on the probability of failure of the railway system from the correct condition to the condition with an intolerable disturbance is shown in Fig.4. A significantly higher probability of condition $P_1(t)$ can be observed compared to the case without system recovery, Fig.4a. According to Fig.4a and b, it can be seen that, under conditions of maximum reliability of the railway system, there is no significant dependence of the condition $P_1(t)$ on the intensity of the repair from the condition with disturbances (2) to the correct condition and the reliability of the safety system - automatic transition from the dangerous condition (3) to the blocking condition (4). On the other hand, when the reliability of the system is high, including λ_{13}, the probability of the correct condition $P_1(t)$ is very high during the exploitation time (time t), but it decreases rapidly with the increase of λ_{13} and over time. According to Fig.4c, it can be concluded that for the case of low reliability of the system, intensive repair can contribute to a high probability of a correct condition. According to Fig.4d, a large decrease in the probability of the correct condition with time can be seen for the case of low system reliability and low repair intensity. In comparison with a similar condition of the system but without unlocking and repairing the system from condition (4), Fig.2, a significant increase in the probability of a correct condition can be observed.

4. CONCLUSION

The application of the new model for analyzing the reliability and availability of data transmission was carried out in railway stations in the Republic of Serbia. The justification of the application of the presented model of process development modeling the reliability and availability of data transmission in the railway system will lead to a reduction in the risk of inadmissible (dangerous) failures, improvement of maintenance planning and planning of spare parts, transition from maintenance by time to maintenance by condition and reduction of exploitation costs.

As a consequence of the change in traffic technology on high-speed railways, there is a need to develop a system to ensure the movement of trains with continuous and punctual two-way data transmission to achieve speeds of 300 km/h and more. Digitization, as a basic innovation of new technology, provides the possibility of integrating transmission paths, since different forms of signals are no longer used for certain forms of communication. In other words, the huge and complex network of connecting the structure of signal systems, which until now consisted of copper conductors of various sections, is replaced by one or two fiber optic cables. The process and operational level of the system are safety, they consist of the electronic station switchboard and the system for automatic guidance and protection of trains ETCS. Both of these systems are basic safety systems, directly responsible for the operational management of traffic on the railway. Through computer support, it is possible to integrate the entire operational level and fully automate it.

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