Досліджено вплив основних технологічних параметрів на ймовірність відмови та час безвідмовної роботи вчасного приймання та відправлення транзитних вантажних поїздів. Встановлені закономірності формування відмов при зміні добового навантаження, технологічного оснащення транзитних парків та величини нерівномірності вхідного та вихідного потоків. Дослідження проводились імітаційним моделюванням (Java SE 7.0 (Oracle), середовище розробки Eclips, AnyLogic) на прикладі типових норм технічних станцій

Ключові слова: технологічна надійність, імовірність відмови, безвідмовність, імітаційне моделювання

Исследовано влияние основных технологических параметров на вероятность отказа и время безотказной работы своевременного приёма и отправления транзитных грузовых поездов. Установлены закономерности формирования отказов при изменении суточной нагрузки, технологического оснащения транзитных парков и размера неравномерности входного и исходящего потоков. Исследования проводились имитационным моделированием (Java SE 7.0 (Oracle), среда разработки Eclips, AnyLogic) на примере типовых норм технических станций

Ключевые слова: технологическая надёжность, вероятность отказа, безотказность, имитационное моделирование

UDC 656.22 : 656.23
DOI: 10.15587/1729-4061.2017.91074

A STUDY OF THE TECHNOLOGICAL RELIABILITY OF RAILWAY STATIONS BY AN EXAMPLE OF TRANSIT TRAINS PROCESSING

V. Matsiuk
PhD, Associate Professor
Department of process control traffic
State Economy and Technology University of Transport
M. Lukashevicha str., 19, Kyiv, Ukraine, 03049
E-mail: vmatsiuk@ukr.net

1. Introduction

Meeting the deadlines of cargo delivery (subject to safety) with a rational use of available production resources can be regarded as the main operational challenge of railways. Therefore, technical regulation, production planning and the overall arrangement of a rail transit system (hereinafter, RTS) should ensure an appropriate level of reliability.

In addition to purely technical and managerial (in terms of efficiency of decision-making by the personnel) components, the technological process itself, as a set of sequential queuing systems, must be reliable enough.

Therefore, a study of technological reliability – such as a study of the influence patterns of an existing set of parameters on the probability of failure and the average duration of trouble-free operational processes of train stations and other rail transport systems – are important scientific and applied problems.

2. Literature review and problem statement

Ensuring the reliability of technical systems remains quite an essential problem for the transport industry [1-8]. For rail transport, reliability is usually considered as part of evaluating operational parameters. Rationing itself is achieved in practice mostly by analytical methods, and it ensures efficient operation of RTSs within confidence intervals of appropriate calculated optima [7, 9, 10]. However, this approach can not guarantee the proper level of trouble-free operation of transport systems as it does not take into account the possibility of exceeding the standards due to fluctuations in the transportation volume [11].

An objective difficulty in researching reliability of transport systems is their complexity and scale. A significant set of output parameters, their stochastic nature and the dynamics of the process as a whole challenge the feasibility of analytical models [3, 4, 5, 9, 10]. In most cases, the probability of failure and the uptime of technical systems may be determined only experimentally, by conducting complex and expensive tests of samples themselves (for technical facilities) [1] or models [2, 12].

Many researchers are trying to investigate multiphase processes by studying individual components of the processes [4], which prevents from determining the overall reliability, as the number of the system states can exceed tens of thousands and make calculations more difficult (or even impossible). Therefore, on balance, one of the few tools for researching the complex multiphase technological processes of railway transport may be simulation methods [12].

The influence of the human factor as a component of reliability on the stability and efficiency of rail transport is adequately covered in [13]. However, generally, the human factor mostly affects the operational organization of the technological process rather than its rationing and development of effective models.

Given the above, it can be argued that research of the technological reliability of operational processes at railway stations has been conducted insufficiently. Moreover, the rate of a probability of failure in receiving trains is typically determined in practice only when assessing the accuracy of complying with the timetable [7]. The lack of assessment methods for determining the reliability of the technological processes at railway stations makes it impossible to find the objective level of failure of a timely receipt and timely dispatch of trains, which significantly complicates the development of standards of an effective interaction of the transport system elements.

3. The purpose and objectives of the study

The research is undertaken with the aim to evaluate the reliability of the RTS operational processes by an example of typical technological standards for the railways of Ukraine.

To achieve this purpose, it is necessary to solve the following tasks:

– to justify the criteria for assessing the technological reliability of the operational processes taking place at railway stations;

– to determine the factors that influence the acceptance and rejection in timely processing of trains in transit lines;

– to study the impact of the factors on technological failure.

4. The tools and methods of studying technological reliability of railway stations

4. 1. The methods of determining technological reliability

Given the complexity and difficulty of the task, one of the few methods of this type of research is experimental measuring of simulation results.

The functional existence of a technological line of trains' processing can be presented as a discrete event process. Each application served by the system discretely is serviced by a particular technological element. Going through the processing steps is a conditional boundary that does not have its own duration. Simulation, according to the technology of processing trains, will reflect a gradual transition of applications through program units of one of the free channels. Each program unit delays an application for some time that corresponds to the pre-set or calculated duration of a relevant technological operation. The conditional transition boundary between technological operations will coincide with the moment of the application transition from one unit to another (Fig. 1). This principle allows the applied software to record the time of the application entry to the program unit, which manifests the beginning of an appropriate technological operation, and the time of the application exit from the unit, which corresponds to the completion of the technological operation. In fact, the results' gathering consists in recording the points of applications' moves between certain units (between the phases of train processing), which will further facilitate data processing as well as determining the likelihood of failure versus non-failing operations of the RTS. The duration of an application stay in a particular unit is defined as the difference between the points of the application's entering a next unit and the moment of its entering the calculation unit:

$$\Delta t_{dalay\ z} = t_{in,unit\ z+1} - t_{in,unit\ z},\ \text{at}\ z = 1,\ 2,\ ...,\ m; \qquad (1)$$

where $t_{in,\ unit\ z}$ is the time of the application entry to the unit z; $t_{in,\ unit\ z+1}$ is the time of the application entry to the unit z+1. The latter time coincides with the time of the application coming out of the unit z.

The whole process of servicing transit trains on the tracks of receiving and dispatching depots can be represented as an interaction of three Queuing Systems (QSs) (Fig. 2).

The first QS: the arrival station is a receiving and dispatching depot; it is a single-channel queuing system (provided there is a consecutive acceptance of trains to the depot tracks). The second QS is complex, n-channel, with m phases of service, where each track of the transit depot is a service channel, so the number of the service channels is equal to the number of the receiving and departure tracks of the depot; each receiving and departure track provides a train with a set of technological operations, which are performed in parallel as well as sequentially to one another. All operations can be roughly grouped into two successive processes:

1) technical (with non-detached repairing) and commercial inspection of railway wagons in parallel to one another. Moreover, technical inspection usually lasts more and overlaps commercial check;

2) attachment of the train locomotive, testing of the automatic brakes, and performance of other final operations before departure.

The third QS: the receiving and dispatching depot is a station of departure; it is a single-channel queuing system (provided there is a consecutive dispatch of trains on the connecting tracks).

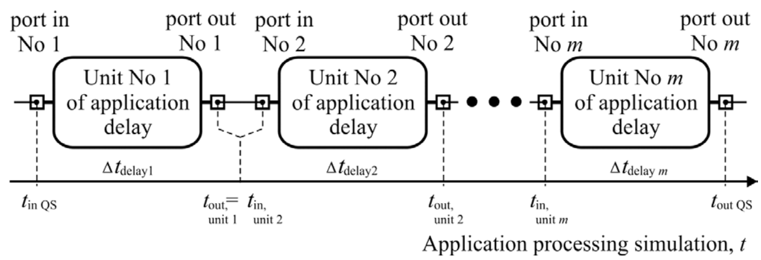

Fig. 1. The principle of a discrete event simulation of the technological process of a RTS at a sequential execution of operations

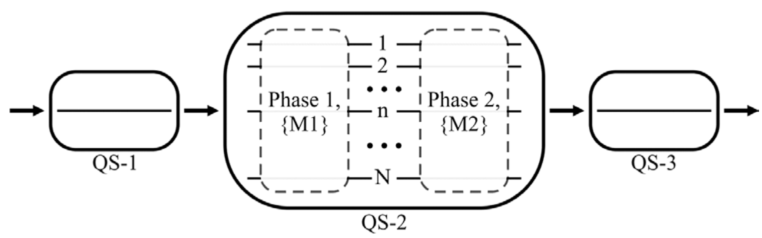

Fig. 2. A QS set in the structure of the technological line of processing transit trains of technical stations with appliance sets to service phase 1 ($\{M_1\}$) and phase 2 ($\{M_2\}$) of QS-2

Given the above, the goal is to study the probability of failure and the factors that affect it when applications are received in QS-2 (the probability of failure of a timely receipt) and when applications are received in QS-3 (the probability of failure of a timely dispatch of trains).

4. 2. The criteria for evaluating the technological reliability

To assess the reliability of the process of operating rail transport systems, the most essential criteria [1] are:

1) reliability (performance): the RTS ability to perform the required functions under certain conditions for a specified time interval or operational time. For practical use, the study of the technological reliability of the RTS should primarily determine the likelihood of uptime (reliability function; survival function): the probability that over a certain period of time there will be no failure at the RTS;

2) failure: an event that consists in the RTS loss of ability to perform the desired function. For example, with a transit line of classification stations, it can be a loss of the line capacity to receive and dispatch transit trains in time.

These indicators should also be considered in terms of the *existing* and *required* reliability:

– the *existing* process reliability can be understood as structural or design reliability: it is the maximum threshold of reliability, which can be provided with adequate technical parameters, local conditions, and the manner of transport operation;

– the *required* (planned) technological reliability: the maximum level of reliability, which is required (planned) to be provided in accordance with the scale of the planned work, its structure, and nature.

In this study, the desired probability of failure will be represented by the value of $\xi_п$=0.05, which corresponds to the desired probability of a timely receipt and a timely dispatch of trains being 0.95.

4. 3. The toolkit of the technological reliability study

The chosen simulation model development tool is the object-oriented programming language *Java SE 7.0* (*Oracle*). The development media are *Eclips* and *AnyLogic* 6.4.1 with the major libraries.

According to the object-oriented paradigm of *Java*, the standard classes of the library *Enterprise AnyLogic* are supplemented with specially created classes:

1) a *class Train* (a class of the type *Entity* – applications). The class fields are variables that characterize the properties of transit trains;

2) a *class Tracks* (a class of the type *Entity* – applications). The class fields are variables that characterize the properties of the receiving and departure tracks of the transit fleet;

3) a *class Teams* (a class of an active object). The class fields are variables that characterize the properties of maintenance teams for technical inspection;

4) a *class Locom* (a class of an active object). The class fields are variables that characterize the properties of train locomotives.

The model architecture is developed in accordance with the "physical" operations of receiving and processing trains. The main physical characteristics of the process are a model time and binary spatial coordinates. A more detailed description of the simulation model is presented in [11, 12].

The model is developed, taking into account and ensuring the following:

1) applications are generated by the intensity that corresponds to the flow of trains in QS-1 under the established law of distribution;

2) the intensity of entering the model channels is regulated according to the established minimal acceptable interval of trains' flow. This simulation will correspond to the physical arrival of trains to the receiving and departure tracks of the station (QS-2) with an interval that will be longer than or equal to the established interval of associated arrivals at the connecting section:

$$p(t)=\begin{cases} p(J_{in}), & \text{at } t \le J_{in}; \\ p(t), & \text{at } t > J_{in}, \end{cases} \qquad (2)$$

where p(t) is the density of distributing the probability of an interval for trains arrival for processing; J_{in} is the minimal acceptable interval of trains arrival from the running line to the station according to the existing means of automation, remote control, and communications;

3) a free channel for maintenance – a free receiving and departure line – is selected according to the established limits and initial conditions of modelling;

4) after receiving an application to a free service channel – the train's arrival at the receiving and departure track, the application delay simulation will correspond to the train set being processed by means of technical inspection. The inspection duration, in addition to the initial static data, is determined according to the variable composition of the trains in which the number of railway wagons is simulated by the given distribution law;

5) the choice of an inspection team (the first set of devices for servicing QS-2) – with several teams under the given conditions of simulation – is determined according to the principle that is determined by the simulation parameters;

6) after simulating technical inspection, the application in the same channel of servicing is expected to be processed by a free device of servicing the second phase of QS-2 – the train locomotive;

7) after simulating the supply of the train locomotive to the train set that is ready for departure, there happens a simulation of dispatch operations;

8) there is a simulation of a queue of all trains ready for departure by the nearest thread of the timetable for QS-3;

9) during the simulation process, it is essential to make measurements of the discrete transitions of applications (trains) along the units of each service channel. It is also important to make measurements of the starting and finishing points of using the channels (channel units) of service and the devices for maintaining the model.

4. 4. The initial parameters of the simulation

The model is implemented by an example of typical flow processes of technical railway depots of Ukraine. The initial parameters are the following:

1) the average daily flow is 60 transit trains per day;

2) the number of service channels in QS-2 (the number of tracks in the transit depot for receiving and processing trains) is 7;

3) the number of maintenance teams and the number of groups in each team: one team of four groups;

4) the number of train locomotives, providing 15 % of the reserve, is 26;

5) the intervals of associated arrivals and associated departures of trains, respectively, are: $J_{a.a.}$=7 min and $J_{a.d.}$=7 min;

6) the number of railway wagons in a train, which is subject to the normal law with the parameters of M(x)=55 wt and σ(x)=2.5;

7) the basic unit of measuring time is one minute;

8) the necessary technological failure probability is $\xi_п \le 0.05$.

4. 5. The model limitations and assumptions

While developing the model, it is assumed that:

1) the input stream of transit trains is the simplest, and that is why it entails a Poisson process;

2) the train timetable is rational and rhythmic: the threads of the transit train timetable are distributed across the hours of the day at an approximately equal interval, which is 1,440/$N_{tr.}$ ($N_{tr.}$ is the average number of transit trains per day);

3) all standards of time for all technological operations are made in accordance with standard rules. In the absence of standard rules, they are made according to the technological processes at the Darnytsia station units;

4) the track development of the station is rational, and it does not significantly affect the retention time for arrival and departure of trains and locomotives. The duration of filling the necks of the station parks is less than the least possible interval of an associated arrival or departure of trains;

5) when selecting the channel for servicing applications in QS-2 (transit park tracks for arrivals), the priority is the channel that has a lower index – from 1 to N, where N is the number of receiving and departure tracks of a transit depot;

6) when selecting the device for maintaining phase one or phase two of QS-2, for a brigade of the maintenance depot or the train locomotive, the principle of *FIFO* (*first in – first out*) is used to select the device that went into the standby mode earlier;

7) an application in the service channels of QS-1, QS-2, and QS-3 is also chosen by the *FIFO* principle.

4. 6. Validation of the software code, the model adequacy, and the results' reliability assessment

The model was validated by testing all of its units separately. During the model code testing, its individual elements were corrected. The model code itself was compiled successfully, confirming absence of software errors.

The adequacy assessment of the simulation results and the simulation model effectiveness is complicated by the fact that the simulation concerns a typical workflow. Therefore, it is impossible to conduct a comparative evaluation of the actual and estimated results. Besides, the structure of the technological timetable of the model rules itself does not contain elements of *downtime to wait for process operations*. However, if only the duration of the operations is summed up, the obtained duration will be the time that is regulated by standard specifications.

To ensure reliability of the simulation, it is necessary to determine the maximum number of iterations (with the same initial parameters) and the duration (model time) of modelling. The solution is based on the principle that the determined number of iterations should provide an arithmetic mean value whose deviation from the statistical expectation does not exceed the specified error level.

It should be noted that because the developed simulation model simulates a technological process in which most elements are of stochastic (although clearly formalized) nature, the outcomes of the "model run" will also be stochastic. Then, for this type of experiments, the key issue is to establish the distribution (and its parameters) of the simulation results.

Therefore, several series of experiments were conducted under various durations of the simulation but at the same initial parameters. Each series contained 400 iterations. The measuring and the analysis were carried out with regard to the selected most important calculation factor, which was the percentage of applications that had been delayed when entering the service channels in QS-2, and in fact it meant the probability of failure in admitting a train to the tracks of the transit park.

The samples' evaluation for a hypothesis about the normal distribution law was confirmed with a high probability of 99 % by the criterion of χ^2. The calculations were conducted in MS Excel (analysis package) by a method of an interval series distribution (Fig. 3).

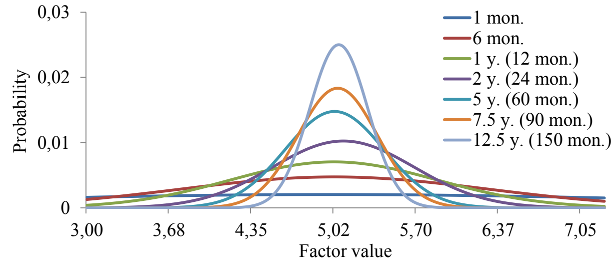

Fig. 3. The density of the normal distribution for the test results from Table 1

According to the property "symmetry" of the normal distribution, ninety-five per cent confidence intervals (a relative error of less than 5 % is accepted for most processes in the transport sector) (Fig. 4 and Table 1) will be the boundaries of, respectively:

$$\begin{cases} \tilde{M}(x) - k\tilde{\sigma}(x); \\ \tilde{M}(x) + k\tilde{\sigma}(x), \end{cases} \quad (3)$$

where k is the number of standard deviations, corresponding to 95 % of the confidence interval of the normal distribution of $k \approx 1.96$.

The minimum number of iterations in which their average values will deviate from the expected value less than the pre-set relative error (10 %, 5 %, and 1 %), along with other results, are presented in Table 1.

Table 1

Assessment of a series of experiments with the simulation model

The experiment parameter		The serial number of the experiment						
		1	2	3	4	5	6	7
The model time, in months		1	6	12	24	60	90	150
Assessment of M(x)		4.99	5.03	5.03	5.10	5.03	5.06	5.07
Assessment of σ(x)		2.92	1.26	0.85	0.58	0.41	0.33	0.24
Assessment of v(x)		0.59	0.25	0.17	0.11	0.08	0.07	0.05
The left margin of the 95 % of the confidence interval		–0.73	2.56	3.36	3.96	4.24	4.42	4.60
The left margin of the 95 % of the confidence interval		10.71	7.50	6.69	6.25	5.83	5.70	5.54
The minimum number of iterations to ensure reliability	90 %	132	25	11	6	3	2	1
	95 %	526	97	44	21	10	7	4
	99 %	13,143	2,410	1,095	503	249	160	86

To ensure reliability of the results of the model simulation, it is possible to choose any connection between "the model time and the number of iterations" at an appropriate level of reliability. Given the principle that for most of transport processes the acceptable level of reliability is 95 %, as well as in view of the full-scale monitoring of the simulation, each experiment relied on the chosen ratio of 12.5 years (150 months) and 4 iterations.

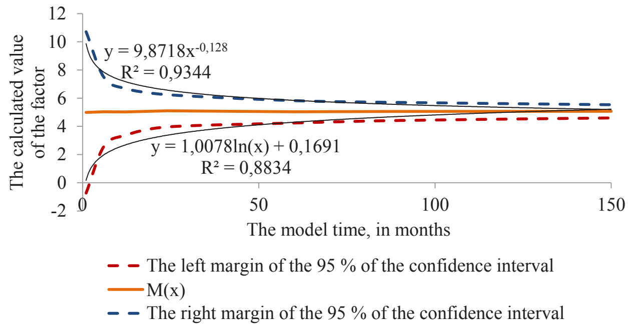

Fig. 4. The estimated confidence (95 %) intervals of a series of experiments (Table 1)

5. The discussion of the research results on the technological reliability of the processing line for transit trains at classification stations

A group of four experiments has produced the following results.

The applications for servicing were received:

– in time: 256,051 (93.6 %);

– late: 17,473 (6.4 %);

– with a probability of failure to receive the trains to the station tracks being $\xi_{r.st.}$=0.064.

The density of distributing the waiting time in admitting trains to the tracks of the transit park with a strong probability (of 95 %) is subject to exponential distribution (Fig. 5) at an intensity of M(x)=49.3 min, when the standard deviation is σ(x)=48.12 min and the variance is ν(x)=0.98.

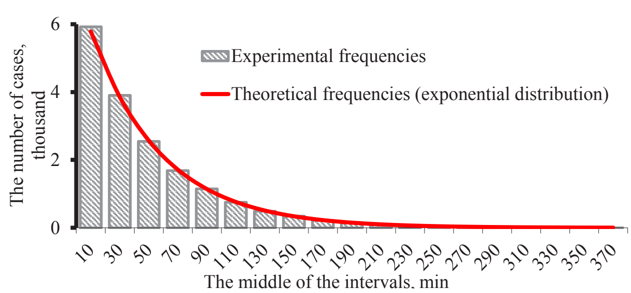

Fig. 5. The density of distributing the waiting time for admitting trains to the tracks of the transit park

The density distribution of trouble-free uptime has a significant left-side asymmetry (Fig. 6): M(x)=3,355 min (2.33 days), the standard deviation is σ(x)=5,752 (3.99 days), and the variation is ν(x)=1.8.

The density of distributing the duration of the total time of a transit train servicing is close to the exponential value (Fig. 7), where M(x)=65.6, σ(x)=39.8, and ν(x)=0.61.

The relative amounts of productive uptime and unproductive downtime (pending operations) in servicing trains as well as the main subunits of QS-2 are shown in Fig. 8.

The impact of changing the number of maintenance teams (the devices of servicing the first phase of QS-2), the number of train locomotives (the devices servicing the second phase of QS-2), the minimum intervals between the arrivals and departures at the probability of failure in timely acceptance of trains (ξ_n) and the inter-operational downtime are shown in Fig. 9–12.

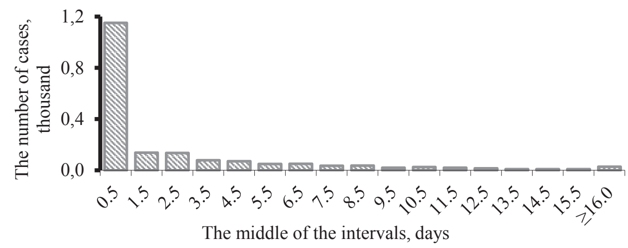

Fig. 6. The density distribution of uptime when receiving transit trains

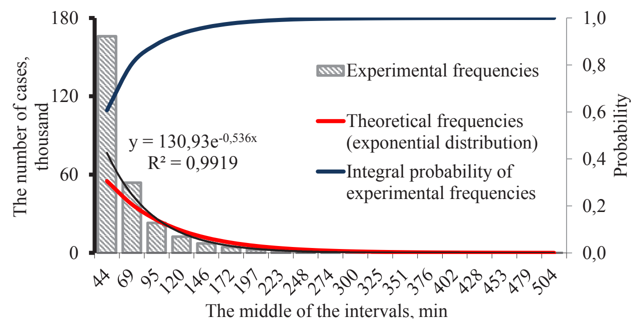

Fig. 7. The density distribution of time for servicing trains on the tracks of the transit park

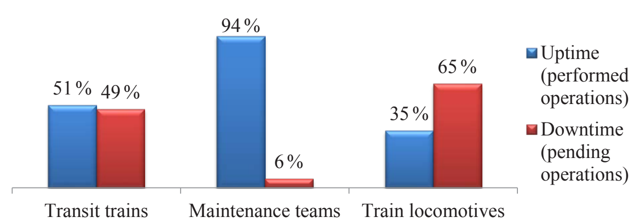

Fig. 8. The relative rates of productive uptime and unproductive downtime of the basic elements of the simulation model

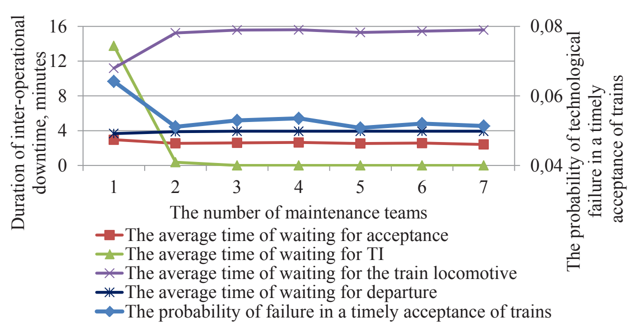

Fig. 9. The dependence ξ_n=f(S_{TI}), where S_{TI} is the number of concurrently working inspection teams

When the parameter β exceeds a value of 0.65–0.7, there happens a rapid increase in the probability of failure of a timely arrival (Fig. 12), which means a possible system failure – a condition in which the process reliability can be ensured only after improving or modernizing the standards and rules. The reason is, probably, the constant increase of the average time of waiting for departure, which begins to increase abruptly at such values of β. The same situation is observed when there is a decrease below the calculated value (M<26) of the operational parameter such as the train locomotives fleet (Fig. 10).

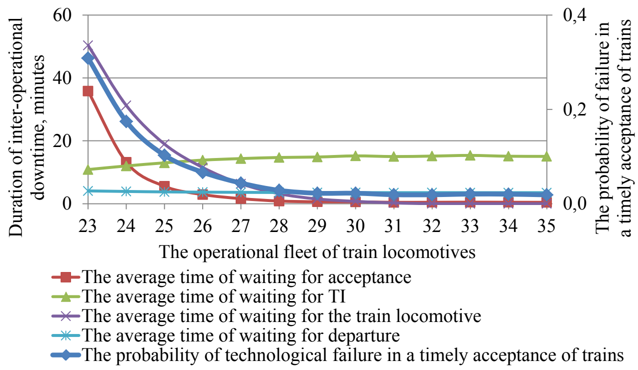

Fig. 10. The dependence ξ_n=f(M), where M is the estimated number of train locomotives

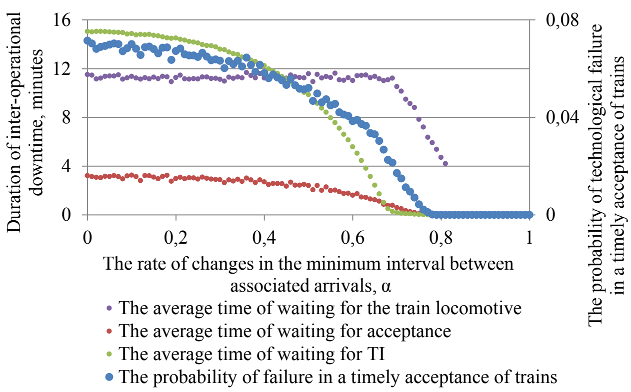

Fig. 11. The dependence ξ_n=f($\alpha t_{arriv.}$), where α is the rate of the average value of the arrival interval $t_{arriv.}$; α∈[0; 1] with a step of 0.01

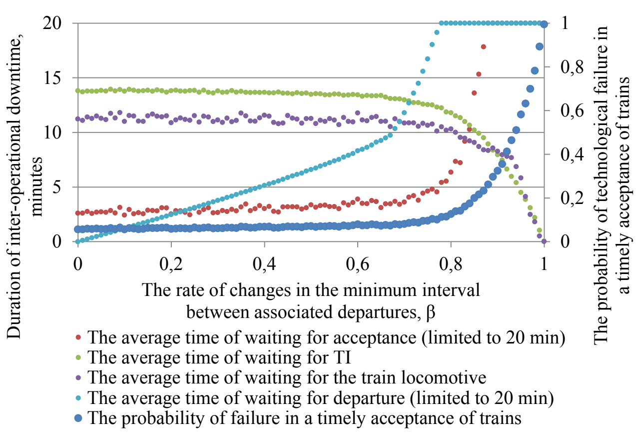

Fig. 12. The dependence ξ_n=f($\beta t_{depart.}$), where β is the rate of the average value of the departure interval $t_{depart.}$; β∈[0; 1] with a step of 0.01

6. Analysis of the research results about reliability of the technological line for processing transit trains of technical stations

The results of the research clearly demonstrate an advantage of simulation modelling (despite the relative complexity of developing models) over the analytical estimates of multiphase processes of railways, and it confirms that the real time when trains stay on the receiving and departure tracks is far longer than the time that is stipulated by the common rules.

Due to the fact that the number of service channels in QS-2 and the devices of servicing them do not match the number and nature of the random flow of trains for processing, there are *technological conflicts* that result in inter-operational downtime. According to the simulation results, such conflicts account for about 50 % of the time of processing trains; therefore, technological conflicts can be understood as common in complex technological processes of a RTS. Moreover, it is necessary to acknowledge that there exists a marginal, technologically rationalized rate of downtime, which should be taken into account in order to normalize process operations on railways.

The existing procedure for rationalizing the time of trains staying on the receiving and departure tracks should take into account the stochastic nature of the technological processes and the work volumes. If the operational process is supplied with standards of required reliability – the required level of technological failure versus uptime, it will facilitate objective assessment of reliability of an existing transportation process.

It should be noted that these results reflect a general principle of assessing the operational process reliability. However, the considered approach and the benchmarks could be considered as universal for studying technological reliability of any railway station.

7. Conclusions

The tests on the technological reliability of the operational process in the RTS were conducted with regard to the typical standards of technical stations and with the following findings:

1) the common features of technical systems' dependability – the probability of failure and reliability – by their essence help assess the possibility for the RTS in its operational process to ensure timely (without delay) acceptance and timely (after processing) departure of trains. All indicators of technological reliability must be considered in two aspects: existing (constructive or technological reliability) required (planned technological reliability). For most of technological processes of the RTS, a rational technological failure should not exceed 0.05;

2) the level of technological failure and trouble-free uptime of receiving and dispatching stations are affected by: the number of simultaneously operating maintenance teams, the size of the operational fleet of train locomotives, the daily uneven number of arriving trains, as well as minimal determined intervals of associated arrivals and departures of trains;

3) with an increase in the number of both existing teams and train locomotives, there is no significant change observed in the probability of failure as to timely acceptance of trains, but there are a reduced time for a train to wait for technological processes and an increased probability of timely departure. When the minimum interval between passing trains' arrivals increases, the probability of failure ξ_n decreases. When the minimum interval between passing trains' departures increases, the probability of failure ξ_n

gradually increases, and after a point of 70–80 % of the average daily interval of arriving trains, the increase becomes stepwise. This proves the impossibility of timely departures of trains at equal intensities of arrivals and departures (the same number of timetable threads). To ensure an adequate level of failure in a timely dispatch of trains (less than 0.05), the number of dispatch timetable threads should be at least 30 % bigger than the number of threads for arriving trains.

References

1. Paramonov, Y. Binary lambda-set function and reliability of airline [Text] / Y. Paramonov, S. Tretyakov, M. Hauka // Reliability: theory & applications. – 2015. – Vol. 10, Issue 03 (38). – P. 37–42.
2. Breznicka, A. Mathematic and simulation modeling for analysis prediction of risk [Text] / A. Breznicka, A. Chovanec // Reliability: theory & applications. – 2015. – Vol. 10, Issue 04 (39). – P. 29–34.
3. Stepanyants, A. S. Reliability and capability modeling of technological systems with buffer storage [Text] / A. S. Stepanyants, V. S. Victorova // Reliability: theory & applications. – 2010. – Vol. 1, Issue 02 (17). – P. 40–49.
4. Kolowrocki, K. Preliminary reliability, risk and availability analysis and evaluation of bulk cargo transportation system in variable operation conditions [Text] / K. Kolowrocki, B. Kwiatuszewska-Sarnecka, J. Soszynska // Reliability: theory & applications. – 2010. – Vol. 1, Issue 2 (17). – P. 173–183.
5. Shramenko, N. Ju. Effect of process-dependent parameters of the handling-and-storage facility operation on the cargo handling cost [Text] / N. Ju. Shramenko // Eastern-European Journal of Enterprise Technologies. – 2015. – Vol. 5, Issue 3 (77). – P. 43–47. doi: 10.15587/1729-4061.2015.51396
6. Skalozub, V. V. Nechitki modeli upravlinnja ekspluatacijeju tehnichnyh system dlja zabezpechennja stijkosti zaliznychnyh perevezen' [Text] / V. V. Skalozub, O. P. Ivanov, O. M. Shvec' // Transportni systemy i tehnologii' perevezen'. – 2015. – Issue 9. – P. 65–71.
7. Butko, T. An improved method of determining the schemes of locomotive circulation with regard to the technological peculiarities of railcar traffic [Text] / T. Butko, A. Prokhorchenko, M. Muzykin // Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 5, Issue 3 (83). – P. 47–55. doi: 10.15587/1729-4061.2016.80471
8. Tartakovskyi, E. Improving the process of driving a locomotive through the use of decision support systems [Text] / E. Tartakovskyi, O. Gorobchenko, A. Antonovych // Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 5, Issue 3 (83). – P. 4–11. doi: 10.15587/1729-4061.2016.80198
9. Katsman, M. D. Mathematical models of ecologically hazardous rail traffic accidents [Text] / M. D. Katsman, V. K. Myronenko, V. I. Matsiuk // Reliability: theory & applications. – 2015. – Vol. 10, Issue 01 (36). – P. 28–39.
10. Myronenko, V. K. Matematychna model' staniv ta nadijnosti zaliznychnoi' transportnoi' systemy pry perevezennjah nebezpechnyh vantazhiv [Text] / V. K. Myronenko, M. D. Kacman, M. M. Gorbaha, V. I. Macjuk // Systemy obrobky informacii'. – 2015. – Issue 9. – P. 161–167.
11. Macjuk, V. I. Doslidzhennja tehnologichnoi' nadijnosti parkiv tehnichnyh stancij dyskretno-podijevym modeljuvannjam [Text] / V. I. Macjuk // Zbirnyk naukovyh prac' Derzhavnogo ekonomiko-tehnologichnogo universytetu transportu. Serija: Transportni systemy i tehnologii'. – 2015. – Issue 26-27. – P. 268–272.
12. Macjuk, V. I. Pryncypy zabezpechennja tehnologichnoi' nadijnosti zaliznychnyh transportnyh system [Text] / V. I. Macjuk // Zbirnyk naukovyh prac' Derzhavnogo ekonomiko-tehnologichnogo universytetu transportu. Serija: Transportni systemy i tehnologii'. – 2016. – Issue 28. – P. 262–271.
13. Samsonkin, V. M. Rozrobka modelej ocinky vplyvu ljuds'kogo chynnyka na innovacijnyj rozvytok pidpryjemstv zaliznychnogo transportu [Text] / V. M. Samsonkin, M. M. Adzhavenko // Problemy ekonomiky. – 2014. – Issue 1. – P. 77–82. – Available at: http://nbuv.gov.ua/UJRN/Pekon_2014_1_11