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Critical failures of turnouts: expert approach

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Abstract

There are three basic tasks undated for the infrastructure of railway transport: increasing the safety, providing the reliability of transportation process, and reducing the technical equipment service charge. The point and point machine are one of the most important components of railway transport infrastructure. Predicting the failures of this item remains an open question. The article presents a research carried out on the rail 1520 with the most common SP type of machine and a DC motor. At the first stage, component failure analysis based on the expert approach, was performed and the main, most critical refusals are identified, taking into account three service strategies. At the second stage, economically grounded approaches to the diagnosis and prediction of certain failures are analyzed. To substantiate the conclusions of the second stage, the results of the mathematical modeling of the critical points' failure are used.

Keywords: Railway turnout systems; Failures; Service strategy

1. Introduction

The analysis of recent works on the diagnosis and prediction of the technical condition of the point machine (PM) elements makes it possible to distinguish between two main approaches: the direct measurement of the controlled critical elements operation parameters, or indirect control, mainly due to the analysis of the current curves or the power consumed by the electric motor during the transfer There are also works on the analysis of sound vibrations in

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the point operation in order to identify the signs and prevent damage to its elements, but such studies have not yet gained popularity.

Among the most illustrative works of the first approach is work [1], where five different types of sensors (force, current, voltage, linear velocity sensor and distance) were used to determine the most informative and economically justified degradation indicators. The economic component of sensors usage was also considered. In particular, the authors noted that the power sensor is the most informative, but it has a price which is 5-10 times higher than the one of the current or voltage sensor.

In the second direction we refer to works [2-8]. In these works, various aspects of the points and drive elements degradation are considered with the usage of various mathematical apparatus for the curve of current or power analysis. This approach is currently the most popular, but specialized systems that already use such approaches to the diagnosis of turnout damage do not cause enthusiasm for the operating personnel [8].

However, warning of certain point failures is important for certain operating conditions and tasks of a particular type of transport. The rationale for improving the prediction of specific types of failures is usually comes down to the traffic safety state reports data analysis [9]. Given the national peculiarities and the significant influence of the human factor on the accounting process, the definition of point's critical components requires a different approach, namely the Failure Mode and Effects Analysis (FMEA).

At the critical components determination stage, the results of using the FMEA to determine the most critical point and point machine failures are proposed in accordance with the three main strategies for applying the prognostics and health management (RNM) approach. There are three possible tasks envisaged, on the solution of which the implementation of RNM approaches to maintenance is directed (see Fig. 1). In each case, depending on the task, developers need to determine what is the main goal [10]: service reliability (safety of traffic flow), availability of assets or reduce maintenance costs.

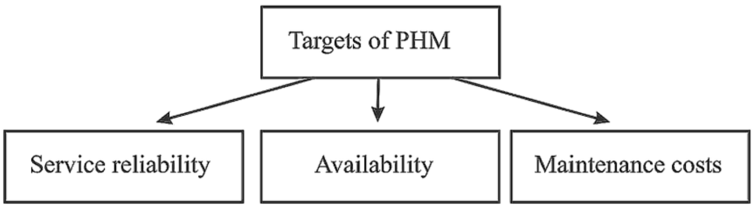

Fig. 1. Targets of prognostics and health management [10].

The system's critical components definition, and the choice of sensors, methods for assessing the resource and methods of prognostication and maintenance planning are depend on the choice of the main purpose

2. Mathematical background of the expert approach

We distinguish between hardware [11]: road bed, upper permanent way; man-made facilities; rolling stock; communication and signaling devices as well as electric power supply devices. The analysis of security divisions of rail transport [9] shows that the share of these components account for about 75% of traffic accidents in the work on the sectors of Ukrainian railways. If we will separate the point components failures on the failure of the mechanical components and the failure of the electric drive components, then the latter do not significantly affect the general statistics. According to [9] all the elements of signaling and communication systems account for only 1,25 % of traffic accidents attributed to hardware failures from their total number. But in the mechanical part, the second key element of hardware are turnout that wear out in 2-3 times faster than rails (see Fig. 2) and it is the main place of rolling stock derailment.

Despite the fact that there is a record of the rail points element's refusals, determining the actual frequency or the probability of one or the other element refusal is difficult enough. First of all, the services of various elements of the railroad turnout system are assigned to various services. The switch motor is serviced by the department of signaling and locking systems, and other components – by track department. Secondly, the quality of accounting for failures is significantly dependent on the human factor. Therefore, a group of experts involved in the operation of turnout systems was formed for the analysis based on the principles of FMEA [12].

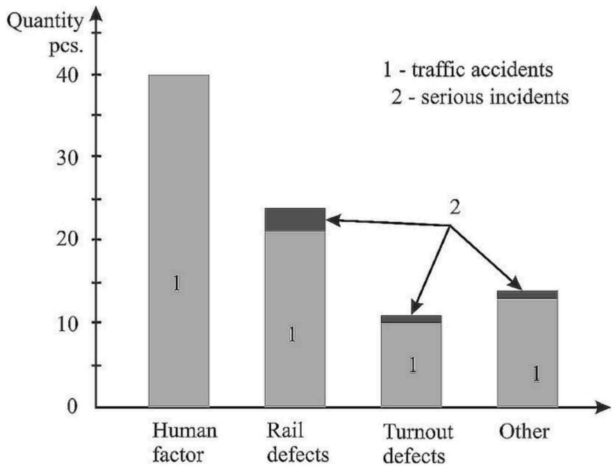

Fig. 2. Analysis of traffic accidents reasons admitted in the track economy.

The group of experts included those responsible for the service areas of the department of signaling and locking systems and the track department of each of the six railways of Ukraine. The list of possible failures is grouped according to Table 1 on the basis of analysis of security divisions of rail transport [9]. The experts also pointed out the reasons for refusals, but in this work, this part is not paid much attention, because for the most part it is either poor quality or inadequate service.

Table 1. Frequency and criticality evaluation of failure.

	Failures of turnout systems	Experts evaluates				
		K_1	K_2	K_{31}	K_{32}	K_{33}
1	Bolts stick to a tongue rail	2.48	2.76	3.04	5.74	4.27
2	Rebound (bias) of a stockrail	5.52	5.28	7.42	6.48	5.34
3	Curvature of a tongue rail	2.57	6.23	5.21	6.90	8.12
4	Switch-point creep age	3.73	1.98	5.29	4.53	5.04
5	Shell or head checks on the rail head of a stockrail	3.90	2.83	3.72	4.90	5.29
6	Extension or narrowing the track around the tongue rails	5.89	3.91	6.41	7.16	4.38
7	Excessive tightening bolts in the heel block	4.89	5.95	3.18	4.79	2.04
8	Contaminated (lack of the lubrication) slide chairs	8.25	3.34	2.81	4.65	2.58
9	Contaminated turnout system	8.21	4.08	2.62	6.07	3.67
10	Accumulation of pressed of snow or dirt between tongue rails and stockrails or in the switch angle	7.48	4.83	3.51	7.35	2.39
11	Weak (or too large) abnormal pressing on brushes to the commutator	5.54	5.39	3.92	6.04	4.50
12	Slowly switching of detection contacts (fatigue of metal of springs)	6.77	6.81	3.35	2.77	3.33
13	Jamming of the throw bar	2.73	6.99	3.18	8.08	5.50
14	Unstable work of the friction clutch	3.72	6.24	2.80	4.53	4.57
15	Broke of the elements of detection contacts	4.01	4.22	5.59	6.61	4.64
16	Precipice of the armature conductors or field winding	4.62	5.00	2.43	5.35	5.15

Coefficient K_1 evaluates the frequency of failures, or estimates the probability of a particular type failure. The coefficient was put forward by experts based on the following concepts: very low probability of occurrence (1-2); low (3-4); average (5); high (6-7); very high (9-10). The coefficient K_2 is used to assess the probability of a failure or defect detection. In this case, the following concepts are used: very high, the reason for the refusal is easy to detect (1-2); high, the reason for failure is simply-detected (3-4); average, the reason for failure is difficult to detect (5); low (6-7); very low (8-9), the reason for failure is extremely difficult to detect (10).

One of the key factors is the coefficient K_3 (the damage or defect severity). Taking into account the need for impact assessment for the three strategies, the coefficient K_{3j} was set separately for safety assessment (K_{31}), for transport process reliability (K_{32}) and for estimation of maintenance costs (K_{33}). In all three cases, the following concepts are used: almost invisible (1-2); small (3-4); medium (5-6); significant (7-8); very significant (9-10).

The calculation of the failures criticality was carried out according to the formula:

$$A_{ij} = \prod_{n=1}^{3} K_{ij} \quad (1)$$

where A_{ij} is the criticality of the occurrence of i-th failure for j-th strategy; K_{ij} – the value of expert evaluation.

The criticality of k-th failure, taking into account its significance in the general list of failures, was determined by the formula:

$$A'_{ij} = \sum_{n=1}^{3} K_{ij} \cdot k_j \quad (2)$$

where A'_{ij} is the criticality of the occurrence of i-th failure for j-th strategy, taking into account its significance in the general list of failures; k_j is coefficient of significance in the general list of failures.

$$k_j^p = \frac{K_{3j}^p}{\sum_{n=1}^{p} K_{3j}^p} \quad (3)$$

where p is the serial number of the refusal in the general list.

3. Analysis and visualization of the results

As a result of the calculations, data received in the form of a graphic are obtained (see Fig. 3). As can be seen from the figure, in terms of a combination of factors such as the frequency of failure and the complexity of its identification, the most critical will be:

- For a safety of train traffic - the rebound of the stockrail (2) and the rail width violation it the tongue area (6), gradual automatic switch work deterioration due to the springs material fatigue (12) and poor control of the detector rods (17)
- For the continuity of the transportation process - the rebound of the stock rail (2) and the rail width violation it the tongue area (6), incorrect adjustment of root bolts (7), violation of the commutator (11), auto-switch failure (12), locking of the throw bar (14) and failure of the detector rods (15)
- For material repairs expenses - the rebound of the stockrail (2) and curvature of the tongue (3), the violation of the commutator (11), and the auto-switch failure (12)

An assessment of the criticality of the damage appearance relative to other failures is indicative (see Fig. 4). It is clear from the graph that from the strategy of ensuring maximum safety point of view, the focus should be on controlling and preventing the stockrail rebound (2), and the rail width violation it the tongue area (6), as well as preventing the violation of detector rods work (17). In terms of ensuring the reliability of the transportation process - the above-mentioned refusals should be supplemented by accumulation of pressed snow. (10), commutator (11) and throw bar (13). From the point of view of the material cost of repair, a stockrail rebound (2) and curvature of the tongue (3) matter.

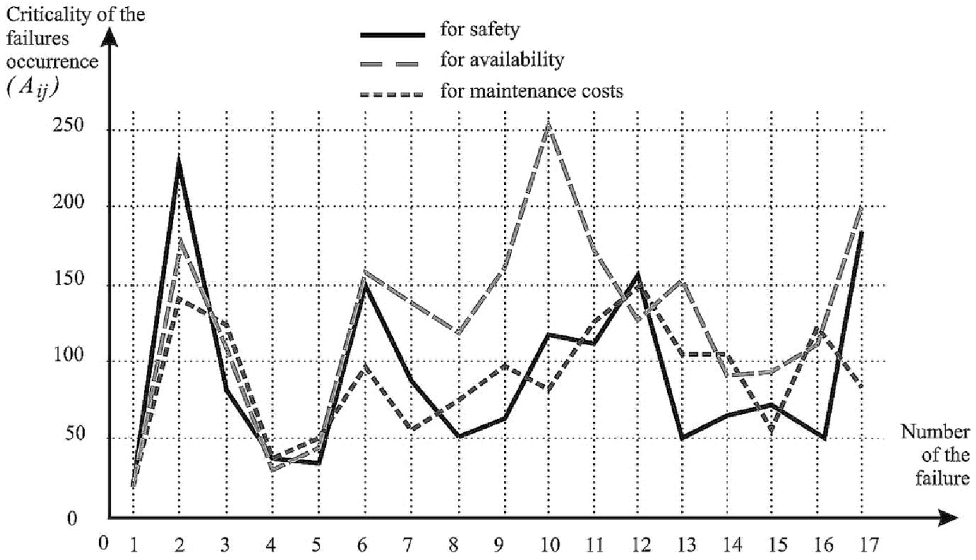

Fig. 3. Severity of the failure appearance.

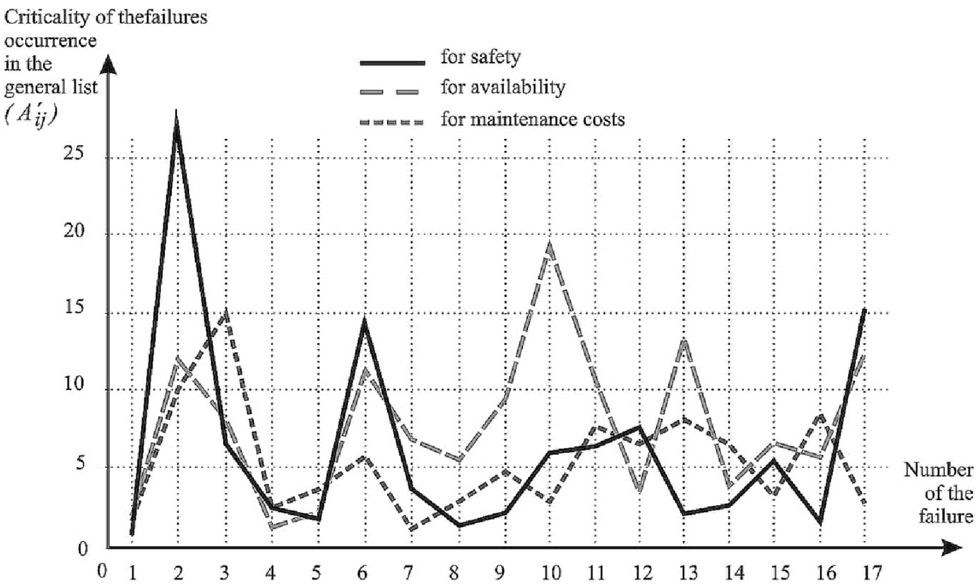

Fig. 4. Criticality of failure occurrence due to significance.

4. Error estimation

An integral issue of using expert methods is the assessment of the consistency of their opinions. In this case, it would be advisable to assess the expert opinions' divergence by calculating the mean-square deviation of the results:

$$\sigma_j^2 = \frac{1}{m-1}\sum_{j=1}^{n}\left(A_j - A\right)^2 \tag{4}$$

where σ_j^2 is the mean square deviation of the failures' results for the cause of j; m is the number of experts interviewed; n is the number of failures' reasons for; A is the expert evaluation.

As a result of calculations, it was determined that the average difference between the results of expert evaluations in the context of the consequences of failures was 27%. Fig. 5 shows the distribution diagram of the deviation response for failures.

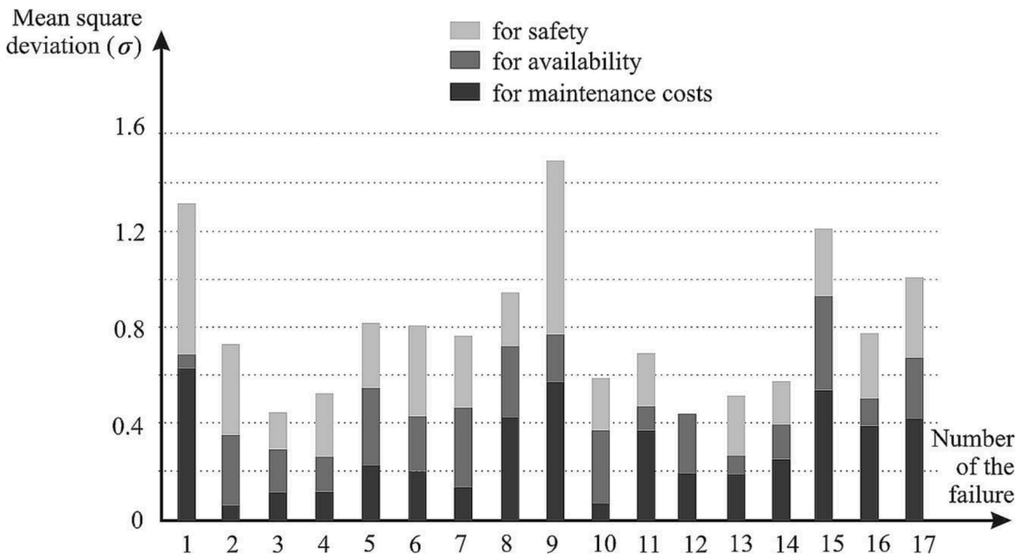

Fig. 5. Distribution of discrepancies in answers of experts for failures.

The picture shows that the highest consistency of opinion is observed for failures 3, 4, 12, 13, 14. The most controversial estimates are obtained for reasons 1, 9, 15, 17. The smallest spread of ratings of 21% was obtained when assessing the impact of failures on the stability of the transport process ,which is reflected by the damages' repair speed. The most ambiguous estimates of 31.7% are related to the estimation of material losses for the elimination of the damage.

If we assess the consistency of expert opinions on the above-identified, most critical failures (2, 3, 6, 10, 11, 13, 17), then the average value will be 20% when assessing the implications for safety and stability of the transport process, and 28% are related to the material costs.

5. Diagnosing and predicting of failures

In section 1 of this work, two basic approaches to diagnosing the elements of the point machine are shown. The analysis of works in this direction shows that the budget variant of diagnostics is an analysis of the current curve by different methods, but according to the author, however, it is necessary to recognize the measurement of the force transmitted from the point machine to the tongues of the point as more informative one.

Such conclusions are inspired by the results of work [1], the analysis of works on the topic and the mathematical modeling of the point machine's operation on the basis of the model [13]. The analysis of the results presented in sections 2-4 of this paper shows that the most critical refusals of the switch are the failure of its mechanical components. Smooth movement of the point's tongues on the flanges is the indicator of the health of the device.

Over the past 10 years, the focus of the researchers is on defining signs of deviation from normal, for a particular point, the values of time and amplitude parameters of the current or power curves. The combination and analysis of such works inspired the simulation of different modes of switching tongues, which enabled to simulate the current curves of the point machine's drive, which is most common in the rail 1520 area.

The resulting curves closely reflect such damage as a switch surface contamination, jamming of the throw bar, friction vibrations of the mechanical components, which often cause the stockrail to break, etc. (see Fig. 6).

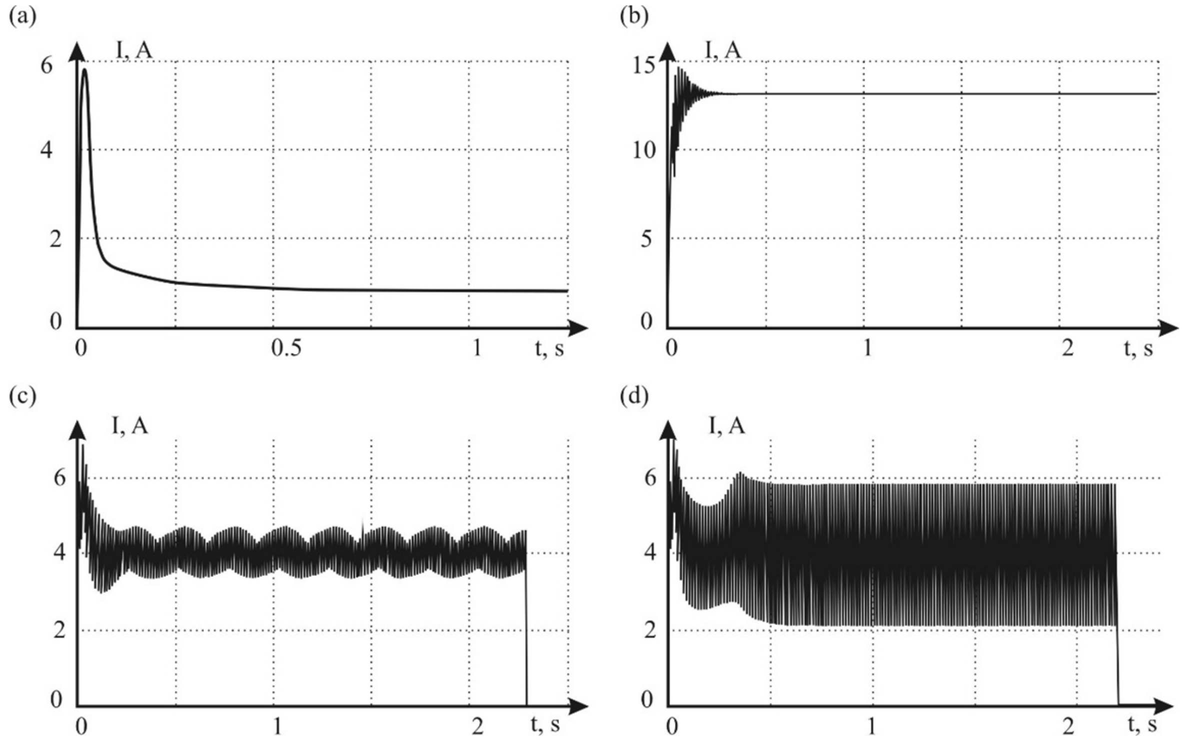

Fig. 6. Diagram of motor current: (a) in normal case; (b) in case frictional fluctuations of the same nature for both point's tongues; (c) in case of not the same nature; (d) in case seizure of the throw bar.

The model [13] describes a three-mass electromechanical system, which allows one to consider the motion of the point tongues separately and take into account their mutual influence.

Fig. 6a shows the nature of the current change with the normal movement of the point. Fig. 6b corresponds to the presence of frictional fluctuations of the same nature for both point's tongues. If the motion resistance for tongues is not the same, the fluctuations are significantly increasing (see Fig. 6c). The interpretation of the curves of Fig. 6b and Fig.6c may be rather wide, such a curve is characteristic of the contaminated surface of the switching, or poorly greased flanges, improper adjustment of elements, etc. The curve of Fig. 6d is interpreted more precisely, which corresponds to the seizure of the throw bar. After a jump of current for the first 200 ms, the system switches to a new operating mode on a friction device.

In all these cases, the analysis of the current curve goes beyond the limits of only time or amplitude analysis, but sufficiently reflects the development of the most critical switch failures, noted in section 3 of this work.

The combination of mathematical modeling and accumulated statistics of current curves of real point motors can significantly improve the probability of damage development prediction. The results of the simulation show that it would be more reasonable to implement the prevention of the most critical failures of point machines of the type SP with the DC motor, by budget methods of diagnostics, namely, the analysis of the point machine current curve. It is possible to make assumptions about the need to prevent not all but the most critical failures of point machine, which will make it possible to optimize efforts and work financing in this direction.

6. Conclusion

Given the national peculiarities of registering railway infrastructure failures, the FMEA has been used to identify the most critical point failures. The study was conducted on the review of the switch operation in the trunk transport for the entire territory of Ukrzaliznytsia Taking into account the need to unify the research results, a group of experts conducted an analysis of critical failures to review the three main strategies: ensuring maximum security; maximum throughput and minimal impact on trains; minimizing the costs of eliminating the consequences of failures.

As a result, among the most critical switch failures was noted the rail expansion, including due to the failure of the stock rails, and the correct work of detector rods. In addition, the distortion of the tongue, the reliability of the transmission mechanism of the transferring the transfer effort to the tongues (throw bar and detector rods), as well as reliable operation of the engine, is noted.

The most progressive approaches to the diagnosis of the switch operation suggest the use of additional sensors (in particular, the force sensor), or the methods of analysis of the current transfer curve. The mathematical modeling of the most critical point machine failures has made it possible to substantiate the expediency of using the methods of current curve analysis as more rational for SP type drives. On the basis of mathematical modeling, specific signs of damage are obtained, which can be used in methods involving the learning of a diagnostic model.

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