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MODEL OF IDENTIFICATION OF RAILWAY EQUIPMENT'S LIMIT TOLERANCE STATE

The paper offers an approach to definition of a limit tolerance state of railway equipment based on the criterion that exploitation of an object on the basis of risk evaluation is unacceptable. Criteria of limit tolerance states shall be specified in specifications for railway equipment.

Keywords: *limit tolerance state, limit tolerance state criteria, railway equipment, technical state, failure, wear, tear.*

1. General information

The criteria of limit tolerance state are used to understand when the operation of an object shall be terminated temporarily or permanently. When reaching limit tolerance state, an object can:

– be transferred into repair for recovering resource;

– be removed from operation (decommissioned or transferred for application for other purposes than intended) and replaced with a new one;

– undergo reconstruction or modernization.

The scheme of decision making as regards an object based on limit tolerance criteria and their use during a life cycle are presented in fig. 1, where we define as LTS – limit tolerance state, TC – technical conditions, and specs – specifications.

The criteria of limit tolerance state as well as failure criteria are specified at the stage of designing for each kind of an object (its separate nodes, items). Here an object means products (railway fleet, power converters, railway telecommunication equipment etc.), constructions (bridges, tunnels), territorially distributed systems (catenary sections, signalling and interlocking equipment on open lines and at stations etc.).

According to GOST [1], for unrecoverable objects there are two kinds of limit tolerance state:

1) limit tolerance state corresponds to disabled state (i.e. the criterion of limit tolerance state corresponds to a failure criterion);

2) the second kind of limit tolerance state is conditioned by the fact that starting from some moment further operation of a still serviceable object starts to be unacceptable in terms of safety or unreasonable

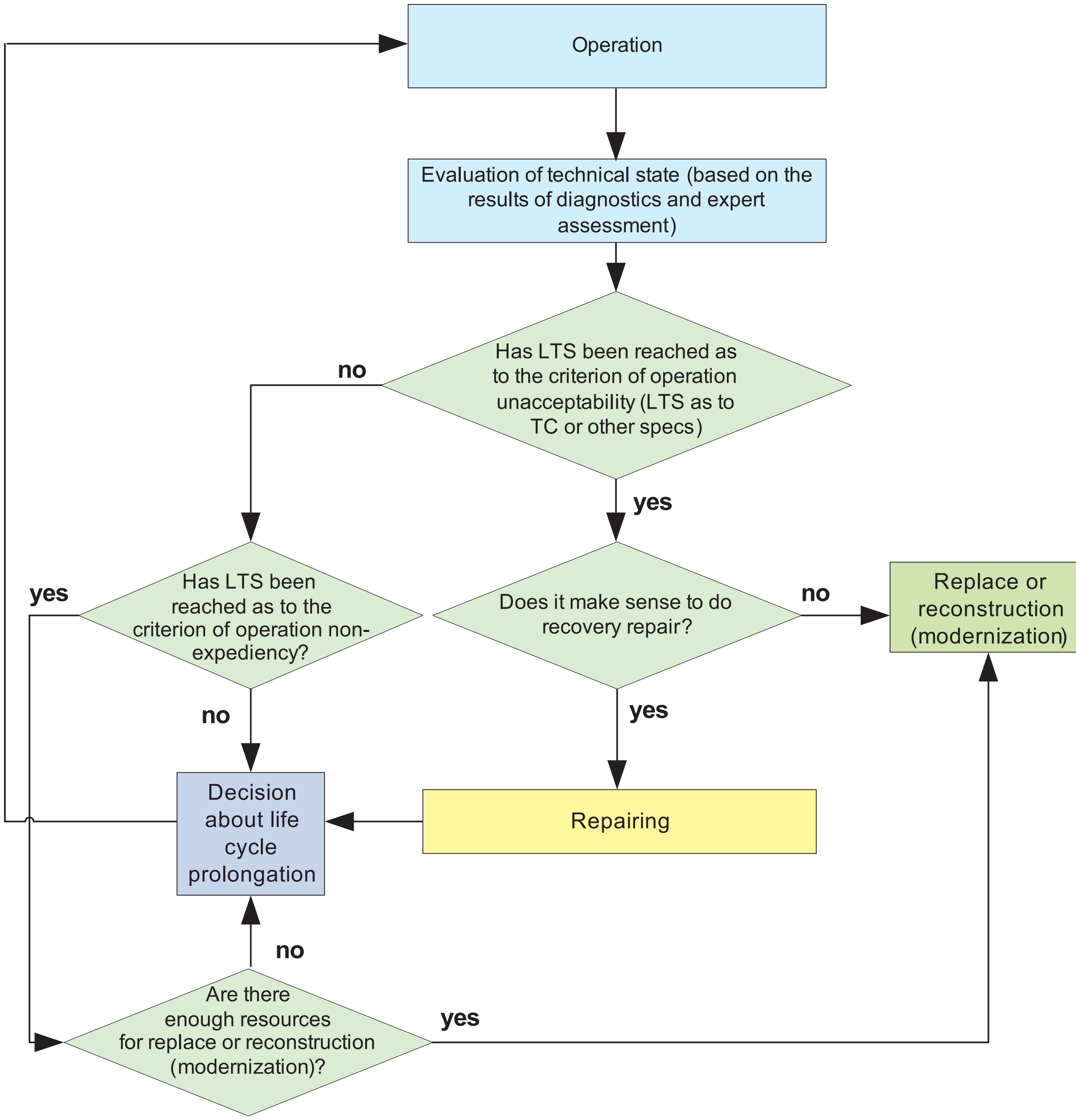

Fig. 1. Scheme of decision making as regards an object based on limit tolerance criteria

in terms of economical considerations (for example, due to obsolescence). The transfer of an unrecoverable object into limit tolerance state of the second kind takes place before the object losing its serviceable state.

For recoverable objects, there are two or more types of limit tolerance states, for example, in addition to those specified above, limit tolerance state requiring the transfer of an object into repair.

With the definition of the term "limit tolerance state" taken into account, the criteria of limit tolerance state should demonstrate that:

– the operation of an object based on risk evaluation is unacceptable;
– the operation of an object based on risk evaluation is unreasonable.

The operation is unacceptable in case that a required level of safety is not provided, i.e. the risk of an object' operation exceeds an accepted level.

Non-expediency of operation is defined by reduction of railway equipment operation efficiency, which is related to increase of life cycle cost or obsolescence of an object.

2. Limit tolerance state as to the criterion of further operation being unacceptable

As we know, the risk is a combination of an event's probability (frequency) and its consequences. In the context of definition of limit tolerance state, an event has to be meant a failure (hazardous failure) of an object or emergence of malfunctions (defects), with whose presence the operation is not acceptable. During life cycle, operation risk tends to gradually increase due to deterioration of technical state of an object as the time goes. Technical maintenance and repairing allow reducing the frequency of failures (malfunctions) and correspondingly reducing the risk. Then the technical state again deteriorates and the risk increases. Therefore, the curve of risk values during maintenance can be qualitatively represented as a saw-toothed curve (fig. 2).

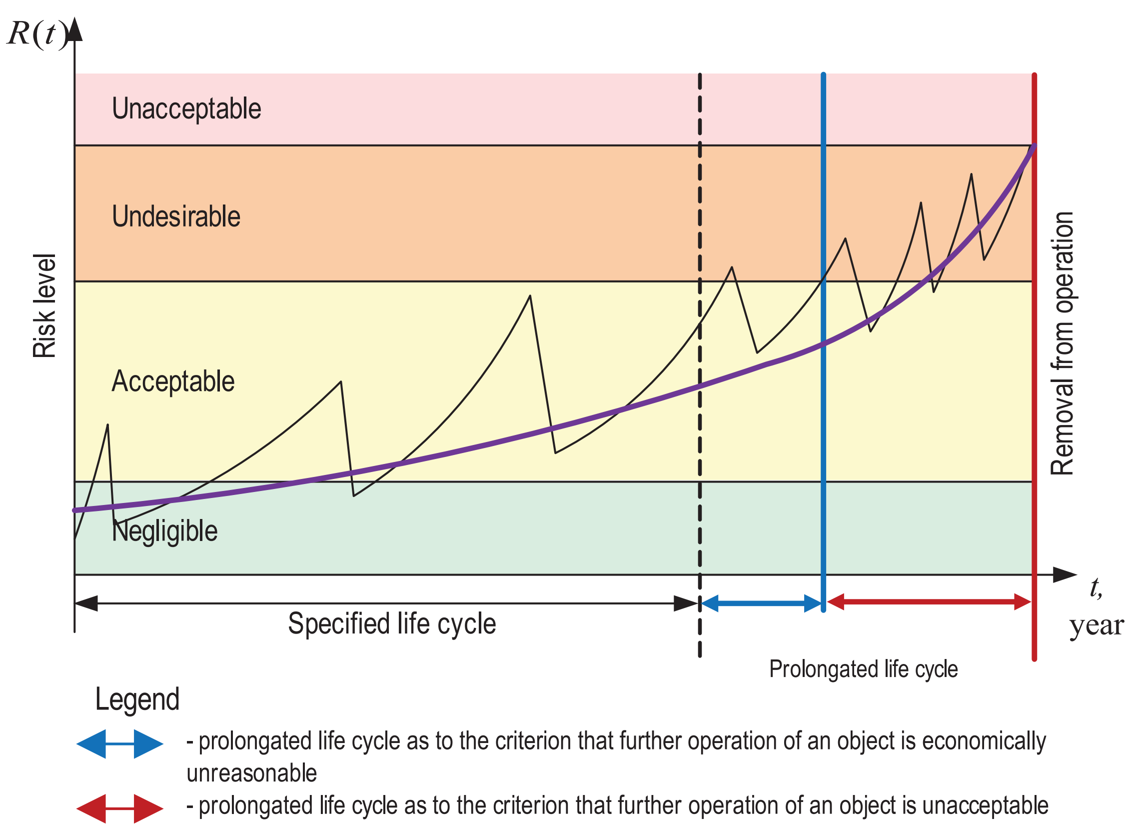

Fig. 2. Risk level changing related to the functioning of an object during its life cycle

Fig. 3 and 4 exemplify the variants of changing of failure rates during life cycle for various types of failures and corresponding densities of distribution of consequence probabilities. The scale of risk levels in fig. 2 and the scale of failure rates in fig. 3 are chosen in accordance with GOST R [2].

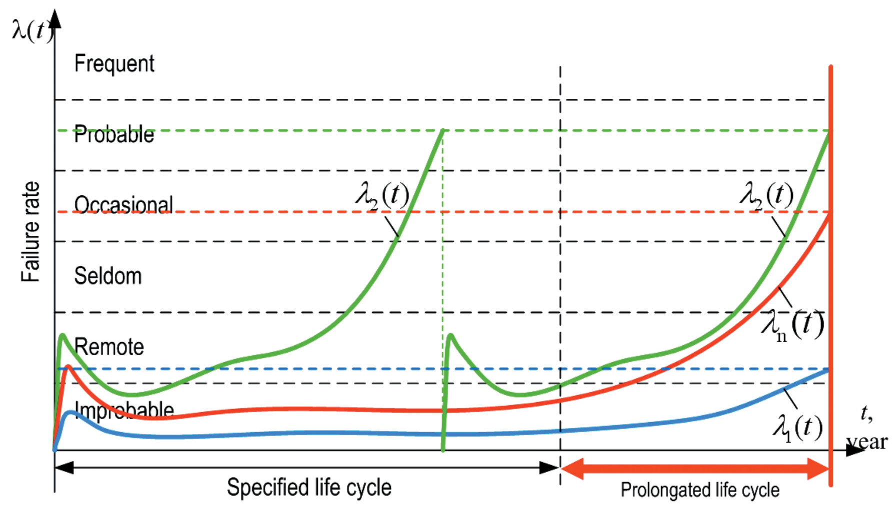

Fig. 3. Relation between failure rates and life cycles for different kinds of object failures

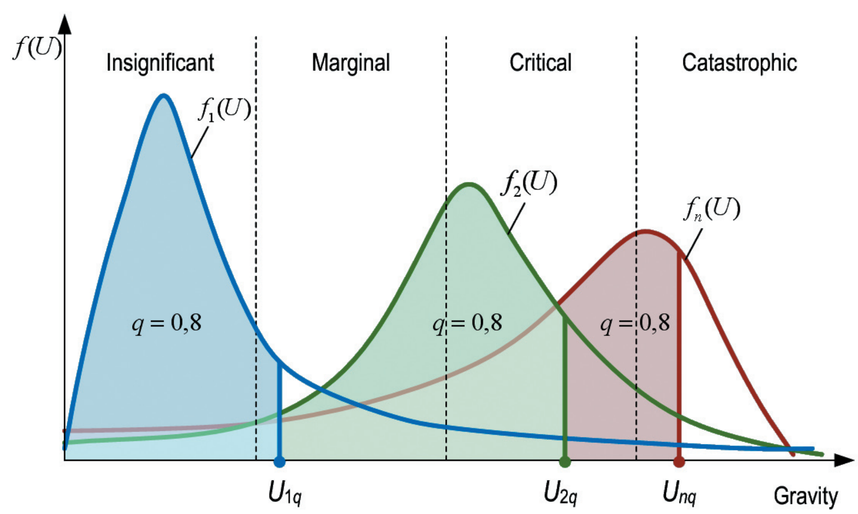

Fig. 4. Densities of distribution of consequence gravity for different kinds of object failures

Note: U_{1q}, U_{2q}, U_{3q} are fractiles of densities of distribution of failure consequences gravity for various types of objects (they correspond to consequences gravity values for the *i*-th type of object failures when a corresponding function of distribution of consequences gravity probability takes on a predefined value, for example, 0,8).

Correspondingly, the total risk during life cycle is defined by the expression

$$R(t) = U_{1q}\lambda_1(t) + U_{2q}\lambda_2(t) + \ldots + U_{nq}\lambda_n(t) = \sum_{i=1}^{n} U_{iq}\lambda_i(t), \tag{1}$$

where U_{iq} is fractiles of distribution of failure consequences gravity for various kinds of objects;
$\lambda_i(t)$ is an object failure rate of the *i*-th type;
n is the number of failure types.

As limit tolerance state actually reflects some level of technical state of an object when it is necessary to cease its maintenance, we should consider in detail a probabilistic constituent of risk which presents a failure rate (hazardous failures) or a frequency of emergence of malfunctions (defects), with whose presence the operation is not acceptable.

Therefore, one of the criteria of limit tolerance state is a predefined acceptable value of an object failure rate.

In order to define it, it is necessary to know why and how particular failures occur, i.e. to find out the causes and mechanisms of failure emerging.

Also the criteria of limit tolerance state presents a set of parameters (characteristics) of railway equipment and their limit tolerance values, as well as in some cases quality attributes that reflect technical state of railway equipment.

If a limit value of a technical state parameter is specified in normative documents, the limit value doesn't require extra regulation.

If a limit value of a technical state parameter is specified in normative documents, the limit value should be specified by a developer in relation to:

- operation conditions, including the type and mode of operational stressing;
- patterns of damage mechanisms;
- operational practice etc.,

and give this value in technical (design) documents for a particular object.

3. Major factors taken into account for definition of limit tolerance state criteria

The criteria of an object's limit tolerance state depend on the set of factors influencing the object or its individual elements in process of their operation.

This set of factors can be divided into the following groups:

1) power stressing;
2) thermomechanical stressing;
3) influence conditioned by friction;
4) corrosive and erosive influence;
5) electromagnetic influence.

Power stressing presents influencing an element of construction by an outside concentrated and distributed force provoking inside the material a corresponding counteraction in the form of inner sectionally distributed forces. An outer representation of power stressing is deformation.

Thermodynamic stressing is conditioned by heat elongation of a construction element in case of limiting its deformation.

The influence conditioned by friction occurs in case of relative movement of construction elements. The outer representation is a change in size and (or) form of conjugated parts in the process of wearing and tearing.

Corrosive and erosive influence presents a gradual change in sixes of a construction element or properties of the material as a result of physical and chemical interactions of a construction element with the aggressive outside environment.

Electromagnetic influence is conditioned by passing of electric current or presence of outside electromagnetic emissions.

More often than not factors belonging to several groups influence an object.

Power and thermomechanical stressing characterize a criterion of constructive robustness. The numeric value of this criterion is described by an optimal distribution of stressed and deformed state of a construction, i.e. by such level of stress in all sections and part points that would exclude the possibility of forming and growing of defects (for example, fractures). Numeric values of this criterion are defined by calculations and can be controlled by means of methods of non-destructive testing.

Also the criterion of a limit tolerance state in this case can be defined in the form of maximum acceptable values of deformations, for example, a maximum acceptable size of fracture.

The bases of robustness calculations as well as their specific features considering the constructions of railway equipment studied here are presented in the following standards [3, 4, 5, 6, 7, 8, 9, 10].

The criterion of a limit tolerance state as to influence conditioned by friction is usually defined in the form of a limit value of wear and tear of a part according to GOST [11].

The limit tolerance state of construction elements suffered during operation from corrosive and erosive damages is a decrease in size of a construction element down to a limit (calculated) value, when its carrying capability is not provided in case of reaching lower values, or limit sizes of defects. One should take into account the fact that the depth of individual local defects (not including fractures) can considerably be higher than the average depth of defects (up to cut-through destruction) without compromising the carrying capability of an element. The accepted number (share) of defects on the surface and their sized should be regulated depending on the nature of load on elements and the properties of used materials.

As regards electromagnetic influence, limit tolerance state is related to a change of properties of materials and characterized by a change of electrical parameters of equipment operation lower (higher) than the maximum acceptable ones.

Table 1 exemplifies key factors that influence on emergence of limit tolerance state of major infrastructure objects and elements using three infrastructure enterprises as examples.

Table 1. Influence of stressing factors on emergence of limit tolerance state of some railway infrastructure objects and elements

List of objects	List of elements	Power stressing	Thermodynamic stressing	Friction (wear and tear)	Corrosive and erosive influence	Electromagnetic influence
Power supply and electrification						
Catenary	1. Metallic pillars	+			+	+
	2. Catenary					+
	3. Overhead wire			+	+	+
Power substation	1. Power transformer	+				+
	2. High-voltage lead wires					+
	3. Alternate current switches					+
Tracks and constructions						
Superstructure	1. Rails for jointed and jointless track для	+	+	+	+	
	2. Concrete sleepers for various types of fastening	+			+	
	3. Ballast stone	+				
Signalling and remote control						
1. Impedance bond						+
2. Electrical machines (point machines, crossing barriers, crossing signalling)						+
3. Relay, battery cabinets and modules for signalling equipment		+		+	+	+

Conclusion

The above approach to definition of limit tolerance state of railway equipment as to criteria of inadmissibility or unreasonableness of object operation based on risk evaluation will allow, on the basis of data on actual technical state of an object, with economical factors taken into account, elaborating the rules for making one of the following decisions:

– to transfer an object into repair to recover resource;

– to remove an object from maintenance (decommission or transfer for application for other purposes than intended) and replace with a new one;

– to submit for reconstruction or modernization.

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10. GOST 27674-88 Friction, wear and lubrication. Terms and definitions.
11. GOST 30479-97 Provision of products durability. Methods of definition of limit tolerance wear ensuring a required level of safety. General requirements.