Basic Simulation Models of Car Failure Flows

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Abstract. In the article, the issue of modelling of a maintenance requirement flow and car failure flow is considered. Two modelling approaches are mentioned: the use of the “blackbox” principle without taking into account the regularities of the system elements interaction, and the approach providing modelling not only the interaction of the system with its environment, but also the system structure. Reasonability of the simulation model use to solve the considered issue is proved. A classification of car failure flow models is offered. Algorithms of the basic simulation models of car failure flows are described.

1. Introduction

At cars and transport and technological machines operation, a number of tasks is solved that are related to rolling stock selection, optimization of the car park structure [1], determining the need for industrial space areas, personnel [2], spare parts, and materials [3]. These tasks solvation is complicated by the dependence of car efficiency on operational conditions that are changing during the year. The air temperature and road conditions vary especially strongly. Apart from that, car operation rate is changing according to seasons, which has several objective reasons, such as operational conditions change. At a significant seasonal variation of the operational rate and conditions, existing methods of planning, organization and management of maintenance and repair do not allow realizing the potential car quality inherent in design and manufacture.

The reason is that the theoretical developments underlying the methods used for solving the above problems do not fully take into account the operating conditions and their variable nature. In addition, as a limitation, it is assumed that the operational rate does not change over time. At the same time, resource consumption rationing at the car level is made according to operating time, while at the enterprise level, is it made according to time. This contradiction may have a significant impact on the calculation accuracy, and the greater the variation of car operation rate over time is, the stronger the impact is.

To eliminate this contradiction, indicator change patterns of car group behavior over time should be considered. Inside the transport system, a subsystem "Car - operating conditions" is selected. In the operation of this subsystem, a reaction occurs, which is directed outside. For efficient operation of the transport system, it is necessary to compensate this reaction, that is, to restore the "Car - operating conditions" subsystem. When the compensation is absent, or its level is insufficient, the system regresses and goes into a state of failure. When the recovery is excessive, costs and the cost of transport work increase. For the compensating effect to correspond to the system reaction, it is necessary to know its change pattern over time. The existing methods do not allow establishing that
pattern with a sufficient accuracy, as the planning of technical impacts and the need for material and labor resources are not usually connected with time, but with operating time.

2. Research method

There are two approaches to the study of the indicate change patterns of car group behavior over time. When the first approach is used, the "Car - operating conditions" system is presented as a "black box". Then the input and output parameters are connected with the use of regressive or harmonic models. The main drawback of this approach is impossibility to apply the results beyond the conditions for which they are obtained.

The second approach is more effective. The system is structured, and the interaction regularities of its elements, as well as of elements with other subsystems and input parameters, are considered. The concept of the formation of the implemented car quality in operation is used in this case as a methodological approach.

When structuring the "Car - operating conditions" system, the most significant processes occurring within it are determined. The results of the processes are presented as quality integral indicators, and the process intensity is presented as differential indicators. The analysis carried out allowed forming a conceptual model describing the reaction change pattern in the "Car - operating conditions" system over time.

On the basis of the conceptual model, algorithms of simulation models of this type regularities are developed.

3. Results

3.1. A requirement flow model with a continuous process of a quality index change

Now a requirement flow model with a continuous process of quality index change will be considered (fig. 1). To illustrate the model operation, we its functioning is presented in the mode of a conditionally discrete time flow, that is, the results of internal processes are consider in intervals ΔТ.

Depending on time, car operational rate is calculated and operational time increment is defined ΔL during ΔТ. The ΔL values are summed in order to determine the integral operating time (like in the first basic model). The indicators of the main factors of operating conditions are calculated on the basis of the relevant mathematical models, and on their basis, as well as on the basis of the achieved operating time, the values of differential quality indicators are calculated. The integral indicator increment is determined, and summing is carried out. The obtained Yi value is compared to the limit Ylim value.

It should be noted that inequality Yi < Ylim is only used when a quality indicator increases during operation, in the other case, Yi > Ylim inequality is used.

If Yi is less than Ylim, the condition of reaching the ending time of the simulation T2 is checked. If T1 < T2, the cycle counter is increased by one, the next time increment is set, and the calculations are continued for the next cycle. If Yi reaches Ylim, the counter of realization number of the limit state is increased by one and T1 < T2 condition is checked; if it is true, a new cycle starts, in the other case, the calculations are finished. The average number of the limit state realization is calculated in each time interval.

3.2. A requirement flow model with a discrete process of a quality index change

A requirement flow model with a discrete process of a quality index change is developed in two realizations. The first realization is based on the principle of a random failure distribution among objects (fig. 2).

Generating the initial state provides for the determination of current values of object operating time. For that purpose, the generator of evenly distributed numbers is used. Then the first cycle of time increment starts. Indicator values of the main operational conditions factors are set with a table or are calculated with the use of mathematical models. Car operational rate, operating time increment, and
integral operating time are calculated the same way as in the models described earlier for each object at every time moment. The objects are grouped in operating time intervals. In each interval, requirement flow rate and requirement number are calculated. Then requirements are randomly distributed among the objects in each operating time interval.

![Figure 1](image1.png)

**Figure 1.** A high-level algorithm of the basic model of a requirement flow with a continuous process of quality index change.

In the next cycle, the objects are checked for failure. If an element has failed, the failure number counter is increased by one, that object’s operating time is equaled to zero, and the next object is checked. In the other case, the next object is checked. After the cycle finishes, the condition of the simulation ending is checked. Depending on the result, either the next cycle starts, or the procedures of the modelling ending block are carried out. The next basic model is a requirement flow model with a discrete process of a quality index change (the principle of failure measure accumulation) (fig. 3).

![Figure 2](image2.png)

**Figure 2.** A high-level algorithm of a basic model of a requirement flow with a discrete process of a quality index change (principle of a random failure distribution among objects).

The initial system state is generated. The following procedures are carried out:

- for each object, a current value of operating time is determined;
- for each object, a current value of failure measure is set.

A time increment is set, and the following events are initiated:

- operating time increment is calculated for each object in the time interval $\Delta T$;
- failure flow parameter is calculated for each object in the time interval $\Delta T$;
- the current failure measure is determined for each object;
- the obtained values of failure measure are compared to the limit values;
- if failure measure is equal to or exceeds the limit state, the failure number counter is increased by one, and a replacement process is imitated; replacement imitation is realized by equaling failure measure to its initial value;
- if failure measure is less than the limit value, or an object replacement imitation is carried out, the ending condition of the cycle of all objects checking is checked. If the condition is not met, then the
cycle repeats until the ending condition is met; in the other case, the condition of modelling ending is checked;

if the condition is not met, time is incremented by one step, and the calculations repeat; in the other case, the procedures of the modelling ending block are carried out.

**Figure 3.** A high level algorithm of a basic model of requirement flow with a discrete process of a quality index change (the principle of failure measure accumulation).

**4. Inference**

A space-time concept of car quality formation is offered, which, in contrast to similar concepts developed earlier, takes into account the seasonal variation of operating rate and conditions.

One of the key provisions of the proposed concept is to take into account (when assessing the change of car quality) the variation of car operational rate over time. For its implementation, the regularities of operational rate seasonal changes were determined.

On the basis of this provision, new regularity classes are allocated. The regularities of quality indicator changes over time are separated from the regularities of quality changes according to operating time. The regularities of failure flow changes over time are separated from the regularities of failure flow changes according to time.

Hypotheses about the model type of car group behavior are developed. Simulation models are proved to be most effective. A classification of car failure flow models is developed. The algorithms of the basic simulation models of car failure flows are described.

The developed models allow solving the tasks of rolling stock selection, optimization of the car park structure, determining the need for industrial space areas, service and repair stations, personnel, spare parts, and materials when using cars in changeable operational conditions.

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