Agent-based modeling of service maintenance and repair of rolling stock

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Abstract. Currently, a great number of modern passenger rolling stock is being put into operation. The organization of service maintenance and repair of passenger rolling stock is one of the key objectives for a rail carrier. At present, maintenance and repair costs constitute about 75% of the total expenses of carrier companies. This paper examines a simulation modeling system designed to integrate the scheduling tasks of service maintenance and repair of passenger rolling stock, and the main stages of building a discrete-event model of a passenger rolling stock maintenance system using the AnyLogic environment. The simulation model will allow recreating the system and obtaining the performance indicators for the service maintenance strategy. The modeling results will enable carrier companies to evaluate the service maintenance and repair strategy, which affects making managerial decisions.

1. Introduction

The organization of service maintenance and repair of passenger rolling stock is one of the most complex steps in the scheduling process, which also accounts for a major share of the financial expenses of carrier companies. The organization of service maintenance and repair becomes a strategic decision that envelops several decades of passenger rolling stock operation and presents a tremendous capital investment for service operators.

The keeping of passenger rolling stock in good working order is divided into two categories: service maintenance and repair of rolling stock. The strategy for service maintenance and repair affects three factors (safety of operation, passenger comfort, and the cost of the work performed) throughout the entire life cycle.

In order to select a suitable strategy for service maintenance and repair of passenger rolling stock, both non-metric (safety of operation, quality of passenger services) and metric factors (cost of maintenance and repair, cost of spare parts, failure rate) should be taken into account. The optimal strategy for service maintenance and repair will determine the balance between the cost and quality of the work performed.

At present, scientific support of the service maintenance system fails to provide an accurate operational readiness assessment of passenger rolling stock. We are unable to predict the possible development of events with the set financing limits, changes in passenger traffic, logistic support, and failure rate [1, 2]. The described methods are not integrated into a single complex model of the service maintenance system.

The time and financial parameters that have not been fully accounted for, and changes in the service maintenance and repair rate result in predictive estimates that are incomplete. For the purposes
of optimization, we suggest performing system modeling, which includes simulation of service maintenance and repair of passenger rolling stock. The generated resulting simulation model is a system that allows repeated implementation of various production scenarios, thus facilitating the evaluation and forecasting of the state of the service maintenance system [3].

In reference [4], the maintenance scheduling model is based on the probability of equipment failure at a certain point in time. The model is built on: capacity planning, purchasing spare parts, determining the service maintenance and repair interval. The studies conducted by Pierskalla and Voelker [5], Osaki and Nakagawa [6], Sherif and Smith [7], Valdez-Flores and Feldman [8], Cho and Parlar [9] focus on determining the optimal resources for maintenance and finding the minimum economic life cycle. They distinguish traditional methods of problem solving through linear and dynamic programming, stochastic models, and analysis of the current values.

The Russian scientists pay great attention to the use of mathematical methods for solving tasks related to organization and management of rolling stock maintenance and repair. Wide application of statistical methods with the use of the mathematical apparatus of the queuing theory and the theory of random processes for placement of car-repair plants within the railway network is described in the studies of V. V. Tsyganov, N. F. Sirina, M. M. Bolotin [10–12].

This paper provides a general approach to modeling a strategy for service maintenance and repair of passenger rolling stock. System modeling will allow us to determine the rationality of the strategy in terms of overall average cost of work performed per unit of time. It will also ensure the accuracy of predictive estimates of passenger rolling stock operation and repair, which to a large extent determine the effectiveness of passenger rolling stock life cycle management as a whole.

2. Modeling methods
The object of the simulation model under development is the model of service maintenance and repair of passenger rolling stock. Simulation modeling varies under uncertainty, performing a multitude of computer simulations and analyzing the model output data. Modeling allows us to estimate the potential impact of various input parameters on the modeling result, using the strategy of searching for the best model variant and analytical search methods.

Simulation modeling of technical processes is based on the mathematical apparatus of the process being described. The model is built using the system dynamics apparatus of simulation modeling. This apparatus includes both discrete-event and agent-based modeling in the AnyLogic environment. System dynamics is a simulation modeling approach, whose methods and tools allow us to understand the structure and dynamics of the designed model. System dynamics is characterized by a high level of abstraction and can be used for the strategic system modeling [4].

Discrete-event modeling is based on the concept of incoming requisitions, which are defined as the rolling stock going into maintenance or repair. Discrete-event modeling presents the modeled system as a process, i.e. a sequence of operations performed with modeling agents. The model is represented graphically as a process diagram, whose blocks stand for individual operations.

Agent-based modeling allows us to describe the discrete system of a process in the form of several subsystems specified by agents. Each agent of the designed model interacts with other agents, thus forming the outside environment of the simulation model. The structure of the agent-based model can be described not only graphically, but also using a preset scenario.

A modeling agent is characterized by autonomous behavior and makes decisions in accordance with a specified set of rules and restrictions. The agent's behavior in a simulation model is linked to other interacting agents. The behavior algorithm of the model's agents is described by a state graph [3] of the modeled service maintenance and repair system. Thus, the formalization of a discrete system by modeling agents is shown in Figure 1.

The system state graph is a directed graph \( G = (S, P) \), where: vertexes \( S \) are agent states, arcs \( P \) are the probabilities of events that change an agent from one state to another.
In the designed model, an agent is regarded as a system modeling module that controls the process (Figure 2). The agent performs an analysis of the model in time and gets feedback from the results of modeling. Then, the agent controls the initial data input to set the modeling task when designing an experiment. The agent structure interacts with the modeling process using the “agent's behavior-restrictions-experiment” iteration to specify the respective uncertainties and assumptions adopted in the system modeling process.

In order to change an uncertainty space, the agent selects a number of experiments generated from the initial model of the agent's behavior and groups similar model behaviors to show the results of the design model's behavior as a whole.

Agent-based modeling is an alternative view on the behavior of the modeled system. The agent's behavior can be preset by various actions upon occurrence of certain events.

In essence, a simulation model is a model that builds a trajectory of system state changes. We can say that any simulation model is a set of rules, according to which a system passes from one state to another. The rules are specified by means of differential equations and state diagrams. The model's output data allows us to analyze the system's behavior within the preset parameters to make managerial decisions.
The purpose of this approach is to model an experimental environment being an actual organization of service maintenance and repair. To achieve the purpose in hand, the simulation model responds to various input data in accordance with a real-life situation. An agent-based simulation model represents dynamic characteristics of a discrete-event model.

A simulation model is an object-oriented model developed using the hybrid approach (discrete-event modeling) in AnyLogic. The model is capable of describing passenger rolling stock characteristics.

Model development involves formulation and conceptualization of the system under consideration. The results-oriented modeling approach presents a transition from one iteration to another, allowing us to perform analysis. The analysis of the output data of iterations presents an evaluation of an integrated model by quantifying the model details and parameters.

3. Conclusion
Discrete-event agent-based modeling is an excellent method for modeling various production processes related to service maintenance and repair of passenger rolling stock. When using all the features of AnyLogic, the modeled situation is displayed in full, reflecting the model's behavior and its characteristics. This model is designed to determine the optimal deployment sites for the service facilities and, by doing so, ensures a high availability rate of rolling stock with minimum time and financial resources spent on maintenance and repair.

The service facilities will provide both maintenance and repair of passenger rolling stock. The developed model will be used as a foundation when building a simulation model for estimating the production capacity of facilities providing passenger car maintenance and repair services. The model will allow us to forecast equal distribution of rolling stock among enterprises. For further development of the model, elaboration of the optimization model is suggested, which will include statistical data on rolling stock failures. This will allow us to study the probability of downtime of rolling stock waiting for repair, and the impact on the availability rate and financial expenditures.

The simulation model will allow estimating their operational efficiency from a financial standpoint. Within a short time, we will be able to assess the introduced changes, their impact on the maintenance

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**Figure 2.** Structure of modeling agent.
and repair system, and to determine the optimal financial expenditures for both repair and maintenance of passenger rolling stock.

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