A simulation model of the process of organizing the movement and maintenance of trains at a Railway Station

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Abstract. The article presents the results of research of a simulation model of the process of organizing the movement and maintenance of trains at the Railway Station. The model is built as part of a discrete-event approach using the theory of queuing systems and is implemented using the GPSS Studio simulation tool. The simulation model makes it possible to evaluate the efficiency of a Railway Station (workload of personnel, time and delays in servicing trains and performing operations at different stages) to make optimal decisions on organizing the movement of trains and shunting operations taking into account the current situation. Experimental studies of the model were performed on different input data, an analysis of the adequacy of the model was carried out by comparing the experimental results of the workload of the station personnel and the time of operations with the real data of a Railway Station in one of the cities of Russia.

1. Introduction

Currently, issues of improving Railway Stations and bringing their work in line with modern requirements of a market economy are becoming particularly relevant. An effective means of analyzing and evaluating the performance indicators of stations under various conditions, their technical, technological and economic parameters is a simulation of station processes, which, combined with modern computer technology, becomes a powerful tool for researching stations and optimizing their operation [1].

To date, a great deal of experience has been gained in the field of developing simulation models of different classes that describe the functioning of transport systems [2]. For studying the operation of Railway Stations, different approaches to simulation are used, namely, discrete event, agent, system-dynamic or their combinations [3]. Given the specifics of the functioning of Railway Stations, the most convenient approach to formalizing the description of station processes is discrete event modelling, in which the object under study is presented in the form of a queuing system. Also, this approach has been well studied, and the effectiveness of its application has been proved by solving a large number of real practical problems related to the modelling of railway systems [4, 5, 6].

The discrete-event approach is based on the concept of requests, queues, resources, and flowcharts that determine the sequence of passing a request through model blocks that simulate processing devices, delay elements, service channels, and communication between them.

For implement simulation models, various specialized software environments and modelling languages have been developed [2], one of the primary languages is GPSS. The language is well
debugged, provides adequate modelling results and has many examples of practical use in various subject areas. To automate the construction of GPSS-models and conduct experiments with them, the company «Elina-Computer» created the Russified graphical environment GPSS-Studio, the latest version of which was released in December 2019. Using GPSS-Studio, you can efficiently and quickly build discrete-event models, develop structural diagrams of simulated processes, model interface, save the model as an exe file. The system also includes a module for conducting multivariate experiments, means for visualizing the model, and the possibility of textual and graphical presentation of simulation results.

The purpose of this work is to develop and study a discrete-event model of the process of organizing the movement and maintenance of trains at a Railway Station for a comprehensive assessment of the effectiveness of its work and making optimal decisions on the organization of train movement and shunting operations under given initial conditions. The model is built and researched using real data from the operation of a Railway Station in one of the cities of Russia. The GPSS-Studio environment was chosen as a valid modelling system. The choice of GPSS-Studio is due to the reliability, and comprehensive functionality of it for the development, experimental research, analysis of simulation models and the full presentation of simulation results in text and graphical forms.

2. Description of organizing the movement and maintenance of trains at a Railway Station

When organizing the movement and maintenance of trains at the station, it is necessary to ensure traffic safety, the implementation of the traffic schedule and shunting operations under the requirements established by the rules for the technical operation of railways, regulatory instructions and the technological process of the station. All these requirements were taken into account during the development of the model.

The simulation model implements the process of organizing the movement and maintenance of trains by station employees. We give a description of this process and the functions performed by the station personnel.

The station organized the work of personnel in two shifts. In each shift, there is an assistant station master, flagman, yardmaster, locomotive engineman, freight train inspector, train dispatcher, inspector-repairman of cars. The duration of the first and second shifts is 12 hours, respectively: from 04.00-16.00 and 16.00-04.00.

Applications for the arrival (departure) of 4 types of rolling stock are received at the Railway Station: Freightliner, hopper-batcher, passenger-24.5m train, passenger-25.5m train. Passenger trains arrive at the station following the standard train schedule. The arrival of freight trains and hopper-batcher trains is not subject to a strict schedule and is described by a probabilistic distribution law.

The assistant station master carries out operations to prepare the routes for receiving trains (from the control panel of the devices) and transmits an order for the reception of rolling stock. The incoming rolling stock takes up a clear track at the station (12 tracks in total). Next, the assistant station master processes applications and transmits an order on the attachment of rolling stock on the station. The flagman then installs scotch block (SB) for the rolling stock. Installation time of SB depends on the type of rolling stock. The organization of the acceptance of freight cars and hopper-batcher cars is carried out by the freight train inspector.

The delay of rolling stock at the station is regulated depending on the type of train and shift during a given time interval. The assistant station master sends an order on setting out of cars, and the yardmaster removes the fixed SB, the time of the operation depends on the type of train. The flagman and yardmaster record and control the fastenings (bypassing all racks, checking the correctness and reliability of fastenings) during the shift.

The assistant station master carries out operations to prepare train departure routes and transmits orders for train departures. Rolling stock departs from the station. The assistant station master after arrival (or return), departure, or the passing of trains informs the assistant station master and train dispatcher about this.
Also, the duties of the assistant station master include receiving (entering) train and operational information from the automated railway system for the operational management of transportation, maintaining train documentation.

Also, the assistant station master carries out operations for preparing shunting movements, such as dialling with making up a train and opening a shunting signal, forms a shunting sheet and talks with locomotive enginemen.

The direct executors of the shunting operations are the shunting crew (locomotive engineman and yardmaster). There are typical shunting operations: breaking up the train, making up a the train, interposition of car and setting out of cars, cleaning of cars and car supply to freight and other points of station, freight shunting operations.

Also, the assistant station master presents the trains for maintenance. Next, the locomotive engineman feeds the train. A team of car inspectors and repairman carries out maintenance, trains readiness control (technical processing and testing of brakes).

The train dispatcher generates and transmits orders on the organization of train traffic, for the fulfilment of which the assistant station master is responsible.

The standard time for the implementation of various types of work is established.

3. Development of a simulation model

As the initial data for the development of the simulation model were used:
- technical characteristics of the Railway Station (number of inbound yard tracks, track’s capacity);
- characteristics of arriving trains (number of cars in a train, type of rolling stock);
- time parameters: the intensity of receipt of service requests, the processing time of requests, the duration of maintenance.

The temporal characteristics of the receipt and servicing of requests are distributed according to the probabilistic distribution law, the type and parameters of which were estimated by experts and based on experimental data. Basically, to describe the processes of receipt and servicing of requests, a uniform distribution law was used in a given interval, and a gamma law was also used in the model to specify the intensity of arrival of freight trains. Figure 1 shows a structural diagram of the model in the form of a Q-diagram. The model describes an open queuing system (requests come from the external environment and go after processing to the external environment); at any time, there can be an arbitrary number of requests in the system.

![Q-diagram](image_url)

**Figure 1.** Q-diagram of movement and servicing of trains at Railway Station.
The following notation is used in the diagram: A1 – freight rolling stock; A2 – hopper-batcher train; A3 – passenger-24.5m train; A4 – passenger-25.5m train; A5 – operations for preparing of shunting movements; A6 – operations for preparing of tracks to pass of trains; A7 – requests for maintenance of rolling stocks, for checking the readiness of trains; A8 – requests for orders of train dispatcher on the organization of trains movements and getting (putting) of information from the automated railway system for the operational management of transportation; A9 – requests for maintaining train documentation; A10 – requests for the implementation of account and control of attachment of rolling stock on the station; D1 – D15 – storages for accumulating of requests that describe queues for service channels; S1 – service channel – assistant station master (processing of the request, order on installation and removal of fixed SB); S2 – freight train inspector (processing of freight cars); S3 – locomotive engineman (implementation of shunting operations); S4 – yardmaster (remove of fixed SB, implementation of shunting operations); S5 – flagman (installation of SB); S6 – train dispatcher (transmission of orders on the organization of train movements); S7 – inspector-repairman of cars (maintenance, readiness control of trains).

In total, the model sets the receipt and processing of ten types of requests related to the work of the Railway Station; station personnel are described as seven service channels.

4. The results of an experimental study of the model
Experimental studies of the model were carried out separately for two shifts. 50 model runs were performed 10 times (one run is a shift during 720 minutes), which corresponds to 500 days of work of the Railway Station personnel. Further, the results were averaged over all tests.

The following loading factors for station personnel were obtained as a result of the simulation (first shift): assistant station master - 91.5%; freight train inspector - 18.6%; locomotive engineman - 70.2%; yardmaster - 68.6%; flagman - 54.8%; train dispatcher - 16.4%; inspector-repairman of cars - 54.7%. The average occupancy of station tracks was 56.9%. The results obtained are consistent with the actual performance of the station management. The incomplete loading of personnel can be explained by the fact that the model does not describe all the operations performed by the station employees, but only the basic ones related to the movement of trains within the same station. For example, a train dispatcher provides guidance on a site that consists of 15 stations, and the model takes into account work with only one station.

Table 1 shows the results of the simulation of the Railway Station for the first shift: the average value of the service time of rolling stock depending on the type, the number of deviations from the established standards for the time spent on servicing trains on the station’s tracks, the total number of trains. The total percentage of deviations from the norms of time was 7.6%. Deviations from the established standards were also revealed when performing maintenance work on the trains (10.1%). These deviations did not exceed 5 minutes, which is an acceptable value in the operation of the station.

| Type of rolling stock | Average time of service, Minutes. | Average time of attachment of rolling stock on station, Minutes. | Number of deviations from normalized standard | Number of processed requests |
|-----------------------|----------------------------------|---------------------------------------------------------------|-----------------------------------------------|----------------------------|
| 1 Freight             | 69.59                            | 8.8                                                           | 251                                           | 2049                       |
| 2 Hopper-batcher      | 73.2                             | 7.12                                                          | 49                                            | 651                        |
| Passenger-24.5m train | 38.88                            | 13.22                                                         | 97                                            | 500                        |
| Passenger-25.5m train | 356.96                           | 8.44                                                          | 3                                             | 2000                       |
Figure 2 shows a histogram of the distribution of the time for shunting operations, the operation time is adequately described by gamma law. The test was performed using the compliance criterion $\chi^2$ (p-value = 0.0504) at a significance level of 0.05.

Figure 2. A histogram of the distribution of the time spent on shunting operations with the imposition of the density function of the gamma law (first shift).

Figure 3 shows a histogram of the distribution of time for maintenance of trains in a depot (first shift). According to the $\chi^2$ criterion, the hypothesis of a uniform distribution of maintenance time is not rejected (p-value = 0.0772) at a significance level of 0.05.

Figure 3. A histogram of the distribution of time for maintenance of trains with the imposition of a uniform law density function (first shift).

Based on the simulation results, the coefficients of utilization of the personnel, the characteristics of the queues at each stage of service, the occupancy rates of the station tracks, the number of excesses of the standards for the types of services for each shift were determined. An analysis of the adequacy of the model was carried out by comparing the results with real performance indicators provided by the station management, and it was concluded that the model was highly accurate.
5. Conclusion
The developed model provides the calculation of the leading indicators of the effectiveness of the Railway Station, depending on the source data. By varying the input data (the intensity of arrival and maintenance of trains, the number of employed personnel, it is possible to evaluate different situations in the operation of the station and make optimal management decisions. For example, in summer, the train flow increases by 30%, this situation was simulated using the model. As a result, the workload of the station personnel increased, the throughput capacity of the station decreased, and the number of requests completed exceeding the established standards for a time increased. The way out of the situation is to reduce the execution time of many operations related to the preparation of the documentation by automating processes and implementing an information system. The first version of such a system has already been developed and is at the stage of trial operation.

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