An Agent-Based Simulation for Optimizing the Parameters of a Railway Transport System

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Abstract

The article presents results of optimization of the railway transport system's parameters. The researches were made by computer simulation. The simulation model is developed based on real supply chains of iron ore concentrate from the Poltava Mining and Processing Plant (Ukraine) to transition points within Ukraine (Pivdennyi seaport, Izmail seaport, Chop rail station). The simulation model was developed and implemented in the AnyLogic and Java SE environment and is based on discrete-event and agent-based principles. The simulation model is the interaction by agents of the railway transport business processes, loading and unloading points, and vehicles. Due to results of the optimization and sensitivity experiments was possible to determine the optimal fleet of locomotives and cars; and to establish the basic transport-technological indicators of the annual transport work.

Keywords

agent-based simulation, AnyLogic, Java SE, railway transport technologies, parameter optimization

1. Introduction

The main task of the National transport system is to fully meet the transportation needs of the economy. In addition, there is a certain conflict of interest between transport companies, cargo owners and passengers. On the one hand, customers demand the highest quality of the transportation services; on the other hand, transport companies are limited in productive resources. Therefore, the key and topical issue of transportation organization is the search for optimal technological parameters of transport systems depending on the planned volume of transportation.

Establishing the optimal parameters of railway transport systems is one of the key points in their design, construction and operation. While the criterion of optimality can be the maximum level of reliability (reliability or fault tolerance) of processes [1] or safety in terms of the method of organization [2] or maintenance of critical transport infrastructure [3]. These criteria are a systemic indicator of effectiveness. Moreover, this issue is equally relevant both for global multimodal processes [4] and for distributive city logistics [5].

The most common ways to optimize transport processes are analytical methods and models. Such methods are actively used in the planning of transport processes [6], including the use of Big Data technologies [7], the search for rational routes of distribution logistics [8].

However, the most effective tool for the study of complex and large technological systems, in terms of reliability, completeness and convenience, is simulation. This tool is quite actively used in the study of a wide range of applied transport issues, ranging from logistics of mining companies [9] and optimization of ordering [10], ending with planning issues based on Big Data [11].

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2. Materials and methods

2.1. Theoretical substantiation

In accordance to the peculiarities of the organization of railway transport production, the main technological parameters of railway transport systems have always been three components: the required fleet of locomotives, the required fleet of cars and the available capacity of railway routes. Together, these three elements directly proportionally determine the carrying capacity of the railway transport system:

$$N_{cc} = f\left(N_{loc}, N_{car}, N_{cap}\right), \quad (1)$$

where N_{loc} – regulatory fleet of locomotives;

N_{car} – regulatory fleet of cars;

N_{cap} – regulatory capacity of the railway lines.

In expression (1), the parameter (N_{cap}) should be understood not as the maximum possible, given the technical equipment of the railway transport infrastructure, the size of train traffic, but the set number of trains that will ensure the planned volume of cargo N_{cc}. Then the parameters of the need for rolling stock (N_{loc}, N_{car}) will also depend on the planned size of the train traffic (N_{cap}).

On the other hand, the implementation of the planned transportation schedule will depend on the available (sufficient) fleet of cars and locomotives. Therefore, the complex methodology for determining the required parameters of the railway transport system to ensure the required carrying capacity has certain difficulties due to the interdependence of variables and function (1). In addition, in the conditions of branched railway networks, there are certain problems in estimating the required fleet of locomotives and cars, as the required amount of transportation is a certain set within different directions.

Given the peculiarity of the technological process of railways, the main element of their technological equipment are locomotives. First, the locomotive fleet is the costliest element in the structure of operating costs. In addition, the fleet of locomotives has the greatest impact on the performance of the entire railway transport system. The delivery time (considering the expectation of a free locomotive) should be the minimum possible. Therefore, it is advisable to form the following optimization problem:

$$T_{del} = f\left(N_{loc}, N_{car}, N_{cc} = f\left(N_{cap}\right)\right) \to \min,$$
$$\begin{cases} \xi_{\text{р}} \le \varphi(N_{loc}) \le \xi_{\text{н}}, \\ \xi_{\text{р}} \le \varphi(N_{car}) \le \xi_{\text{н}}, \end{cases} \quad (2)$$

де $\varphi(N_{loc})$, $\varphi(N_{car})$ – utilization rate of locomotives and cars, respectively;

$\xi_{\text{р}}$ – the limit of the rationality of the using parameters;

$\xi_{\text{н}}$ – the limit of reliability (fault tolerance) of the using parameters.

Since the optimization model (2) is presented implicitly, its solution will be carried out by simulation.

2.2 Development of a simulation model

Given the complexity and, at the same time, the discreteness of railway transport technologies, the model will be based on discrete-event and agent-based principles. AnyLogic University Researcher ([12], License Serial Number # 03926) with a built-in compiler Java SE was chosen as the simulation development environment. The simulation is carried out through the interaction of the following agents:

1. *Main* – the main agent through which the presentation and interaction of all other agents of the model should be conduct.
2. *Production* – an agent of simulations of production processes of railway transport.
3. *DestinationPoint* (N_{cc}) – population of agents of delivery cargo points.
4. *Locomotive* (N_{loc}) – the population of agents of locomotives.
5. *Car* (N_{car}) – population of car agents.

6. *Order* (N_{cc}) – the population of agents of applications for transportation.

The model is implemented on the example of supply of iron ore concentrate from Poltava Mining and Processing Plant (Ukraine). Delivery is carried out by international traffic, all of which pass through three exit points in Ukraine: the ports of Pivdenny and Izmail and the Chop railway station. Therefore, the whole railway transport process is an interaction of the point of origin of the freight mass and the three points of their conditional repayment. The operational work of the fleet of vehicles is executed centrally within three railway directions. The Main agent by means of a real GIS-marking of railway routes (fig. 1) carries out simulation of train movement by the network.

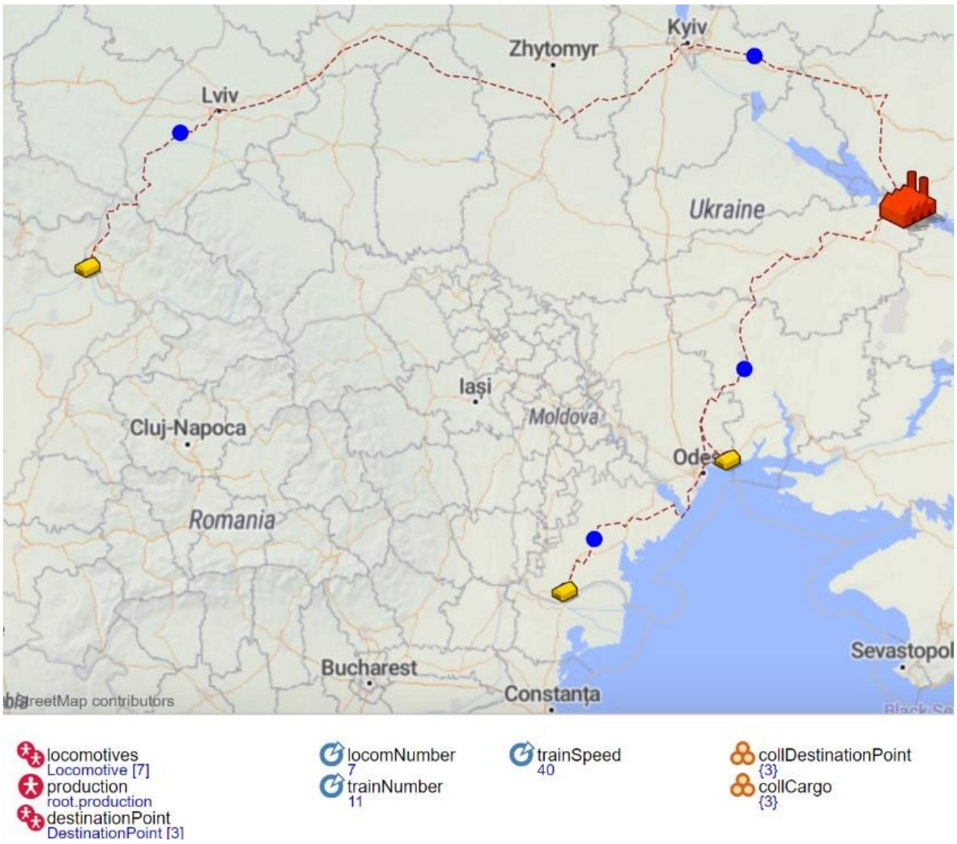

Figure 1: Presentation at Agent Main

The logic of the whole business process begins with the population of the *DestinationPoint* agents (Fig. 2), which simulates the stochastic accumulation of cargo mass to the norm of composition.

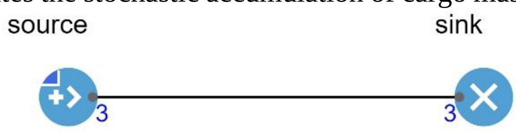

Figure 2: Business process of the agents *DestinationPoint*

The *source* block exponentially generates events of a cargo consignment of cargo (N_{cc}) to the point of accumulation - the *sink* block. At formation of necessary, for loading of one structure of weight of cargo, the Java-code is realized:

```
«Order order = new Order( this );
send ( order, main.production);»
```

simulating the sending of an information request for readiness to send the appropriate consignment.

The main business process is modeled in the *Production* agent (Fig. 3, 4).

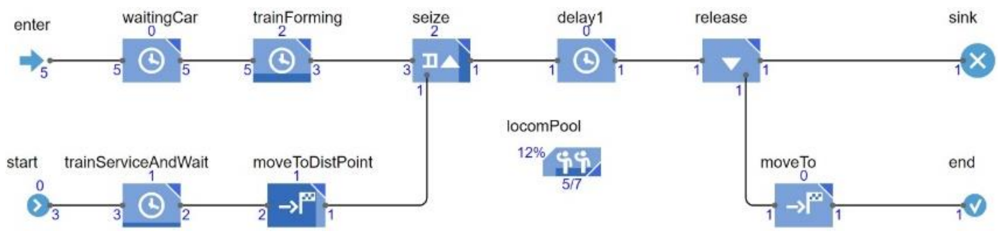

Figure 3: Business process of Production agent (train movement on the network)

The event of the information message about the readiness of the cargo consignment to be sent by one of the three routes is sent to *enter* block (Fig. 3). Then the application is sent to the *waitingCar* block, where at the entrance the condition of the required number of free cars available for loading is checked:

```
«if (waitMainDepo.size() > 0 ){
    waitingCar.stopDelay(waitingCar.get(0));
    waitMainDepo.stopDelay(waitMainDepo.get(0));
}»
```

When the condition is met, the time delay for loading the corresponding consignment into the selected cars (*trainForming* block) is simulated. After that, the loaded train is waiting for a free locomotive (*seize* block). If there is a free locomotive (block *locomPool*, with the number of locomotives equal to N_{loc}) block *seize* "captures" this resource and starts a subprocess that simulates the processing of the train on departure and following it is by network to the destination: blocks *start*, *trainServiceAndWait*, *moveToDistPoint*.

Block *delay1* simulates the processing of the train on arrival at the destination; it is unloading and processing before returning to the station of the next load. The *moveTo* block simulates the return flight of the train to the loading station, where the production resources (locomotive and cars) are sent to the sludge waiting for the next sending.

The second subprocess of the *Production* agent (Fig. 4) simulates the turnover of cars in the train. This subprocess is almost completely controlled by the first subprocess (Fig. 3).

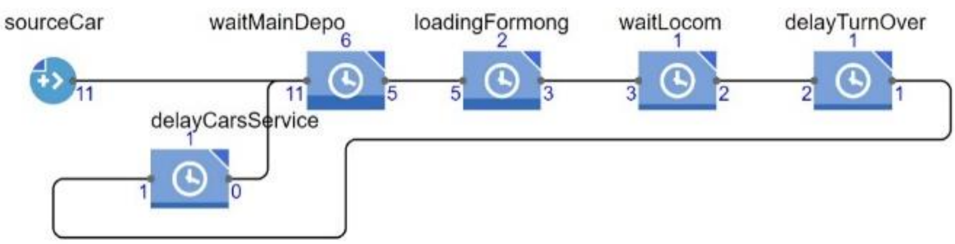

Figure 4: Business process of the *Production* agent (car turnover)

2.3 Implementation of the model and search for optimal parameters.

The model was implemented based on open data on the commercial activities of the Poltava Mining and Processing Plant (Ukraine) for 2015 – 2017. Duration of the modeling time – one calendar year. The initial data are indicated in the table. 1, the simulation results are summarized in the table. 2, 3 and fig. 5 – 8.

Table 1
Initial data on the supply of iron ore concentrate in Ukraine from the Poltava Mining and Processing Plant (Ukraine) for 2015 – 2017

Parameter	Value
Annual quantity of sent cargo, by route (in trains), N_{cc}:	
- South port	1375
- the port of Izmail	625

- Chop station	900
Number of cars in the train	56
Train weight, net tons	3920
Route speed of the train by network, km / h	40
The required number of locomotives, N_{loc}	calculated
The required number of cars, N_{car}	calculated

Table 2
Optimal calculated values

Estimated parameter	Value
Estimated number of locomotives, N_{loc}	9
Estimated number of cars, N_{car}	616
Locomotives' utilization factor, $\varphi(N_{loc})$	0.66
Cars' utilization factor, $\varphi(N_{car})$	0.64

Table 3
The model results (one model year)

Indicators of the time (hours)	
Average batch delivery time	15.6
Turnover of cars, of them:	33.3
- in a usage (movement and conducting operations)	20.2
- waiting for cargo	12.0
- waiting for locomotives	1.1
Locomotive turnover	27.3
Mileage indicators, km	
Weighted average route length	796
Dimensions of trains:	
- in average per the day	7.9
- in average per the year	2895
Car mileage:	
- in average per the day	574
- in average per the year	209493
Locomotive mileage:	
- in average per the day	701
- in average per the year	256047
Indicators of efficiency of transportation work (per year)	
Thousand tons per car	18
Mln. tons-km per car	3859
Thousand tons per locomotive	1261
Mln. tons-km per locomotive	322858
The need of rolling stock for the organization of supply	**1 mln. tons per year:**
- the needs in locomotives, N_{loc}:	0.793
- the needs in cars, N_{car}:	54.3

Thanks to optimization experiments, the dependence of the average delivery time on the calculated fleet of locomotives and cars are obtained.

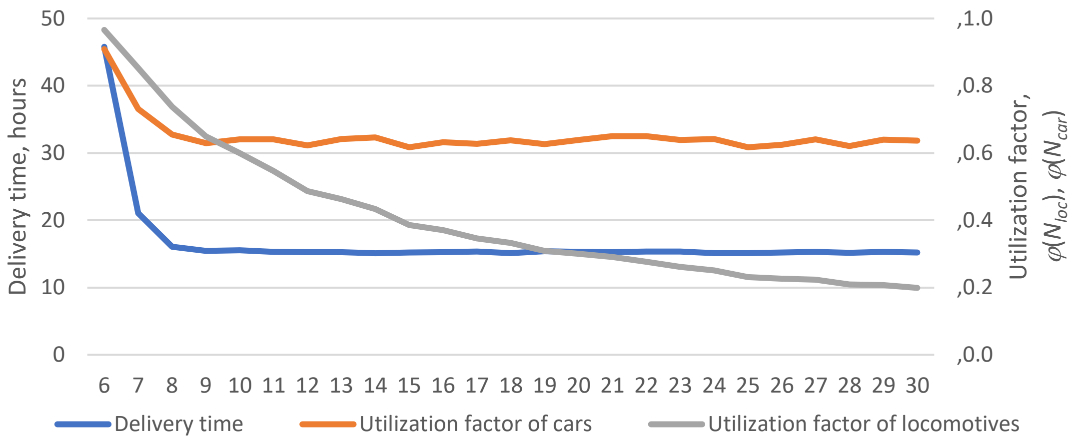

Figure 5: The dependence of delivery time and coefficients of use of cars and locomotives depending on the estimated fleet of locomotives (fleet and volume of traffic are constant, correspond to the values of tables 1 and 2).

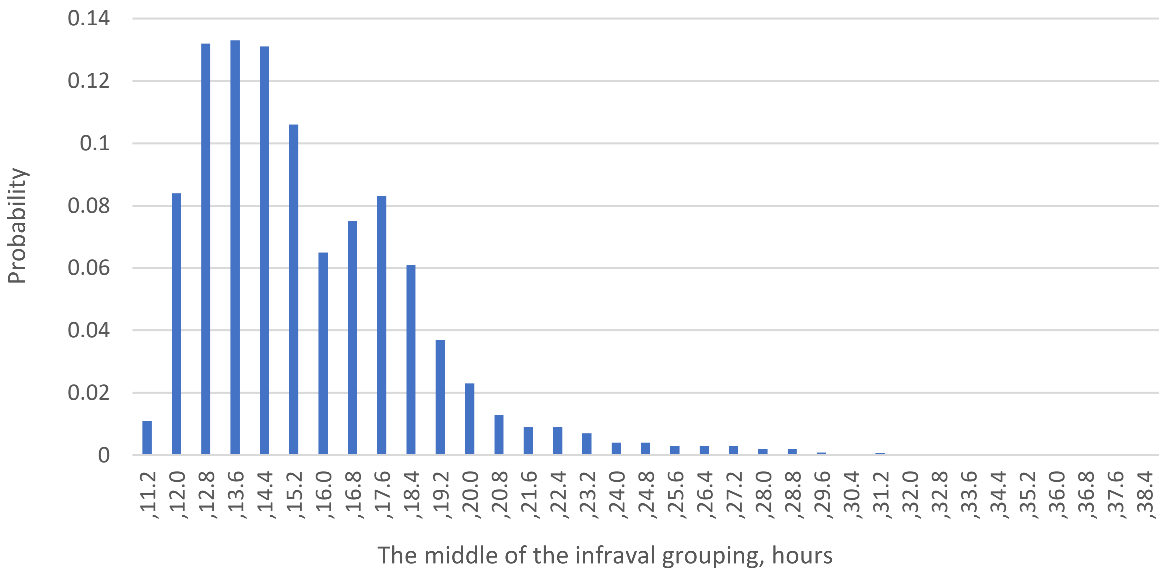

Figure 6: Density of time distribution f consignment of cargo

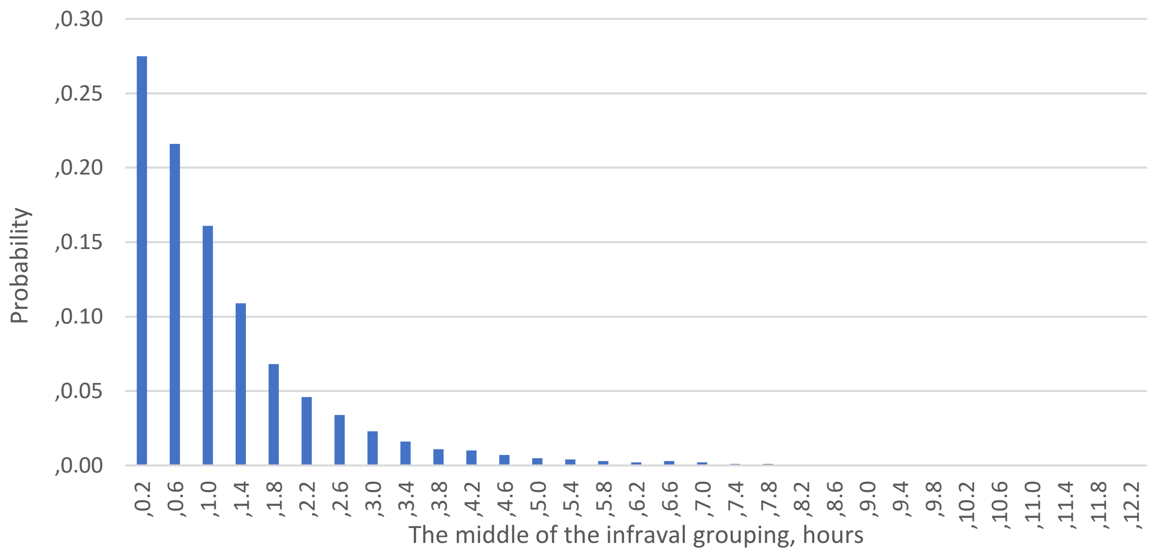

Figure 7: Density of distribution of time of waiting of a locomotive

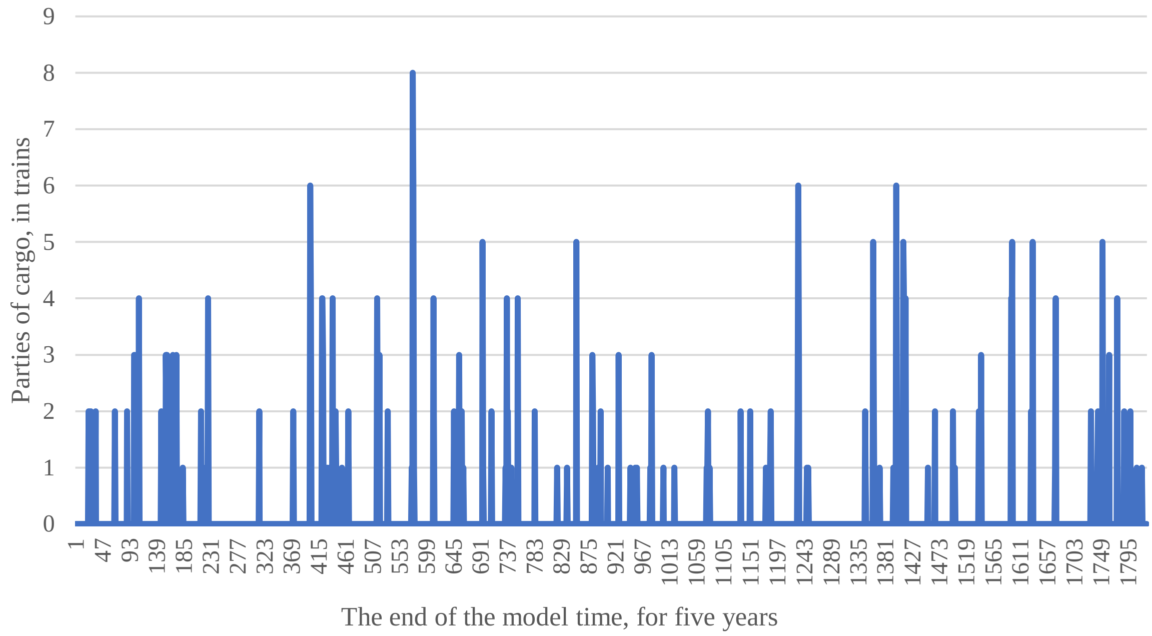

Figure 8: The formation of a queue of ready-to-ship cargo waiting for cars (one unit corresponds to the rate of loading into the warehouse, i.e., 3920 tons)

The density of the locomotive waiting time distribution (Fig. 7) is exponential, which confirms the typical process of failure formation. The obtained "typicality" indicates a completely natural modeling process and the adequacy of the simulation model itself.

The nature of the formation of the queue of ready-to-ship cargo indicates sufficient fault tolerance of the delivery process (Fig. 8): the queue is formed, but the technological system has enough internal reserves to get out of the state of temporary failure.

3. Discussion and conclusion

Centralized management of the fleet of locomotives and cars can significantly increase the efficiency of their use, as applications for freight are formed in one turn. This is especially true of branched networks. The presented simulation model allows estimating the real need for locomotives and cars in the conditions of organization of supply chains on the branched transport network. The agent principle of model building and formalization of business process logic allowed modeling real supply chains in the conditions of formation of a single queue for transportation: one point of departure and several delivery points. It is under such conditions that it is theoretically possible to achieve significant productivity and efficiency of transportation organization. Given that the presented business process can be considered close to the typical in the realities of Ukrainian railways, it can be argued that for the railway transport network of Ukraine, in theory, it is quite possible to achieve results in other segments of freight. To organize the transportation of one million tons per year of consignments, the need for locomotives and cars will be approximately 0.793 and 54.3, respectively.

Another important result of this study is the confirmation of the greatest impact on the stability and efficiency of the organization of rail freight transportation of the locomotive fleet. Reducing the number of locomotives below the critical value leads to significant delays in the movement of goods and disruption of the stability of most units of the railway, including the cars fleet. The increase in the fleet of locomotives has almost no effect on the acceleration of delivery and reduction of the load of the transport system, and only leads to a decrease in the load factor of the locomotives themselves.

4. References

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