DIGITAL MODEL: BEHAVIOR FORECAST IN TRANSPORT PROCESSES

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ABSTRACT

In today's world, many processes and events depend on forecasting. With development of mathematical models, an increasing number of factors influencing the final result of the forecast are taken into account, which in turn leads to the use of neural networks. But for training a neural network, source data sets are required, which are often not always sufficient or may not exist at all. The article describes a method of obtaining information as close to reality as possible. The proposed approach is to generate input data using simulation models of an object. The solution of a problem of generation of data sets and of training of a neural network is shown at the example of a typical marshalling railway station, and of a simulation of operations of a shunting hump.

The considered examples confirmed the validity of the proposed methodological approach to generation of source data for neural networks using simulation models of a real object, based on a digital mathematical model, which makes it possible to obtain a simulation model of movement of transport objects, which is reliable in forecasting transport processes and creating relevant control algorithms.

Keywords: *digital mathematical model, neural network, simulation modeling, analysis, forecasting, transport processes, behavior of objects, railway.*

Background. *The transport process is a set of operations deployed in time and space that are necessary to move an object from one point of space to another [1, p. 12]. Operations on the basis of which the transport process is managed must be local, elementary, deterministic, directional and massive, since otherwise it will not be possible to build an algorithmic control procedure based on them [2, p. 15].*

The basis of the digital mathematical model consists of alphabets:

- $Y = \{S_i, B_j, H_k, V_l, R_m, N_p\}$:
- S_i – *starting and ending points;*
- B_j – *empty zone;*
- H_k – *control of further action;*
- V_l – *transport object;*
- R_m – *branching of a track and choice of further action;*
- N_p – *an obstacle blocking the movement;*
- $Q = \{q_0, q_1, q_2, \dots, q_n\}$ – *set of states of a transport object.*
- $D = \{ST, EX, RE, R, L, R(S_k)\}$:
- *ST – forward movement;*
- *EX – stop/wait;*
- *RE – movement in the opposite direction;*
- *R – movement to the right;*
- *L – movement to the left;*
- $R(S_k)$ – *one step movement from zone R to zone* S_k.

Events that occur in a similar model, and the reactions of a transport operator can be represented by expressions of a similar type [2, p. 16]:

$$\frac{V_i}{q_j} BST \frac{V_i}{q_j}, \tag{1}$$

where the first three characters characterize an event that may occur in the transport process:

$$\frac{V_i}{q_j} B, \tag{2}$$

and the second three characters demostrate one of possible reactions of an operator:

$$ST \frac{V_i}{q_j}. \tag{3}$$

In general, these two triples indicate a certain logical operation suitable for managing the transport process at some stage of its development [1, p. 13].

Digital mathematical model allows to build a digital simulation model of the movement of transport objects, which can be used when predicting transport processes using neural networks.

Objective. *The objective of the authors is to study a method to generate input data using simulation of digital models of an object, allowing to train neural network to predict transport processes.*

Methods. *The authors use mathematical methods, methods of digital modeling, digital simulation, neural network training, transport operations' data analysis.*

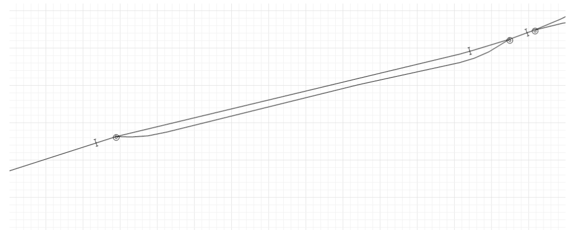
Results.

The inclusion of neural networks in forecasting requires data for their training. In the transport industry, such source datasets are not always available, or they may not exist at all.

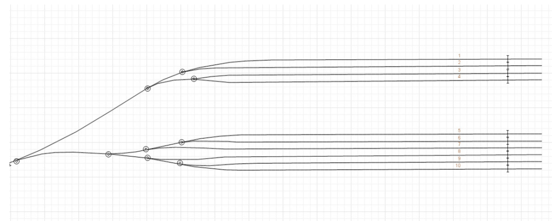
If a similar situation arises, it is possible to follow two ways:

- *One of them implies either manual selection of parameters, which requires spending a lot of time, while the result is not guaranteed, either trying to get relevant data from an industry representative, which in turn is no less difficult and sometimes takes more time than the selection of parameters;*
- *The second way is construction of some simulation model, perhaps even a little idealized, but having theoretically calculated characteristics allowing to reproduce the process corresponding to reality.*

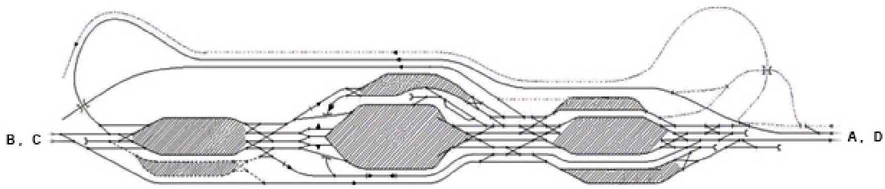
Using the simulation model, it is possible to analyze correctness of the choice of parameters, to more clearly examine the process, the results of which need to be predicted, and eventually to get the initial data sets for training the neural network, which in turn are no longer abstract, but very close



Pic. 1. The area of the shunting hump, containing an access track and a track for overtaking the locomotive.



Pic. 2. Section of the shunting hump, containing a hump and tracks of formation of trains.



Pic. 3. Traffic directions within marshalling yard (the picture is retrieved from graduation project of V. R. Markova «Design of new marshalling yard with automated shunting hump and of node chart», Moscow, Russian University of Transport, 2017).

Table 1

Statistics of the work of the hump for section 1 (AD)

Hours	AD				
	Number of trains per hour	Number of sorted wagons			
		Track 1	Track 2	Track 3	Track 4
1	2	3	4	5	6
1	2.2	38	32	27	35
2	2.2	30	27	39	35
3	2.3	39	29	32	35
4	2.2	38	41	30	25
5	2.2	39	27	37	29
6	2.1	32	34	33	25
7	2.1	27	31	26	42
8	2.1	35	24	37	32
9	2.2	37	36	28	31
10	2.4	32	35	39	39
11	2.2	28	30	45	30
12	2.2	28	25	40	41
13	2.3	27	28	43	41
14	2.1	38	26	34	27
15	2.2	42	37	31	23
16	2.5	40	38	35	37
17	2.0	28	29	32	31
1	2	3	4	5	6
18	2.4	30	27	44	40
19	2.2	31	34	33	31
20	2.3	40	27	35	33
21	2.5	36	39	38	36
22	2.3	40	41	22	32
23	2.3	25	43	34	38
24	2.2	34	40	27	29
TOTAL	53.5	814	780	821	797
		3212			

Table 2

Statistics of the work of the hump for section 2 (BC)

Hours	BC					
	Number of trains per hour	Number of sorted wagons				
		Track 5	Track 6	Track 7	Track 8	Track 9
1	2	3	4	5	6	7
1	2.8	30	39	32	29	37
2	2.8	31	40	34	36	27
3	2.8	26	41	38	29	31
4	2.8	33	40	32	29	31
5	2.8	33	26	39	32	36
6	2.9	36	30	26	40	42
7	2.9	34	38	34	33	35
8	2.9	33	40	32	33	33
9	2.8	37	34	35	31	30
10	2.6	30	27	30	37	30
11	2.8	38	39	28	36	25
12	2.8	39	33	35	26	32
13	2.7	33	30	41	31	27
14	2.9	29	43	39	38	25
15	2.8	29	29	30	49	29
16	2.5	24	29	30	27	39
17	3.2	40	40	32	36	41
18	2.6	31	36	31	19	41
19	2.8	34	31	27	31	47
20	2.7	30	34	36	26	38
21	2.5	5	42	36	35	32
22	2.8	35	31	34	36	30
23	2.7	26	29	30	43	34
24	2.8	43	27	26	36	37
TOTAL	66.4	759	828	787	798	809
		3981				

to real ones. It takes much less time to build a simulation model than to select parameters. When predicting processes of the same type, it is possible to change or to adapt the simulation model for a specific task, that, on the one hand, will allow one to have additional control over the results, and on the other hand, one can compare the forecasting methods.

This approach is relevant for any transport industry: railway, road, sea or air transportation. Each mode of transport has its own specific organization of traffic, but with introduction of some limitations and assumptions in the digital mathematical model, it becomes applicable for forecasting operations of any mode of transport.

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Let's consider using the example of a simulation model of a shunting hump a possibility to generate input data for training a neural network [3, 4].

Let us take the structure of the developed simulation model of a standard shunting hump (Pic. 1) and the tracks of train formation (Pic. 2), created using the AnyLogic modeling software [3, 4]. Based on the task of generating data and analyzing the work of the marshalling yard, we can assume that a shunting hump is the key element that influences what data will be obtained at the output [5–13].

Let us suppose that for analysis using a neural network, we may need the following data:

- *daily schedule of the marshalling yard;*
- *types of wagons most used and their characteristics;*
- *number of departure and reception tracks;*
- *curvature of the shunting hump;*
- *braking coefficient at braking points;*
- *number of operated locomotives;*
- *number of locomotive crews;*
- *weather conditions.*

Table 3

Statistics of waiting time of trains in the reception area by each hour of work of the marshalling yard

Hours	Waiting time
1	15.06
2	12.04
3	12.00
4	12.04
5	12.08
6	12.08
7	12.00
8	12.04
9	12.04
10	12.04
11	12.04
12	12.04
13	11.96
14	12.04
15	12.04
16	12.04
17	11.65
18	12.04
19	12.04
20	12.04
21	12.04
22	11.96
23	11.92
24	12.04

Such a list is minimal in order to make an approximate analysis of the work of the sorting node and to develop some forecast [5–15]. Even this initial information is not easy to be obtained in a convenient form due to the fact that the automated control system of the marshalling yard consists of many modules, and therefore the information is stored in different places and different formats. Part of the information, including the daily schedule, is compiled manually.

However, even having a minimum data set (car turnover, the number of locomotives used, the number of departure tracks, distribution of cars by directions), it is possible to build the required simulation model.

Tables 1–3 show what data can be obtained using a simulation model for a typical marshalling yard with one shunting hump. Data obtained with simulation model correspond to directions of traffic shown in the chart of marshaing yard (Pic. 3).

Conclusion. *The combination of the considered examples confirms the validity of the proposed methodological approach to generation of source data for neural networks using simulation models of a real object. At the same time, the fundamental principle of theoretical construct is naturally a digital mathematical model, which makes it possible to obtain a simulation model of movement of transport objects. This model is reliable for forecasting transport processes and creating control algorithms for them.*

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