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INVESTIGATION OF ROAD TRANSPORT ENTERPRISE FUNCTIONING ON THE BASIS OF SYSTEM DYNAMICS

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The work is devoted to the study of the possibilities to apply the System Dynamics method for the analysis of processes at the road transport enterprises. The study contains a concise review on examples of three simulation paradigms application for creating models, associated with the road motor transport. The following paradigms were under consideration: Discrete Event, Agent Based, and System Dynamics. Furthermore, the paper describes the causal loop diagram designed using the principles of system dynamics. This diagram is a qualitative model that represents the relationships between the main factors affecting the performance indicators of a road transport enterprise. The quantitative model constructed using the principles of system dynamics is also represented. The mentioned model reflects the process of functioning of a road transport enterprise during the year. The model is developed using Vensim simulation software.

Keywords: road transport, simulation, system dynamics, Vensim

1. Introduction

In many countries road transport occupies a leading position in the field of transport logistics and the efficiency of the road transport and has a significant impact on the economic performance in various sectors of the national economy. For example, in 2016, 85.0% of the total cargo turnoff in Kazakhstan were transported by road and only approximately 8.4% by rail. According to the World Bank report, road transport in Kazakhstan is mainly used to deliver both everyday goods and durable goods. It is known that the vast majority of transnational companies operating in Kazakhstan deliver imported goods to Almaty and after that transport them by road to various regions of Kazakhstan. According to the World Bank estimations, 98.0% of road freights in Kazakhstan are internal (World Bank, 2017).

Up to date, Kazakhstan has launched a lot of research works aimed at increasing the efficiency of the entire transport sector and logistics complex as a whole. Among these works, an important place is occupied by work related to the study of the efficiency of road transport. The authors of this article, in the framework of one of these studies, made a theoretical and practical assessment of the opportunity to apply the simulation for the analysis of the performance of a particular road transport enterprise.

In the first part of the work, there is a brief review of examples, related to the application of various paradigms in the field of simulation modelling for studying the processes associated with the road motor transport. The causal loop diagram, constructed using the principles of system dynamics, is described below. This diagram is a qualitative model that represents the relationships between the main factors that may affect the performance of the road transport enterprise. Additionally, there is a quantitative model constructed using the principles of system dynamics, which corresponds to the process of the road transport enterprise activity during the year.

2. Application of Various Paradigms for Transport Processes Simulation

It is currently conventionally accepted that three main paradigms are used to model processes in manufacturing, transportation and logistics systems, namely: Discrete Event, Agent Based, and System Dynamics (Borshchev, 2013).

The Discrete Event paradigm is characterized by a relatively low level of abstraction is applied to translocate information from the real world to the model. When the model is set on a computer, a network structure is created by connecting the fixed blocks, through which flows of movable objects shall pass. Blocks are usually grouped into the library of the software package, however, they can also be programmed by the model developer. The network structure blocks display the operations, invoked on movable objects using the technical or human resources of the simulated system. Movable objects may represent vehicles, cargo units, passengers and other real-world objects that are able to translocate in the space. The model of such space is created using exactly the network structure blocks. The low level of abstraction is set in order to create the model, in which the real-world objects are directly displayed in the model as separate software elements. For example, there is a movable object "the truck" that corresponds to each simulated truck and for each place of unloading at the ramp there is a block of the type "unloading place". The Discrete Event paradigm usually uses queuing systems as conceptual models.

The Agent Based paradigm assumes that individual objects of the model, such as movable objects and resources may contain arbitrarily complex properties, in the most extreme case, even comparable to the properties of individuals or legal entities that participate in the simulated process. It is important to emphasize that not only physical characteristics or information parameters (identifier, mass, size, speed, current state, etc.) can be specified as properties of agents, but also algorithms or even complex behaviour strategies in certain situations. With respect to the modelling of complex processes in production, transport and logistics, it may be argued that Agent Based models have more developed form in comparison with models that belong to Discrete Event type. At the same time, the principle of modelling remains same. The essence of the principle is characterized by the interaction of movable objects flows with the resources of the system. Models of the Agent Based type use the same mechanism of event planning and processing as the models of Discrete Event type.

Models reflecting mass flows of the anonymous vehicles are called by the special term "traffic flow simulation". If the Discrete Event approach is used, such models are belonged to the class of microscopic models. In the field of traffic flow simulation mesoscopic and macroscopic model classes are defined. Microscopic simulation models of traffic flows are more frequently created for roads and road intersections with the intensive flow, and groups of vehicles that belong to the particular company and perform a particular set of functions within the logistic system are not illustrated. One of the most common traffic flow simulation software is the VISSIM (Lownes and Machemehl, 2006).

Models in which the specific processes of cargo transportation are displayed using the Discrete Event or Agent Based principles are most likely created by using universal simulation packages that support the described paradigms. For example, in (Rizzoli *et al*., 2002) is described a simulation tool for combined rail-road transport in intermodal terminals, which was created on the basis of the universal MODSIM III package. This tool allows to develop specific terminal models in which road transport is used to transport goods from terminal to terminal and to their regional clients. In (Reis, 2014), a model of the Agent Based type is described, which compares the efficiency of intermodal transport and direct transportation by road in relatively short distances. The model is created in the AnyLogic package. The Discrete Event model, which is described in (Herazo-Padilla *et al*., 2015), is used to solve the optimization problems of freight traffic routes in cities with intensive traffic. For the analysis of long distance transportation, a model of the Agent Based type, described in (Holmgren *et al*., 2013), is designed. At the same time with the agent based approach, the authors have shown the possibility of increasing the level of abstraction, mapping the studied processes with the transition to the macroscopic level of modelling.

Exactly in case of a macroscopic level of modelling that a paradigm is associated with the term System Dynamics (Sterman, 2000). In such models, there are no discrete objects that move in a real simulated system. The model consists of formulas that calculate the number of such objects in each node of the network structure of the model in time, which changes with a given constant step "delta T". Nodes of the network structure, in which thread objects can accumulate, are modelled using a particular type of block called "level". The streams themselves are called "rate" and are variables, which values are equal to the number of objects that move from one node to another during the step "delta T". Movable objects cannot be delayed in flows, therefore blocks of the "level" type are used to model both the storage nodes of the system and the transport channels.

The review (de Jong *et al*., 2004) considers 65 publications and six national systems for modelling of future freight turnoffs and traffic flows, many of them are based on the System Dynamics method. Undoubtedly, some of these works have already lost their relevance, as they relate to the period from 1980 to 2002. In the new review (Shepherd, 2014), six main areas of applications of the System Dynamics method in modelling transport systems are highlighted. These areas were mentioned in 54 publications that appeared from 1994 to 2014. For the topic of this article, only the area of "Supply Chain Management with Transportation" is relevant, especially for that the author of the review noted 6 publications. It shall be noted that the vast majority of these publications contain varieties of a well-known abstract model called "bullwhip effect" that cannot be used to analyze the performance of a particular road transport enterprise.

As relatively new, we may note the publications (Azhaginiyal and Umadevi, 2014), (Stroombergen *et al*., 2017) and (Thaller *et al*., 2017). In (Azhaginiyal and Umadevi, 2014), the problems, related to the influence of the transport system on the energy consumption and emission level are studied using the example of a particular city. The solid report (Stroombergen *et al*., 2017) describes a cargo transportation model within the framework of one large region in New Zealand. The model allows to particularly investigate the influence of factors leading to a decrease in road capacity and delays in transit. The problems of transporting goods in urban environments are discussed in (Thaller *et al*., 2017). In this paper, a model of the System Dynamics type is represented only in the form of causal loop diagrams, i.e. it still cannot be applied to numerical experiments.

As it was mentioned above, the key aim of this research is the estimation of possibilities of using simulation approach for the analysis of the performance of the specific road transport enterprise. However, the authors deliberately refused to use models such as Discrete Event or Agent Based. It is widely known that on the basis of these paradigms, it is possible to build models of the investigated processes as detailed as possible, but the labour and cost of the process of creating such models are usually unacceptably high, in case of a model is ordered by an enterprise that refers to small and medium businesses. In the following, attention will be paid to the perspectives of using the System Dynamics paradigm, since models of such class are almost simpler and more compact than models of firs two paradigms. The first of the described models exists in the form of a causal loop diagram and the second one is a complete model based on the principles of System Dynamics, which contains the result of numerical experiments that shown for it.

3. Causal Loop Diagram for Business Process of a Road Transport Enterprise

The task of choosing a suitable carrier relates to the classical tasks of decision-making in logistics. The method "analytic hierarchy process" (AHP) is proposed in order to solve it. The method is developed by Saaty about 40 years ago (1980) and ubiquitously used. The AHP method refers to the multi-criteria decision-making techniques. When we use this method in order to compare enterprises providing transport services, qualitative and quantitative indicators are applied as a key criteria, which characterize the performance of each enterprise and appear to be the most important from the potential customer's point of view.

Figure 1 represents the indicators that are often used by a potential customer to assess an enterprise that provides services in the field of road transport. These indicators are combined into two groups: basic indicators and additional indicators. The differences are all about the positions of the customer and the service provider and if the customer is only interested in the actual values of these indicators at the time of making the decision, while the activity of the transport enterprise should be aimed at their continuous improvement.

In the causal loop diagram shown in Figure 1, various factors are shown that affect the values of both the basic and additional indicators. Factors that directly affect the indicators may be divided on following categories:

- the "State of the infrastructure" is an external factor that a particular enterprise can hardly influence;
- the "Size and condition of the truck pool" and "Qualification of employees" factors can be altered to the positive or negative side depending of the actions of the enterprise.

Of course, each company seeks to increase the size of the truck pool and reduce the average age of trucks. However, the first aspiration is limited by the size of the production space of the enterprise and the level of demand in the accessible market segment. The possibility of buying new trucks often depends on the terms of lending offered by partner banks.

The qualification of employees is the most important factor affected by the position of the transport enterprise and its competitors. In this case, we mean the qualification of both drivers and workers of the repair and maintenance base and managers. The qualifications of drivers depend both on the average speed of the trucks and on the accuracy of the delivery times specified in the contract with the customer. Concerning the qualification of managers and the management of the enterprise as a whole, the importance of three indicators for the customer may be emphasized:

- safety and preservation of goods during the transportation;
- availability of additional services for picking and delivery of goods;
- the use of modern information technology for cargo tracking and tracing.

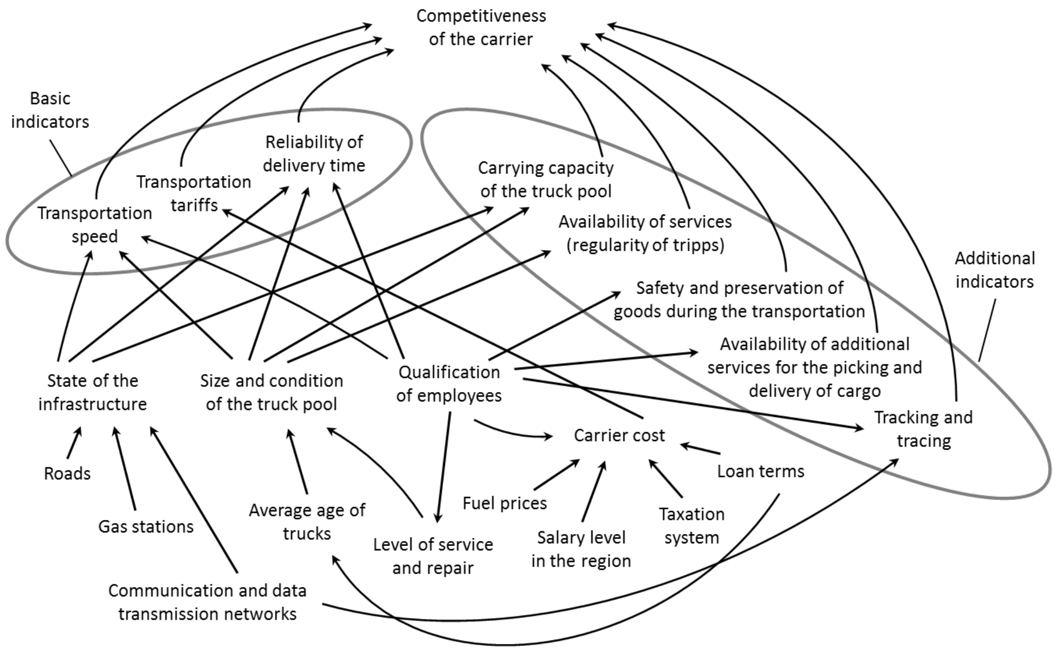

Figure 1. Factors and indicators that determine the competitiveness of the carrier

A high level of qualification of employees, for sure, may negatively affect the cost of transportation, since for more skilled workers it is necessary to establish a higher level of wages. In addition, the company can finance activities aimed at improving the skills of employees. Such additional costs may, however, be compensated by high competitiveness indicators and a stable position in the transport services market.

The main economic indicator is the tariffs for transportation, which the company offers to its customers. This indicator depends, firstly, on the cost of transportation, which is determined by the level of expenses that the company is forced to produce to support its operations. In Figure 1, you can see that there are at least five factors that affect these expenses, four of which are related to external factors that the individual enterprise is not able to influence.

The causal loop diagram presented in Figure 1 is not intended to be converted to a complete model of the System Dynamics type, since many of the factors and indicators shown in it have a purely qualitative nature and no numerical values relating to them can be determined. This diagram is one of the forms of modelling the business process in the enterprise, and it can serve as a basis for analyzing this process in order to identify "weaknesses" and develop an action plan to eliminate them.

4. System Dynamics Model of a Road Transport Enterprise

We consider a following model of operation process in a road transport enterprise, designed in the form of a system dynamics model in the software package Vensim.

4.1. Conceptual model

The road transport company primarily deals with the international transport and has 200 trucks in its pool. Transportations with the duration from 4 to 21 days have the commercial significance. The company receives orders for transportation every day. The number of orders that an enterprise takes to perform on a particular day is determined by the number of trucks available up to date. If the number of orders received is greater than the number of available trucks, then part of the orders is rejected, i.e. a customer receives a refusal. Trucks that have returned from a regular trip and are not in an idle state due to repair or maintenance work are considered available. Figure 2 shows that the duration of such work is from 1 to 4 days. The percentage of trucks that should be transferred to idle status after the trip is determined by their technical conditions and the company's strategy aimed at ensuring a high level of traffic safety. The share of trucks that can be sent on a new trip on the next day, in practice, is from 60 to 80 percent.

One of the tasks of modelling of this road transport enterprise is to assess the impact of the strategy of transferring trucks to idle times on the annual profit of the company at different levels of demand for transportation, i.e. various intensities of the flow of orders for transportation λ.

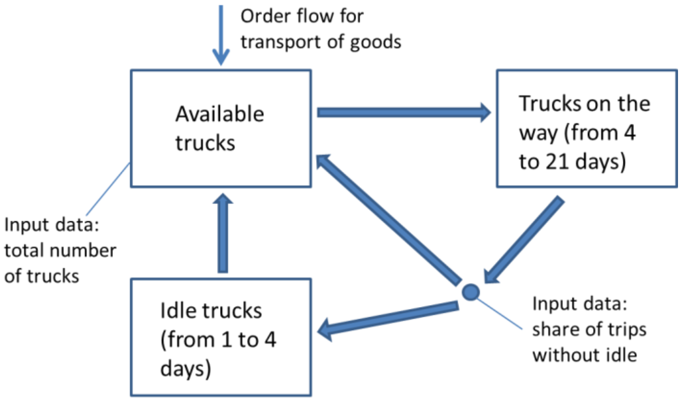

Figure 2. Structure of the conceptual model of the road transport enterprise

The statistical properties of the order flow are determined by the set of probabilities p_i (i=4,…, 21), each probability refers to the possible duration of the trip in the range from 4 to 21 days. The intensity of the order flow λ does not affect the probability distribution form p_i, but only determines the total number of orders received within one day, one week, or the whole year.

For each duration of the trip, the value of its average profitability q_i (i= 4,…, 21), the calculation of which takes into account the fact that part of the trips brings the enterprise losses, which also may be called a negative profit. For the duration of repair from 1 to 4 days, the probabilities are set as r_j (j=1,…, 4). Numerical values of p_i, q_i, and r_j, used in the model are based on real data on the work of a road transport enterprise during the year.

4.2. Model input data

The input data of the following model is shown below in the same form as it is stored in the model on Vensim package.

On the "share of travel days" chart (Fig. 3), the cumulative form shows the probabilities p_i, and on the chart "share of idle days" probability values r_j are shown. The cumulative form of the probability representation was used in order to simply verify the condition that the sum of the probabilities p_i or r_j is equal to one. The chart "final profit of the trip" shows the average profit in EURO q_i for all values of the trip duration from 4 to 21 days.

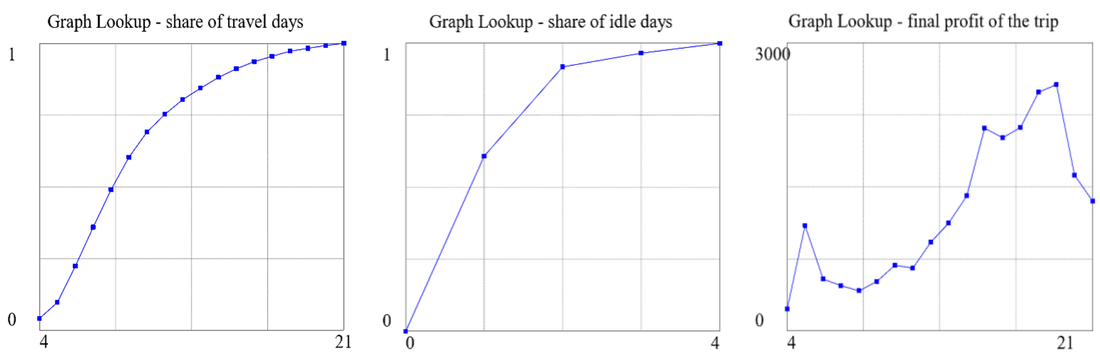

Figure 3. The initial data of the model as the determined variables

Figure 4 depicts the histogram of the empirical distribution of the number of orders that are received by road transport enterprise during the week. The number of orders ranged from 110 to 180. Exactly this random number of orders will be generated in the model with the intensity of the order flow λ=1. Based on the histogram, a cumulative distribution function "distribution function for number of orders" was plotted. In Figure 4, this function is shown in an inverted form, since it is used to generate a random number of orders using random numbers lying in the range [0,1). The argument in this case is the standard RANDOM UNIFORM function from the Vensim package.

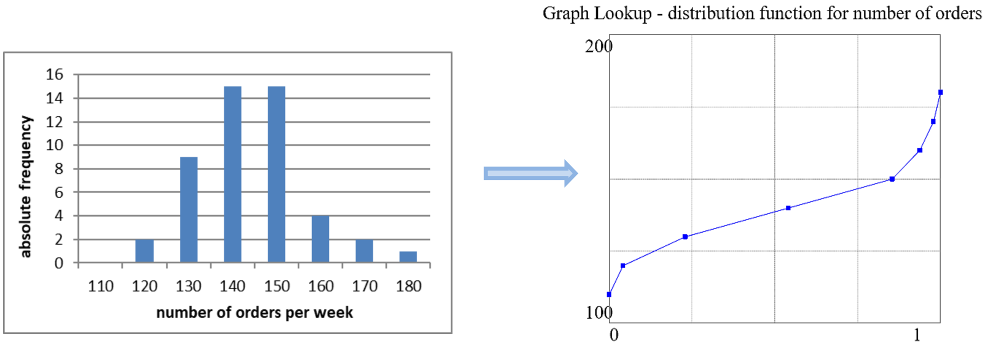

Figure 4. The initial data of the model as the distribution function of a random variable

The initial data of the model, which was set during the simulations, also contains two constants. The first constant is "Share of trips without idle" means the relative share of trips after which the car is not sent for repair or maintenance procedure. During the experiments, this parameter takes values in range [0.6; 0.7; 0.8]. The second constant is "Order flow intensity factor" is the value of λ described above, which takes the values [0.8; 0.9; 1.0; 1.1].

4.3. Building the Vensim model

The time step in the model (TIME STEP) is set as 1 day, the duration of the model run until 365 days (FINAL TIME). The main logical part of the model is shown in Figure 5. At each new instance of time, the variables "trucks available" and "day orders" are calculated. As the result of their comparison, the variables "accepted orders" and "rejected orders" are defined.

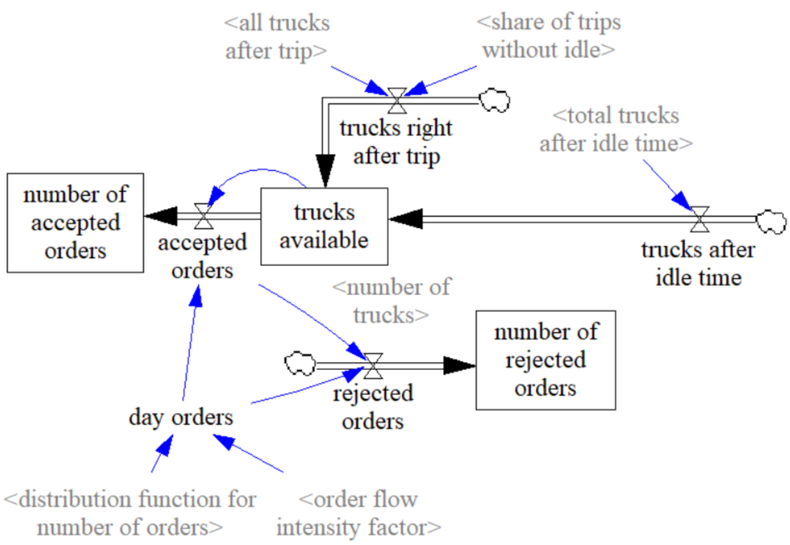

Figure 5. The main part of the model in Vensim

Figure 6 explains how exactly to simulate a random travel time in the range of 4 to 21 days in a situation where the delay DELAY FIXED function of the Vensim package does not allow you to simulate a random delay time. The vehicles flow is sent on the given day. The number of vehicles is equal to "accepted orders", is divided into shares, according to the "share of travel days" diagram (Fig. 3). Each share of cars is delayed in the block by analogy with "4 days on the way" block. Figure 6 shows only the first three delay blocks and the total number of them within the model is 18.

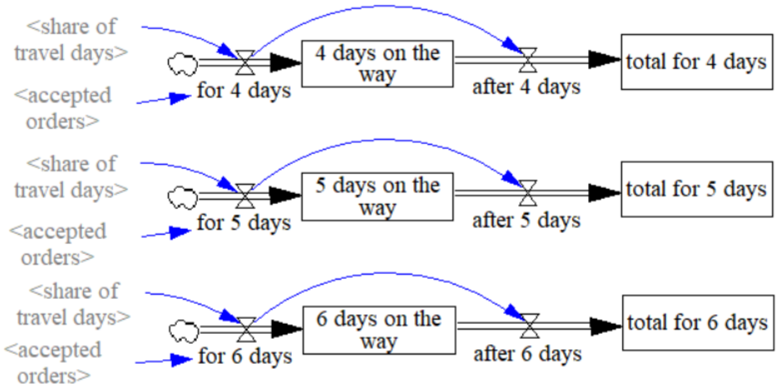

Figure 6. The method to model the random duration time of the trip

The Figure 7 represents the method of calculating the variable "trucks to idle", the value of which is equal to the number of trucks set to the idle state on a considered day. Further we can see that the variable is used to simulate idle time for groups of trucks for 1, 2, 3 or 4 days. The same method is applied to simulate the random length of idle time, which is shown in Figure 6. Finally, the model calculates the variable "total trucks after idle time", which values are taken into account when we define the number of available trucks in the main part of the model, which was shown above (Fig. 5).

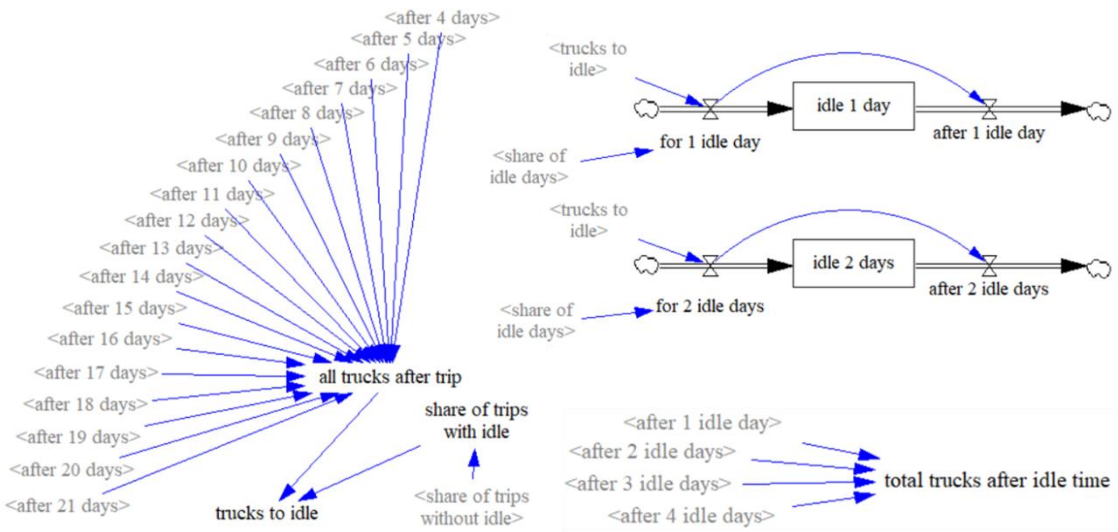

Figure 7. Modelling of trucks' maintenance and repair

The model also contains special extensions for calculating the indicator "Final profit (thousand €)", the value of which is equal to the annual profit of the road transport enterprise.

4.4. Experiments with model

It is noted above that the task of road transport enterprise modelling was to assess the impact of the strategy of transferring trucks to idle state on the company's annual profit at various levels of demand for transportation. This task of research corresponds to the structure of Table 1.

The parameter "Share of trips without idle" took the values [0.6; 0.7; 0,8] and the parameter "Order flow intensity factor" took the values [0.8; 0.9; 1.0; 1.1] respectively. The dependence of the "Final profit (thousands €)" indicator on both parameters is also shown in Figure 8.

Table 1. The result of experiments with the model of the road transport enterprise

Experiment No.	Input data		Simulation results		
	Share of trips without idle	**Order flow intensity factor**	**Number of accepted orders**	**Number of rejected orders**	**Final profit (th. €)**
1	0,6	0,8	5816	0	4564
2	0,7	0,8	5816	0	4564
3	0,8	0,8	5816	0	4564
4	0,6	0,9	6470	73	5080
5	0,7	0,9	6504	38	5106
6	0,8	0,9	6523	20	5119
7	0,6	1	6603	667	5184
8	0,7	1	6689	580	5252
9	0,8	1	6776	494	5320
10	0,6	1,1	6618	1379	5196
11	0,7	1,1	6708	1289	5267
12	0,8	1,1	6800	1197	5339

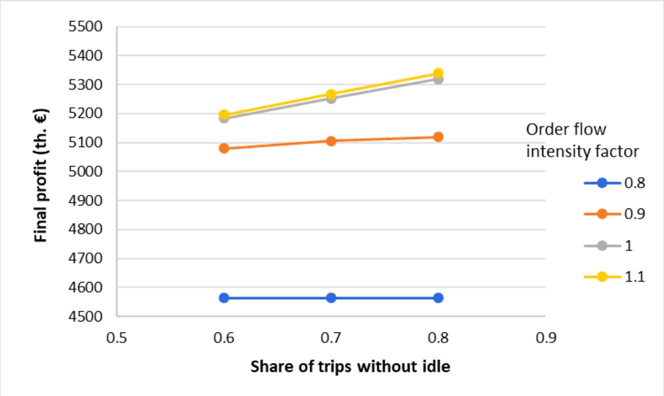

Figure 8. The impact of two factors on the company's annual profit

The result of the simulation testifies that with a low level of demand for transportation, the parameter "Share of trips without idle" does not affect the annual profit of the enterprise. At the demand level of 0.9 this relation becomes hardly noticeable. At the demand level of 1 and bigger, as a result of changing the "Share of trips without idle" parameter from 60% to 80%, the annual profit of the enterprise increases by approximately 3%. In case if the increase in this parameter may affect the level of traffic safety, it seems quite reasonable to leave it at the level of 60%.

5. Summary and Conclusions

The analysis of publications allows us to conclude that in the field of transport and logistics, the system dynamics method is mainly used to develop models that may be applied to survey all modes of transport in a particular area or to individual modes of transport used on this territory. The peculiarity of the model described in this article is the fact that it reflects to the work of a road transport enterprise without a direct binding of the processes of transporting goods to a particular territory. Relation to the territory is manifested by using real statistics on the duration of trips in the interval from 4 to 21 days.

Typically, these models of the enterprise operation are designed on the basis of simulation software that supports the Discrete Event or Agent Based paradigm. The reason that such models are rarely used for the analysis of specific enterprises is, in particular, the fact that for the development of models the company is forced to invite specialists from outside organizations that can professionally work in the field of simulation. The complexity of methods and tools aimed at applying the above two traditional paradigms is most often an obstacle for the employees of the enterprise to master the methods of modelling at a professional level in a relatively short time. In addition, there is no sense for the company to buy such tools if it is planned to conduct one particular study using simulation. The perspective of model development looks quite different if the system dynamics is used as the modelling paradigm. It is known that the Vensim PLE package is a very common free product with a simple user interface and the package may be easily mastered by any employee of the enterprise with a mathematical style of thinking. The example described in this paper shows the possibility of obtaining easily interpreted and useful results by developing and applying a relatively simple model that maps processes to a particular transport enterprise.

References

1. Azhaginiyal, A., Umadevi, G. (2014) System Dynamics Simulation Modeling of Transport, Energy and Emissions Interactions. *Civil Engineering and Architecture*, 2(4), pp. 149-165.
2. Borshchev, A. (2013) *The Big Book of Simulation Modeling: Multimethod Modeling with Anylogic 6*. AnyLogic North America, Lisle, IL.
3. de Jong, G., Gunn, H.F., Walker, W. (2004) National and international freight transport models: an overview and ideas for further development. *Transport Reviews*, 24(1), pp. 103-124.
4. Herazo-Padilla, N., Montoya-Torres, J.R., Nieto-Isaza, S., Ramirez Polo, L., Castro, L., Ramírez, D., Quintero-Araújo, C.L. (2015) Simulation-Based Analysis of Urban Freight Transport with Stochastic Features. *Enterprise Interoperability: Interoperability for Agility, Resilience and Plasticity of Collaborations* (I-ESA 14 Proceedings), pp. 175-180.
5. Holmgren, J., Dahl, M., Davidsson, P., Persson, J.A. (2013) Agent-based simulation of freight transport between geographical zones. *Procedia Computer Science*, 19, pp. 829-834.
6. Lownes, N., Machemehl, R. (2006) VISSIM: A multi-parameter sensitivity analysis. In: *Proceedings of the 2006 Winter Simulation Conference*, pp. 1406-1413.
7. Reis, V. (2014) Analysis of mode choice variables in short-distance intermodal freight transport using an agent-based model. *Transportation Research Part A: Policy and Practice*. Volume 61, March 2014, pp. 100-120.
8. Rizzoli, A.E., Fornara, N., Gambardella, L.M. (2002) A simulation tool for combined rail-road transport in intermodal terminals. *Mathematics and Computers in Simulation* (MATCOM), vol. 59, issue 1, pp. 57-71.
9. Saaty, T.L. (1980) *The analytic hierarchy process: planning, priority setting, resources allocation.* McGraw-Hill.
10. Shepherd, S.P. (2014) A review of system dynamics models applied in transportation. *Transportmetrica B: Transport Dynamics*, 2(2), pp. 83-105.
11. Sterman, J. (2000) *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Irwin/McGraw-Hill.
12. Stroombergen, A., Stuart, G., Barsanti, T. (2017) System dynamics investigation of freight flows, economic development and network performance. *NZ Transport Agency research report 629*, 55 pp.
13. Thaller, C., Niemann, F., Dahmen, B., Clausen, U., Leerkamp, B. (2017) Describing and explaining urban freight transport by System Dynamics. *Transportation Research Procedia*, Volume 25, pp. 1075-1094.
14. World Bank. (2017) Turning the tide in turbulent times: leveraging trade for Kazakhstan's development. http://documents.worldbank.org/curated/en/563511493645817442/Turning-the-tide-in-turbulent-times-leveraging-trade-for-Kazakhstans-development