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Simulation model of oil products transshipment
in a seaport

The paper considers the problem of finding an optimal strategy for ordering railway tank cars for the export of oil products from the seaport terminal. Since the arrival of the ordered wagons is a random process that substantially impacts the costs of the cargo owner, it was decided to use the simulation modeling method to solve the problem. The paper provides an overview of methods and specific examples of simulation modeling for solving related problems in transport logistics. Particular attention is paid to the experience of using spreadsheets in the practice of simulation modeling. It is noted that a spreadsheet as a modeling tool has certain advantages over special packages for simulation modeling. The paper substantiates the decision to use the VBA language in the MS Excel environment to develop a model for the transshipment of oil products at the terminal in the seaport. The following details describe the stage of conceptual modeling, the stage of data preparation using distributions of random variables, and conducting experiments with the model. Five possible scenarios were investigated, which differ in the boundary conditions of the processes of the arrival of empty cars at the terminal. Based on the results of the study of these scenarios using statistical modeling methods, the requirements were developed that the cargo owner must impose on the railway in order to minimize the costs arising both from the delay of the vessel in the port and the idle time of wagons on the terminal territory.

Key words: Oil Products Transshipment, Marine Oil Terminal, Simulation, Spreadsheet.

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Теңіз портында мұнай өнімдерін
ауыстырып тиеудің имитациялық моделі

Жұмыста теңіз портындағы терминалдан мұнай өнімдерін шығару үшін теміржол вагон-цистерналарына тапсырыс берудің оңтайлы стратегиясын іздеу міндеті қарастырылады. Тапсырыс берілген вагондарды қабылдау жүк иесінің шығындарына қатты әсер ететін кездейсоқ процесс болғандықтан, аталған мәселені шешу үшін имитациялық модельдеу әдісін қолдану туралы шешім қабылданды. Жұмыста көліктік логистиканың туыстық міндеттерін шешу үшін имитациялық модельдеуді қолданудың әдістері мен нақты мысалдарына шолу жасалады. Имитациялық модельдеу тәжірибесінде электрондық кестелерді қолдану тәжірибесіне ерекше назар аударылады. Электрондық кестелер модельдеу құралы ретінде арнайы имитациялық модельдеу пакеттерімен салыстырғанда белгілі бір артықшылықтарға ие екендігі атап өтіледі. Жұмыста теңіз портындағы терминалда мұнай өнімдерін ауыстырып тиеу моделін жасау үшін MS Excel ортасында VBA бағдарламалау тілін қолдану туралы шешім негізделеді. Ары қарай тұжырымдамалық модельдеу кезеңі, кездейсоқ шамалардың үлестірілуін қолдана отырып мәліметтерді дайындау кезеңі және модельмен эксперименттер жүргізу кезеңі толығымен сипатталады. Терминалға шекаралық шарттарымен ерекшеленетін бос вагондардың түсу процестерінің бес мүмкін сценарийі зерттелді. Осы сценарийлерді статистикалық модельдеу әдістерімен зерттеу нәтижелері негізінде жүк иесі кеменің портта кідіруінен, сондай-ақ терминалдың аумағында вагондардың тұрып қалуынан туындайтын шығындарды азайту мақсатында темір жолға көрсетуге тиіс талаптар әзірленді.

Түйін сөздер: мұнай өнімдерін ауыстырып тиеу, теңіз мұнай терминалы, имитациялық модельдеу, электрондық кестелер.

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Имитационная модель перевалки нефтепродуктов
в морском порту

В работе рассматривается задача поиска оптимальной стратегии заказа железнодорожных вагонов-цистерн для вывоза нефтепродуктов из терминала в морском порту. Так как поступление заказанных вагонов является случайным процессом, оказывающим сильное влияние на затраты владельца груза, было принято решение о применении метода имитационного моделирования для решения поставленной задачи. В работе приводится обзор методов и конкретных примеров применения имитационного моделирования для решения

родственных задач транспортной логистики. Особое внимание уделяется опыту применения электронных таблиц в практике имитационного моделирования. Отмечается, что электронные таблицы, как инструмент для моделирования, обладают определёнными преимуществами по сравнению со специальными пакетами имитационного моделирования. В работе обосновывается решение о применении языка программирования VBA в среде MS Excel для разработки модели перевалки нефтепродуктов на терминале в морском порту. Далее подробно описываются этап концептуального моделирования, этап подготовки данных с использованием распределений случайных величин и этап проведения экспериментов с моделью. Были исследованы пять возможных сценариев, которые отличаются граничными условиями процессов поступления порожних вагонов на терминал. На основании результатов исследования этих сценариев методами статистического моделирования были разработаны требования, которые владелец груза должен предъявлять железной дороге с целью минимизации затрат, возникающих как из-за задержки судна в порту, так и простоя вагонов на территории терминала.

Ключевые слова: перевалка нефтепродуктов, морской нефтяной терминал, имитационное моделирование, электронные таблицы.

Introduction

The object of research in this work is the transshipment process of oil products at the seaport. The product is delivered to the port by tank ships and departs from the port by rail loaded into the tank cars. Intermediate storage of the product at the terminal is carried out using storage tanks. From the point of view of modern logistics, such an object is at the lowest level of the hierarchy, all other levels of which can be represented as follows:

- supply chain,
- mixed, intermodal, and multimodal transportation,
- points of cargo transshipment,
- seaport terminals,
- sea terminals for transshipment of liquid cargo.

The natural desire to find the most favorable conditions for the operation of a particular terminal, subject to specific conditions and constraints of both technical and economic nature, led to the decision to use simulation modeling. Approximate deterministic calculations using the process parameters' average values do not give results sufficient for making justified decisions since the actual process is non-stationary. Besides, the dynamics of the process are strongly influenced by random factors.

Simulation modeling has long been considered the most effective tool for investigating processes at all the above supply chain hierarchy levels. In the late 90s, LLamasoft specialists introduced the concept of the Four Step Approach, the essence of which is the combination of simulation and optimization technologies to solve strategic problems of supply chain planning (Hicks, 1999). The basic principles of this approach are used by LLamasoft in the Supply Chain Guru (Chwif et al., 2002). Today this approach has been further developed within the most advanced supply chain modeling package, anyLogistix (anyLogistix, 2021). The vast majority of supply chain simulation models are developed within the framework of the discrete event paradigm. However, there are also regular works that describe models based on the principles of system dynamics. The background and experience of this highly abstract supply chain modeling practice are detailed in (Campuzano et al., 2011). An example of a study of a specific multimodal transport system can be seen in (Pérez-Lespier, 2013). In recent years, the agent approach has also been applied to modeling supply chains since participants in the supply chain can often be represented as agents with their own individual goals and rules (Borshchev, 2013).

Current practice and prospects for the application of simulation modeling in the Ports and Maritime Industry are described by (Zarzuelo et al., 2019). The authors note, in particular, that Flexsim/ FlexTerm, Simio, ARENA, PortOPS, CHESSCON, Enterprise Dynamics, and ProModel packages are most often used to create such models. Cargo transshipment processes are most often modeled for ports where container terminals operate (Roşca et al., 2013; Lee et al., 2014). The experience of modeling the processes of oil transportation through seaports is reported in (Carotenuto et al., 2014). The authors of (Widjaja et al., 2019) use simulation modeling to identify the advantages and disadvantages of investment options in various types of oil terminal infrastructure in the port.

Summarizing the review, it should be pointed out that each project related to the application of simulation modeling involves the development of a new specific model, which is specifically designed to study only one particular object. Universal simulation models do not exist and impossible in principle, just as there is no universal photograph of a man or a woman: all photographs are absolutely individual. In the following section the procedure for deciding on a method for modeling processes will be considered in a situation where the model developer knows

well the logic and statistics of the functioning of a real system, but has no experience with commercial modeling packages. The main part of this work contains a description of the methods for preparing experiments with the developed model and analyzing the results of these experiments.

Material and Methods

Reasoning behind the selection of the modeling method

In the case where simulation modeling is applied to support a large and expensive project related, for example, to the reconstruction of an oil terminal or the analysis of a complex supply network, the project manager will turn to specialists who have a positive experience in developing such models. Professionals are known to use the generic modeling packages noted above (Zarzuelo et al., 2019) most often. Typically, these packages are an expensive commodity. In addition, even after learning the principles of working with the package, a novice user will not be able to develop models at a professional level for several months or even years. In the case of planning a relatively small simulation project, it makes no sense for the client to turn to a professional, since he or she will not agree to work for a small fee, and the client will not want to pay a hefty fee for a small project.

An alternative to commercial modeling packages is the use of MS Excel spreadsheets. This method of developing models has long been discussed by experts (Seila, 2006). There is a well-known group of commercial products that use MS Excel as a basis and are designed for risk assessment using the Monte Carlo method (Schriber, 2009). The most common packages are @RISK, Crystal Ball, Risk Analyzer and ModelRisk. There are works that use spreadsheets to model supply chains (Sezen et al., 2007; George et al., 2014).

The fundamental question is whether the VBA programming language is used when developing a model in an MS Excel environment. Working with analytical models using the Monte Carlo method, one can often use only formulas, since these models are static, that is, they do not reflect the development of the process in time. Models of some simple inventory management systems in the form of dynamic models can also be created without the use of VBA. The evolution of the process in time in such models is displayed in the form of a table, in which each row corresponds to one step Δt of the model time. In the case of using the VBA language, almost all restrictions

on the complexity of the model are removed, but the model in this case does not qualify as "spreadsheet simulation", since the spreadsheet itself is used only as worksheets for data input and output.

The following section describes the experience of creating a simulation model, in which exactly the last of the above methods of applying a spreadsheet is used. The model of the transshipment process of oil products at the seaport terminal is implemented using the VBA language in the MS Excel environment. In the table showing the dynamics of the modeled process, each row corresponds to one day of the real process, and this row shows data on the state of all elements of the modeled system at the end of the current day.

Results and Discussion

Conceptual model of the transshipment process of oil products at the port

Exactly once a month a tank ship comes to the port with 20,000 tons of product on board. The ultimate goal of transshipment is to ship the entire product volume using rail tank cars. One wagon has a capacity of 65 tons, so 308 wagons are required to ship the entire volume of the product. In practice, in this port, on average, 308 wagons are loaded. If it is possible to form a complete railway train, then it consists of 50 wagons, which can accommodate 3250 tons of product. If on some day it is not possible to form a full railway train, then 5-20 wagons can be sent on that day. A special feature of the oil terminal is the presence of storage tanks, into which the product is loaded when there are no empty wagons. The temporary storage of the product is carried out in these tanks, after which the product is loaded into the wagons. Figure 1 shows a material flow diagram corresponding to the process described above.

More complex is the process diagram demonstrated in Figure 2, which shows six operations (processes) and four storages. The first gateway of the "parallel" type indicates that the vessel can be unloaded both in the direction "tank ship → tank cars" and "tank ship → storage tanks". Simultaneously, the main direction of transshipment of the product is the direction "tank ship → tank cars", and the speed of transportation of the product from the vessel is about 200 tons per hour. At this speed, the ship is unloaded in 100 hours, that is, in 4.17 days of continuous operation. The second and third gateways of the "parallel" type indicate that in the presence of empty wagons, transshipment can be carried out both in the direction of "tank ship → tank cars" and "storage tanks → tank cars".
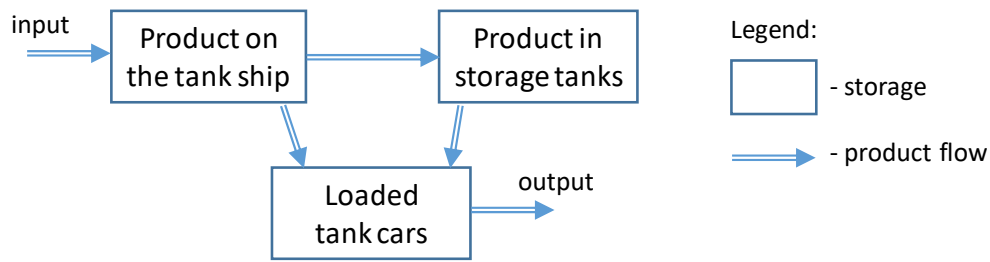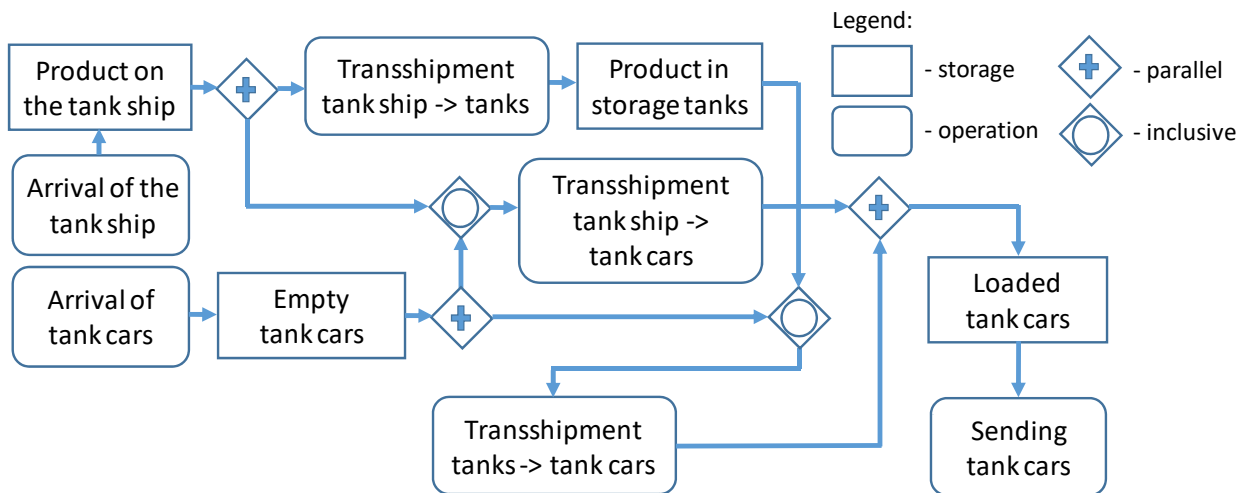
Figure 1 – Material flow diagram

Figure 2 – Process flow diagram

The main problems in the terminal's operation are related to the process of receiving empty wagons. If there are few such wagons during the unloading time of the vessel, then there will be an excess idle time of the vessel. The standard anchorage time of the vessel is 5 days, and for each day in excess of the standard day, the owner of the cargo must pay 20,000 euro. With a large number of wagons that are awaiting the arrival of the ship or cannot be dispatched from the terminal for other reasons, the fee for the time spent by the wagons on the terminal territory increases. If the duration of the arrival process of all 308 cars exceeds 30 days, costs will rise due to the excess time of using the storage tanks.

Additional features of the processes of arrival and departure of wagons are as follows:

• empty wagons arrive at the terminal in a random manner in groups of 5-20 wagons;

• the first 200 wagons, i. e. 13,000 tons of product, are usually shipped using four trains of 50 wagons, and the remaining 108 wagons in groups of 5-20 wagons per day;

• no more than one train with a product quantity of 3250 tons is loaded per day;

• if continuous loading of the first four trains is not ensured, then a situation may arise when, due to the lack of free capacity in the tanks, the process of unloading the vessel is interrupted.

The cargo owner knows the scheduled date of arrival of the vessel. Proceeding from this, he or she orders from the railway the first day of the arrival of empty wagons. At the same time, the cargo owner tries to take into account the risks associated with the uncertainty of the process of receiving empty wagons. The ideal option for him is when at least 50 wagons per day will be available in the first four days of unloading the ship, but he or she cannot order wagons "much in advance" because of the increased payment for the time spent by the wagons at the terminal.

The main goal of building a simulation model is to give the cargo owner the opportunity to estimate the costs arising from the implementation of various hypotheses describing the random processes of

the arrival of empty wagons on the territory of the terminal. It is also assumed that, on the basis of such estimates, he or she will be able to form requirements for the railway, containing quite definite restrictions on the random process of the arrival of cars at the terminal.

Description of the arrival process of tank cars using randomized parameters

Figure 3 shows a graphical model of the process of arriving empty cars at the terminal, during the development of which it was assumed that the user could set the minimum and maximum values for three random parameters that determine the process of arriving empty wagons:

• the time that will elapse from the arrival of the first batch of wagons until the arrival of the vessel;

• the duration of the arrival process of the first 200 wagons;

• the duration of the arrival process of the remaining 108 wagons.

The lines at levels 1 and 2 demonstrate two options for the start of the arrival of the first 200 wagons, which are especially important for the cargo owner. For each of these options, two options for the end of the arrival of wagons are marked, assuming that the arrival of 200 wagons can last 10 or 12 days. Four lines numbered from 3 to 6 show the options for the arrival of the remaining 108 cars, while they start at four points on the time axis, which correspond to the moments of the end of the arrival of the first 200 cars. It is assumed that the arrival of 108 wagons can take from 12 to 14 days. Thus, Figure 3 as an example shows two options for the start of the arrival of wagons 10 and 7 days before the arrival of the vessel and eight options for the possible end of the arrival of all 308 wagons. All this information taken together is one of the possible scenarios for the arrival of empty cars at the terminal. The developed simulation model offers the user a means to describe and investigate such scenarios.
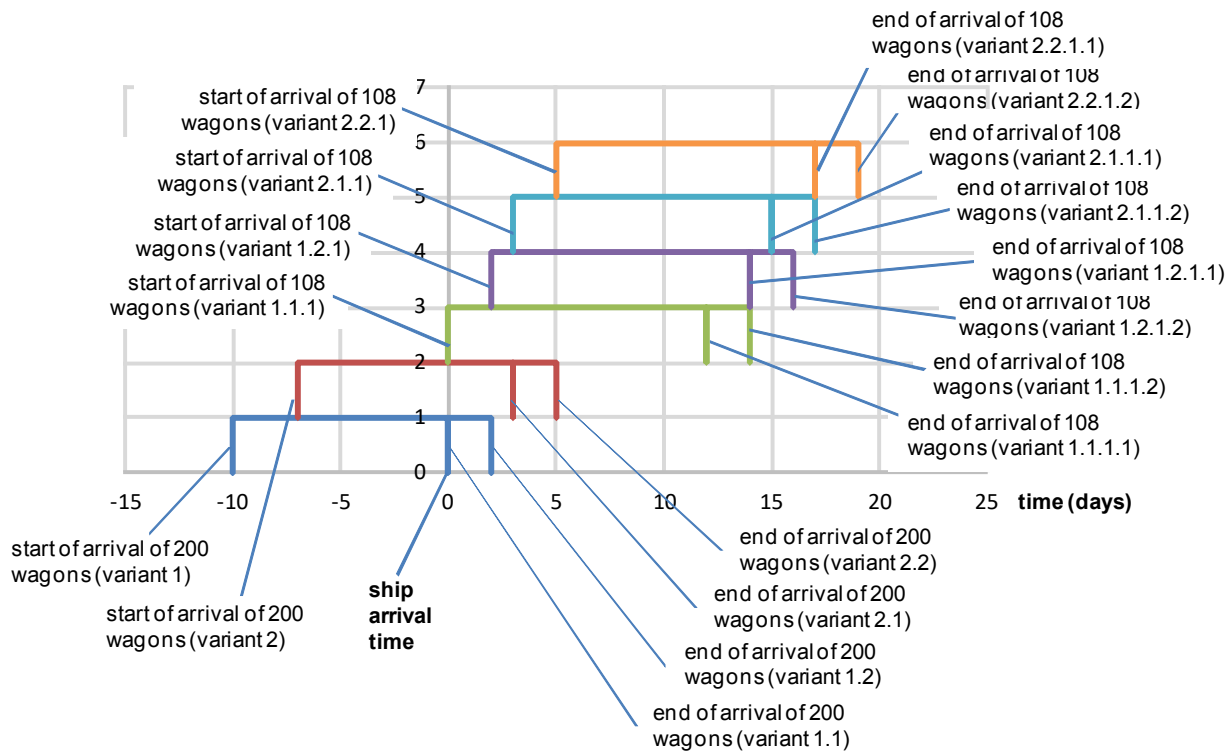
Figure 3 – A scenario of the empty tank cars arrival process at the terminal

In the developed model, all moments of time and duration of processes are played out as random variables with given distribution laws. The time points shown in Figure 3 are examples of input data that are used as boundary values when assigning distribution laws for the above three random input parameters of the model.

When choosing a distribution law, the user is offered graphs of the distribution density of distribution laws well known from probability theory

(see Figure 4). The numerical values of the argument in these graphs do not matter, since they only illustrate the shape of the distribution density. A feature of the method for describing a specific distribution is the refusal to specify the usual distribution parameters, for example, the mathematical expectation and standard deviation for a normal distribution. When describing each random input parameter of the model, the user sets three values:

- *bottom* – the minimum value of the parameter (lower limit);
- *upper* – the maximum value of the parameter (upper bound);
- *distr* – number of the distribution law (number from 1 to 7; number 1 means using a constant).

For example, in case *bottom* – 7, *upper* – 10 and *distr* = 2, the generator will produce uniformly distributed integers in the range [7; 10]. In the case of *bottom* – 10, *upper* – 14 and *distr* – 3, the integers will correspond approximately to a normal distribution with mean equal to 12.

This method of setting random parameters of the model is a direct support for the user, whose task is to study how the mode of arrival of cars at the terminal affects the indicators of costs during product transshipment. Also, when formulating the requirements for the railway, the terms "no earlier than" and "no later than" should be used, which correspond to the boundary values of the specified time intervals. Figure 5 shows an example of a table for inputting initial data, in which the numerical values of the parameters correspond to the scenario of the arrival of cars shown in Figure 3.
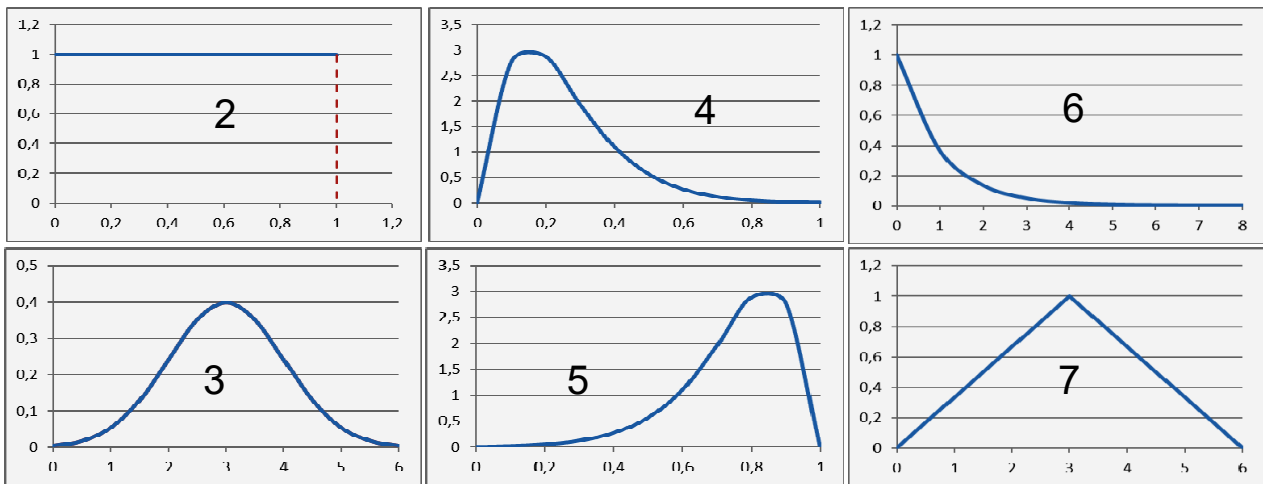

Figure 4 – Distribution laws used when entering initial data

Random parameters					
Parameter number	Parameter	Unit of measure-ments	Bottom bound	Upper bound	Distribution law type
1	time from the arrival of the 1st batch of wagons to the arrival of the ship	days	7	10	2
2	duration of the arrival process of the first 200 wagons	days	10	12	2
3	duration of the arrival process of the remaining 108 wagons	days	10	14	2

Figure 5 – Table for entering the initial data of the process scenario

Analysis of the primary simulation results

The primary simulation results are the data that the model shows at the end of one run. In the model under consideration, the run corresponds to the process of unloading one vessel. During the run, all events and processes that are described in the above conceptual model are modeled:

• the accumulation of empty wagons before the arrival of the vessel and the arrival of the remaining wagons after the arrival of the vessel;

• arrival of the vessel;

• unloading of the vessel and transshipment of the product in the directions "tank ship → tank cars" and "tank ship → storage tanks";

• transshipment of the product in the direction of "storage tanks → tank cars";

• formation and dispatch of complete trains of 50 cars and groups of 5-20 cars.

The model uses a fixed time step $\Delta t = 1$ day. The basic principle of the model is that for each time step, the values of the internal variables of the model are calculated, each of which corresponds to a column in the table shown in Figure 6. Each row of the table corresponds to one day of the terminal's operation, while the data in a row of the table reflects a situation that piled up at the terminal at the end of the simulated day.

Model run

Day number	Wagons arrived per day	Wagons arrived total	Wagons sent per day	Wagons sent total	Remaining wagons at the terminal	Product quantity on the vessel (tons)	Product quantity in storage tanks (tons)	Product quantity in wagons (tons)	Product quantity sent per day (tons)	Product quantity sent total (tons)
1	25	25	0	0	25	0	0	0	0	0
2	19	44	0	0	44	0	0	0	0	0
3	17	61	0	0	61	0	0	0	0	0
4	19	80	0	0	80	0	0	0	0	0
5	13	93	0	0	93	0	0	0	0	0
6	21	114	0	0	114	0	0	0	0	0
7	18	132	0	0	132	0	0	0	0	0
8	22	154	0	0	154	20020	0	0	0	0
9	26	180	50	50	130	15220	0	4800	3250	3250
10	16	196	50	100	96	10420	0	9600	3250	6500
11	4	200	50	150	50	5620	1400	13000	3250	9750
12	8	208	50	200	8	820	5680	13520	3250	13000
13	6	214	14	214	0	0	6110	13910	910	13910
14	10	224	10	224	0	0	5460	14560	650	14560
15	7	231	7	231	0	0	5005	15015	455	15015
16	11	242	11	242	0	0	4290	15730	715	15730
17	8	250	8	250	0	0	3770	16250	520	16250
18	14	264	14	264	0	0	2860	17160	910	17160
19	10	274	10	274	0	0	2210	17810	650	17810
20	7	281	7	281	0	0	1755	18265	455	18265
21	12	293	12	293	0	0	975	19045	780	19045
22	13	306	13	306	0	0	130	19890	845	19890
23	2	308	2	308	0	0	0	20020	130	20020

Figure 6 – Primary model run results

Figures 6 and 7 show the results of one of the random runs of the model. The terminal operation lasted 23 days. Figures 7a and 7b show that the first 25 wagons arrived at the terminal 7 days before the arrival of the ship. The ship arrived on day = 8, since it was on this day that 20,020 tons of product on the ship appeared in the table. On the day of the ship's arrival, the number of wagons was 154. On day = 9, the unloading of the ship and the dispatch of wagons began. On days with numbers 9, 10, 11 and 12, 50 wagons were sent from the terminal. In recent days, starting from day = 14, the schedules of arriving and departing cars merge, since as many cars are sent per day as were received. For this reason, Figure 7b shows the number of wagons for this time period as 0, as this chart shows the number of wagons remaining in the terminal at the end of the day. Figure 7c shows the dynamics of product inventories on board and in tanks. It can be seen that the amount of product in the tanks peaked at 6,110 tons in day = 13. The "Product sent" graph shows the total quantity of product sent from the terminal area. The main sign of the error-free operation of the model is the fact that this quantity reaches the value of 20,020 tons, that

is, the amount that was delivered to the terminal on the ship. This check is one of the points of the model verification procedure.

Based on the data demonstrated in Figure 6, all the cost indicators described in the conceptual model are calculated at the end of each simulation run. The most important indicators are the payment for the excess delay of the vessel in the port and for the time spent by the wagons on the territory of the terminal. Since the excess vessel delay is an exceedingly rare event in all considered scenarios, during the experiments with the model, only the probability of this event was estimated. In the following, the application of the statistical modeling method to study the second of the two main indicators is described: payments for the time spent by cars on the territory of the terminal.
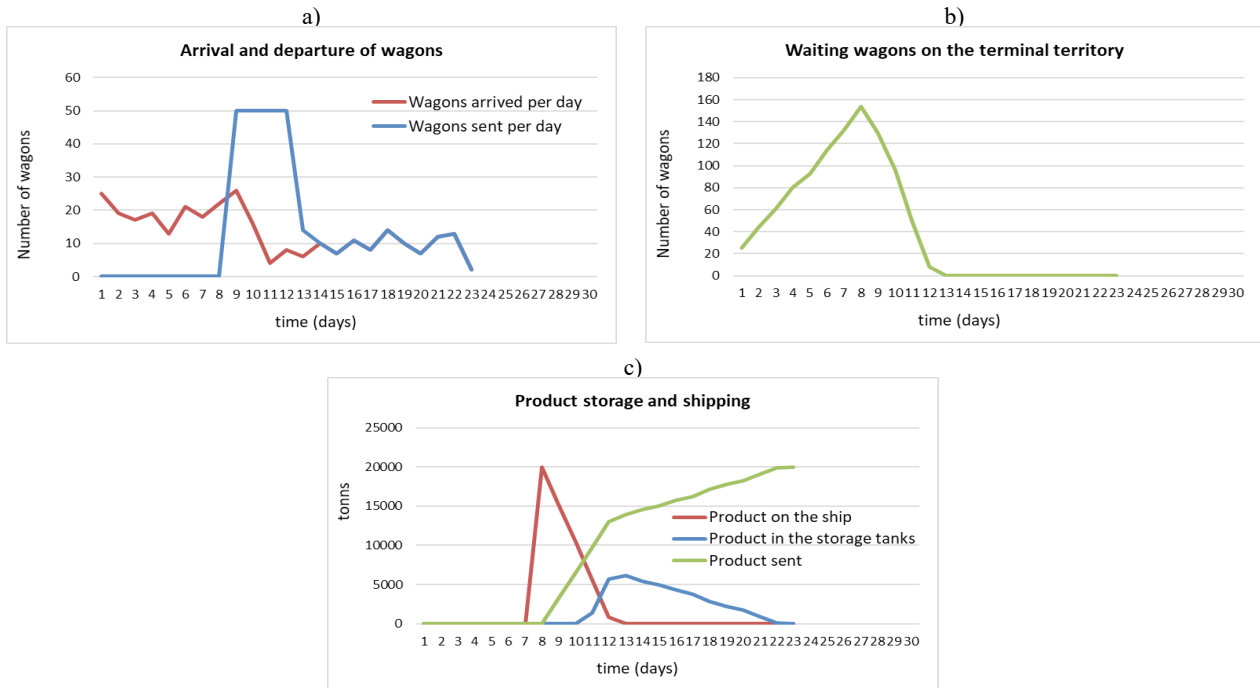
a)

b)

c)

Figure 7 – Process diagrams in a single scenario model

Analysis of the results of statistical modeling of five scenarios

The scenario described in Figure 3 is referred to as Scenario 1. The results of one run of this scenario are shown in Figure 6. Since each implementation of the scenario shown in Figure 6 is a non-stationary random process with a limited duration, to obtain stable statistical results, run each the script was repeated 100 times. Figure 8 shows a histogram of the distribution of the "Tank cars demurrage fees" indicator for Scenario 1, obtained from 100 model runs. This histogram corresponds to a mean of €13,126 and a standard deviation of €2,281. From the data of the histogram, it follows that the possible values of the indicator lie in the range from €8,000 to €19,000.

The developed model was applied to study five scenarios, the initial data of which are shown in Figure 9. In accordance with the table shown in Figure 5, the boundaries of variation of three model parameters are introduced for each scenario. In the described experiment, only a uniform distribution law was applied for all three parameters, therefore the "Distribution law type" column is not shown in the table in Figure 9.
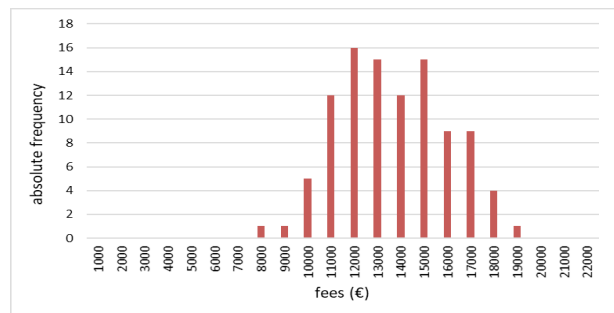
Figure 8 – Histogram of the distribution of the "Tank cars demurrage fees" indicator

Parameter number	Unit of measure-ments	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
		Bottom bound	Upper bound	Bottom bound	Upper bound	Bottom bound	Upper bound	Bottom bound	Upper bound	Bottom bound	Upper bound
1	days	7	10	5	8	6	9	5	8	3	6
2	days	10	12	10	12	10	12	10	12	10	12
3	days	10	14	10	14	10	14	8	12	10	14

Figure 9 – Simulation experiment plan

Each of the scenarios shown in Figure 9 was simulated 100 times. Figure 10 shows the statistical characteristics of the simulation results, for the graphical presentation of which a Box Plot is used.
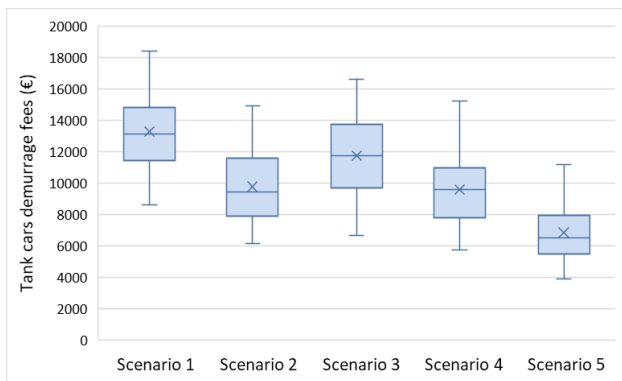

Figure 10 – Results of modeling five scenarios of the wagons arrival process

The data of the diagram shown in Figure 10 indicates that if the conditions of Scenario 5 are met for the process of receiving empty wagons, the smallest amount of costs such as "Tank cars demurrage fees" should be expected. The probability of an excess of the vessel's delay in this scenario is zero. This means that the owner of the cargo must formulate the following requirements addressed to the partner on the railway:

• the first batch of wagons should start arriving at the terminal not earlier than 6, and not later than 3 days before the arrival of the vessel;

• the duration of the process of arrival of the first 200 wagons should be within the range of 10 to 12 days;

• the duration of the remaining 108 wagons' arrival process should be within the range of 10 to 14 days.

The assumption remains that the number of tank cars arriving at the terminal will be a random variable during the day. It is also known that the railway will not be able to withstand any exact schedule for the arrival of wagons; therefore, it makes no sense to calculate such a schedule in a deterministic form. However, the risk of additional costs for the cargo owner will be significantly reduced if the railway meets the non-stringent boundary conditions formulated above.

Conclusions

In this study, all stages of a simulation study are presented, in which statistical modeling methods are applied. The stage of conceptual modeling, the stage of data preparation using distributions of random variables, and conducting experiments with the model are described in detail. The main result of this research is not the numerical results of modeling, which turned out to be very useful for the cargo owner, but the proof of the possibility of effectively using the VBA language in MS Excel as a tool for developing models.

This stage of the model development is practically not described in this paper since its content is elementary programming, in which the "If...Then...Else" statement is the "most difficult". The author expresses confidence that such models can be reproduced by any specialist who knows the technology and economics of the system under study, has logical thinking and can write macros for MS Excel. Of course, the modeler must clearly understand the difference between continuous process models that use the Δt step to display time in the model and discrete event simulation (DES) models. In cases where it is necessary to develop a detailed process model using DES principles, the customer should find the opportunity to use one of the commercial simulation packages. In cases where the accuracy is sufficient to ensure that adequate results are obtained for each day of the process under study, the VBA language in MS Excel is a full-fledged alternative in relation to professional simulation tools.

References

AnyLogistix supply chain software https://www.anylogistix.com/resources/white-papers/ (accessed March 10, 2021)

Borshchev A. (2013) Multi-Method Modeling. Proceedings of the 2013 Winter Simulation Conference, pp. 4089-4100.

Campuzano F., Mula J. (2011) Supply Chain Simulation: A System Dynamics Approach for Improving Performance. Springer.

Carotenuto P., Giordani S., Zaccaro A. (2014) A Simulation Based Approach for Evaluating the Impact of Maritime Transport on the Inventory Levels of an Oil Supply Chain. 17th Meeting of the EURO Working Group on Transportation, EWGT2014, Elsevier, pp. 710-719.

Chwif L., Barretto M. R. P., Saliby E. (2002) Supply Chain Analysis: Spreadsheet or Simulation? Proceedings of the 2002 Winter Simulation Conference, pp. 59-66.

George J., Pillai V. M. (2014) Supply Chain Performance Evaluation Using Spreadsheet Simulation. Applied Mechanics and Materials, 592-594, pp. 2699-2703.

Hicks D. A. (1999) A Four Step Approach for Integrating Simulation and Optimization Technologies to Solve Strategic Supply Chain Planning Problems. Proceedings of the 1999 Winter Simulation Conference, pp. 1215-1220.

Lee L. H., Chew E. P., Jiang X., Zhou C. (2014) A Simulation Study for Next Generation Transshipment Port. Proceedings of the 2014 Winter Simulation Conference, pp. 1831-1842.

Pérez-Lespier L. (2013) Examining the efficiency of multimodal transportation systems: a systems dynamics approach. Masters Theses. Missouri University of Science and Technology.

Roşca E., Raicu Ş., Roşca M. A., Burciu Ş. (2013) Transshipment Modeling and Simulation of Container Port Terminals. Advanced Materials Research (Volume 837), pp. 786-791.

Schriber T. J. (2009) Simulation for the Masses: Spreadsheet-Based Monte Carlo Simulation. Proceedings of the 2009 Winter Simulation Conference, pp. 1-11.

Seila A. F. (2006) Spreadsheet simulation. Proceedings of the 2006 Winter Simulation Conference, pp. 11-18.

Sezen B., KitapÇi H. (2007) Spreadsheet simulation for the supply chain inventory problem. Production Planning & Control, 18:1, pp. 9-15.

Widjaja L., Tsai C.-F. (2019) Discrete Event Simulation for Oil Transshipment Facility. Ports 2019: Port Planning and Development, pp. 489-499.

Zarzuelo I. d. l. P., Freire-Seoane M. J., Bermúdez B. L., Montes C. P. (2019) The role of simulation in the Ports and Maritime Industry: Practical experiences and outlook for the new generation of Ports 4.0. An International Research Conference on Maritime Affairs.