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# CONSTRUCTION OF A SIMULATION MODEL FOR THE TRANSPORTATION OF PERISHABLE GOODS ALONG VARIABLE ROUTES

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***The object of research is the system of organization of transportation of perishable goods. The study subject is the technological process of transportation of perishable goods by small shipments. The problem solved was a multicriteria optimization of the technological process of delivery of perishable goods by small shipments. The results are the built simulation model for the distribution of small consignments of perishable goods and the optimization according to the criterion of minimizing delivery time while limiting the rational use of available vehicles. To construct a simulation model, discrete-event and agent-based principles were used.***

***The model built combines the solution to the transport problem and the traveling salesman problem simultaneously with taking into account the stochastic duration of technological operations. When forming the distribution route, the model algorithm takes into account the minimum allowable batch size to the i-th destination, which allows each time to build a new unique route of the vehicle.***

***Unlike existing ones, the model constructed allows taking into account the peculiarities of the distribution network, the minimum consignment of cargo, and dynamically changing the route in accordance with the available cargo. Each time the cargo mass arrives at the logistics terminal, the condition of a sufficient quantity of goods intended for delivery to points of sale is checked. If the quantity of cargo sufficient for shipment is equal to the capacity of the car body, a new information message is generated on the availability of goods ready for shipment.***

***Scope and conditions of practical use of the obtained results include transport companies, retail chains, distribution logistics***

***Keywords: perishable goods, minimum batch, small shipments, simulation modeling, discrete-event modeling, agent-based modeling***

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## 1. Introduction

Perishable products are products that under normal conditions lose their quality properties, and therefore require special transportation conditions. Unlike conventional goods, perishable products have a much shorter shelf life and sale. Therefore, the time for transportation and storage should be minimized and the organization of delivery requires special attention. The organization of the supply system of such a product as frozen fish requires a special approach to the choice of places and means for transportation, as well as maintaining the shortest transit time to preserve the longest consumer shelf life [1]. Perishable cargo has features, it loses its qualities after a limited period of time under the influence of environmental conditions and requires compliance with special conditions of transportation and storage. Therefore, the process of mathematical modeling is very time consuming, and the complex processes of delivery of products in the fishing industry has many fluctuations in the formation of pariahs of dispatch and the distance between destinations. Simulation is increasingly used to build models in logistics. The process of delivery of small shipments of perishable goods includes time for route development, minimum order volume, cargo capacity of vehicles, distances between delivery points, and conditions of transportation of perishable goods. The simulation process could accurately describe events in the sequence that occur in real time. Therefore, research into construction of the model is relevant. Simulation minimizes the level of abstraction. At the same time, a systematic approach is applied in full. Consequently, simulation modeling provides a more detailed analysis of the transport and technological system under different conditions.

## 2. Literature review and problem statement

In [2], a simulation model of a multi-element grain supply chain by rail-water route is given. The model optimizes the fleet of vehicles, temporary storage capacities, and the technological process of their delivery. At the same time, the model does not take into account the peculiarities of delivery of packaged and perishable goods.

Papers [3, 4] investigate queuing systems using computer simulation but in the cited works the problems of network planning were not studied. In [5], analytical tools of queuing theory determined the parameters of critical infrastructure maintenance. In [6], analytical methods did not make it possible to fully appreciate the efficiency of using the fleet of vehicles, their number, and capacity with respect to the reliability of traffic schedule.

In [7], a multipurpose conceptual simulation model for optimizing cost, environmental impact, quality, and safety of perishable goods transportation is considered, but transportation costs are not taken into account. Study [8] solved the traveling salesman problem to determine the initial order of visits to retailers, and then solved a limited model that in practice does not take into account many criteria. In [9], a combination of improved Clark-Wright saving algorithm with cuckoo algorithm for simultaneous solution of inventory and routing segments is proposed. The authors of work [10] examine the logistics chain of perishable goods but conclude that logistics processes should be customized individually to this group of goods. In [11], a feedback supply chain management strategy was introduced, which takes into account fluctuations in consumer demand and deterioration in product quality, which is important for the transportation of perishable goods. The results of study [12] were the development of an integrated location model, inventory, and routing of perishable products in an emerging market.

Study [13] presents a model of routing the production of perishable products with uncertain demand. The production routing problem model for a perishable product with a short shelf life was built to optimize the total costs of lost products, stale produce, production, inventory, and routing. The proposed model is compared for normal and pandemic conditions. Work [14] focuses on solving the issue of functioning of logistics distribution channels in food retail at the «last mile» stage. The contribution of these studies is to design a toolkit to explore the sustainability potential of logistics and last-mile distribution strategies while assessing the impact of future dynamic changes on the example of local food networks, but these developments are more related to e-commerce.

The results of smart logistics technologies [15] can be used in the organization of multimodal cargo delivery and supply chain risk management but these technologies are not used in practice of small retail chains within the country. In [16, 17], methods for estimating the cost of servicing consumers when transporting small perishable goods in urban areas are proposed. Also, the parameters of the choice of rational brand and carrying capacity of the truck depending on the number of delivery points in conditions of constant change of requirements are considered in work [18]. The regression model built is proposed to be used by carriers when organizing transportation of small consignments of goods in cities but the optimal consignment for transportation is not taken into account.

Work [19] focuses on cold supply chains and current problems of determining the optimal schemes for importing frozen fish and seafood. It is noted that the organization of the supply system of such a product as frozen fish requires a special approach to the choice of places and means for transportation, but fluctuations in the demand of these products are not taken into account.

The purpose of work [20] was to find the most efficient routes for several delivery vehicles with the same capacity if the demand at each point was fully satisfied by one vehicle, but the calculation does not take into account when demand fluctuates constantly. The use of information technology in logistics systems in [21] the use of information technology in logistics systems is aimed at interaction between enterprises in the process of supply and marketing of goods. A further direction of research may be the construction of an integrated logistics system. In work [22], the logistics company solves the problem of operational planning: during the working day to ensure the supply of cold products from distribution centers to end consumers along clearly defined routes but the schedule of the logistics network is fixed and does not take into account fluctuations.

In [23], an agent-based modeling method was used, which allows analyzing the work of agents and determining the behavior of the entire production system. This approach provides a systematic approach and is used to optimize warehouse processes. Analysis of work [24] shows that the developed models will allow for forecasting cargo flows in the city but do not take into account intercity transportation and transportation of perishable goods.

All this suggests that there are not enough studies that consider the technological process of transportation of perishable goods by small shipments, and no study considers the stochastic nature of the incoming flow of orders when forming a batch of shipments. The problem arises due to the requirement of trade establishments to order the supply of products in very small shipments, in sizes from 50 to 250 kg. Therefore, stochastic demand can lead to unscheduled loads on the transport and technological system. Moreover, none of the previous studies took into account the possible variability of distribution routes due to insufficient cargo for individual destinations. Therefore, it would be advisable to construct a mathematical (simulation) model that could take into account the above requirements.

## 3. The aim and objectives of the study

The aim of this study is to identify patterns between the stochastic input flow of perishable goods and the time of their delivery to the end user. The solution to this problem will optimize the parameters of the transport and technological process of delivery of perishable goods under conditions of their uneven receipt and variability in the organization of distribution routes.

To accomplish the aim, the following tasks have been set:

– to build a mathematical model for the distribution of small consignments of perishable goods, which would take into account the minimum batch volume and variability of delivery routes, the number and cargo capacity of vehicles, the distance between delivery points;

– to carry out experimental optimization of the parameters of the distribution route of small consignments of perishable goods.

## 4. The study materials and methods

The object of our research is the transportation of perishable goods on delivery routes. The research hypothesis assumes that the constructed mathematical model will optimize the storage time at the logistics terminal and the time of transportation of perishable products, provided that the existing rolling stock is optimally used.

The study was performed using:

– agent-based and discrete-event computer simulation using the specialized development environment AnyLogic University Researcher (with a Java compiler) – to simulate the technological process of accumulating cargo mass and delivering goods to points of sale;

– methods of probability theory and mathematical statistics for the analysis of initial data and experimental results;

– methods of algorithm theory – for the construction of a simulation model;

– system factor analysis – to determine causal relationships in the technological process of cargo distribution.

## 5. Results of investigating regularities between the stochastic input flow of perishable goods and the time of their delivery to the end user

### 5. 1. Construction of a mathematical model for the distribution of small batches of perishable goods

The distribution route of small consignments of perishable goods refers to the tasks of distribution logistics and the so-called «last mile» problem.

It is established that in the field of retail it is necessary to pay attention to the last link – the «last mile», due to the significant cost of delivery at this stage. The study of the problems of formation of delivery systems for small batches of perishable goods in the logistics system of the retail trade network under the conditions of intercity transportation made it possible to reveal that the existing approaches differ in the depth of reflection of processes and efficiency criteria. The optimal plan for organizing the work of the fleet is based on two mathematical problems:

– transportation problem – as an optimal plan for coordinating cargo flows between points of departure and destination of goods;

– «traveling salesman's task» – as the optimal (according to the chosen criterion of distance or delivery time) route of a truck between points of the route.

At the same time, the combination of two analytical tools, from a mathematical point of view, is quite difficult to use in research and experiments.

Formally, the delivery time is considered as the average storage time at the logistics terminal and the delivery time from the terminal to the final destination. The optimization criteria are the minimization of delivery time (1) with restrictions on the rational use of existing vehicles (2):

$$\overline{t_{st}} + \overline{t_{del}} = \left( \begin{array}{l} f\left(N_{time}, k_{ass}, n_{\min}\right) + \\ f\left(N_{time}, k_{ass}, m_{truck}, n_{cap}, n_{\min}\right) \end{array} \right) \to opt, \tag{1}$$

$$\begin{cases} \xi_l \le f\left(m_{truck}\right) \le \xi_{up}, \\ m_{truck} = 1,\ 2,\ \dots\ M, \\ n_{cap} > \xi_{q.cap}, \end{cases} \tag{2}$$

where $t_{st}$ is the average storage time of cargo in the logistics terminal; $t_{del}$ – average time of cargo delivery from the logistics terminal to the final destination; $f(N_{time}, k_{ass}, n_{\min})$ – a function that will determine the average time of cargo storage in the logistics terminal; $f(N_{time}, k_{ass}, m_{truck}, n_{cap}, n_{\min})$ – a function that will determine the average time of cargo delivery from the logistics terminal to the final destination; $N_{time}$ – average daily cargo receipt to the distribution logistics terminal; $k_{ass}$ – number of assignments of cargo delivery; $n_{cap}$ – capacity of vehicles; $n_{\min}$ – the minimum possible consignment that can be sent to the point of sale; $m_{truck}$ – the number of trucks, which is an integral parameter of the set $M$; $\xi_l$ – average load of the car fleet, which will determine the lower limit of rational use of cars; $\xi_{up}$ – average load of the fleet of cars, which will determine the upper limit of reliability in the use of the fleet of cars; $\xi_{q.cap}$ – the minimum possible quantity of cargo that can be sent to the destination point.

Since the objective functions $f(N_{time}, k_{ass}, n_{\min})$ – and $f(N_{time}, k_{ass}, m_{truck}, n_{cap}, n_{\min})$ are given in an implicit expression, an experimental simulation was used to solve the problem.

To build the simulation model, discrete-event and agent-based principles were used. The list of the main agents of the model and their functional purpose are as follows:

– agent *Main* is the main agent of the model, designed to combine all other agents in the overall functioning of the model, thereby ensuring consistency in the construction of the model. In addition, the *Main* agent contains information on the points (coordinates) of the logistics terminal and the network of destinations;

– *BusinessProcess* agent – the main agent for simulation of the technological process of distribution of products between the point of concentration of cargo (logistics terminal) and points of final sale (supermarket chain);

– population of *RetailPoint* agents – agents responsible for separate chains of the route of trucks in the network. This agent is responsible for the «infrastructure» subsystem of the model;

– population of *Lorry* agents – agents that simulate the following of trucks within the established infrastructure (populations of *RetailPoint* agents) and *Gis* – the coordinates of the map of the *Main* agent. This type of agent takes into account the parameters of the fleet of trucks: the number of cars, body capacity, speed in the city;

– population of *DispatchPlan* agents – agents that simulate the formation of a consignment note and route sheet of a truck following a certain route. This letter establishes the order in which *Lorry* agents follow within the established infrastructure (*RetailPoint* agent population) and *Gis* – the map coordinates of the *Main* agent. However, *DispatchPlan* agents include information on the volume of cargo assigned to each individual point and the order of placement of points on the route;

– agent population *DispatchPlan_Lorry* – a copy of *DispatchPlan* agents. Unlike *DispatchPlan* agents, agents of *DispatchPlan_Lorry* contain information for each individual use of the *Lorry* population agent. This type of agent simulates a specific route sheet for a specific route of the car;

– *Simulation* agent – an agent that simulates a model during the implementation of a basic experiment.

The total digram of agents, and their interactions, is shown in Fig. 1.

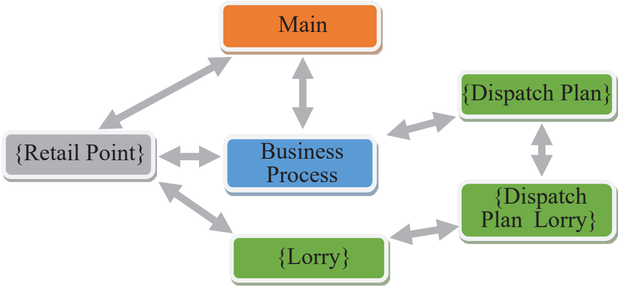


Fig. 1. Simulation model agent interaction diagram

For ease of use of source data arrays, a database formation tool is used. The data was taken from a retail chain that has 112 stores. 16 trade establishments of one service region (the city of Kyiv and Kyiv oblast) were selected as the most typical for this type of scientific and applied tasks. The main segments of the database are the parameters of destinations (supermarket chains), which are given in Table 1:

– sequence number of the destination (indicator *id_Number*);

– name of destination (indicator *RetailPoint_ID*);

– the annual volume of cargo for the reporting period to be delivered as planned (indicator *RetailPoint_Value*);

– coordinates of the destination location (indicators *GIS_X*, *GIS_Y*);

– percent of the total cargo to be delivered to the destination point (*PercentOfCargo* indicator).

Table 1

Base of initial data for the construction of a simulation model

| *id_Number* | *RetailPoint_ID* | *RetailPoint Value* | *PercentOfCargo* |
|---|---|---|---|
| 0 | Market_1 | 784 | 0.002694 |
| 1 | Market_2 | 35,751 | 0.122850 |
| 2 | Market_3 | 17,511 | 0.060172 |
| 3 | Market_4 | 24,262 | 0.083371 |
| 4 | Market_5 | 15,734 | 0.054066 |
| 5 | Market_6 | 9,270 | 0.031855 |
| 6 | Market_7 | 11,205 | 0.038504 |
| 7 | Market_8 | 8,826 | 0.030327 |
| 8 | Market_9 | 7,181 | 0.024674 |
| 9 | Market_10 | 17,415 | 0.059842 |
| 10 | Market_11 | 43,939 | 0.150985 |
| 11 | Market_12 | 8,235 | 0.028297 |
| 12 | Market_13 | 5,671 | 0.019487 |
| 13 | Market_14 | 23,110 | 0.079412 |
| 14 | Market_15 | 8,635 | 0.029673 |
| 15 | Market_16 | 53,485 | 0.183789 |

Agent *Main* is key for the construction of a simulation model since it is the basis for the interaction of all other agents (Fig. 2).

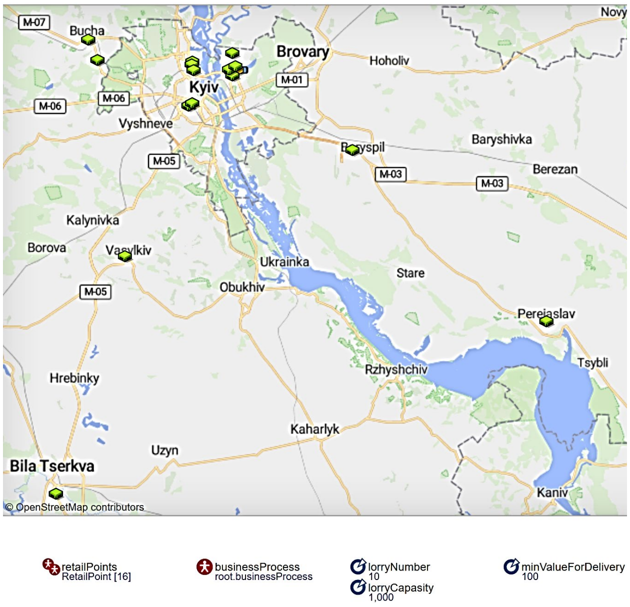
The key idea of devising a simulation model is to use *Gis* coordinates in real road maps, so the main element of the *Main* agent will be the *element Gis map*. The network of destinations is formed in the form of a population of agents *retailPoints*. In addition, the *businessProcess* agent and agent population parameters are added to the *Main* agent:

– *lorryNumber* is the estimated fleet (number) of trucks;

– *lorryCapasity* – estimated capacity (tons) of the truck body;

– *minValueForDelivery* – the minimum quantity of cargo to be sent to the destination point (tons).

Thanks to this planning, agent *Main* provides an opportunity to simulate the conditions for the formation of a transportation plan and supply route: the number and order of location of points on the route, the volume of cargo. In the future, this mechanism will optimize these parameters.



retailPoints RetailPoint [16]
businessProcess root.businessProcess
lorryNumber 10
lorryCapasity 1,000
minValueForDelivery 100

Fig. 2. General view of agent *Main* in the *AnyLogic* simulation model development environment

To simulate the chains of transportation routes, the process of moving cars between the points of the distribution route of small consignments of perishable goods, the duration of cargo operations (loading and unloading time), populations of relevant agents are provided (Fig. 3).

The number of *RetailPoint* population agents is equal to the number of destination chains (supermarket chains). For each *RetailPoint* population agent, there is a set of parameters for the corresponding delivery point:

– identification number (indicator *id_Number*);

– name of destination (indicator *RetailPoint_ID*);

– address of destination (indicator *RetailPoint_Name*);

– annual cargo volume for the reporting period to be delivered as planned (*RetailPointValue* indicator);

– coordinates of the destination location (indicators *GIS_X*, *GIS_Y*).

To simulate the movement of a truck between two points of the route, a discrete-event chain of operations is involved (Fig. 4):

– *enter* – agent enters the process. Simulates the departure of a truck from the previous point *i* of the route $r_{i\text{-}j}$ to point *j*;

– *moveTo* – following on the route from the previous to the next point of the route. Simulates the movement of the machine on the route chain $r_{i\text{-}j}$ from the previous point *i* to point *j*;

– *delay* – delay of the agent for a set time. In this embodiment, it simulates the time of truck operations at point *j* of the route;

– *exit* – the agent's exit into the process of the next supply chain.

To simulate the technological process of the distribution route of small batches of perishable goods, discrete-event diagrams of the process of forming cargo mass, forming freight shipments and turnover of trucks on delivery routes have been constructed.

All these processes are represented as a *Business Process* agent (Fig. 4).

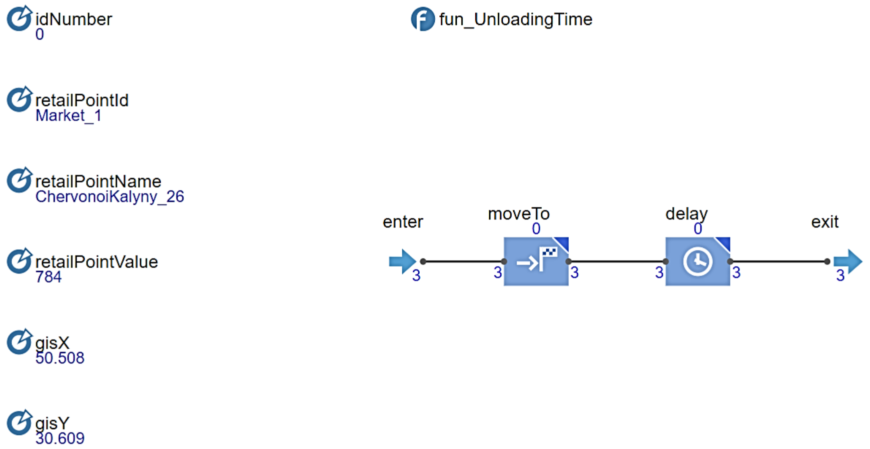


Fig. 3. Agent *RetailPoint* window

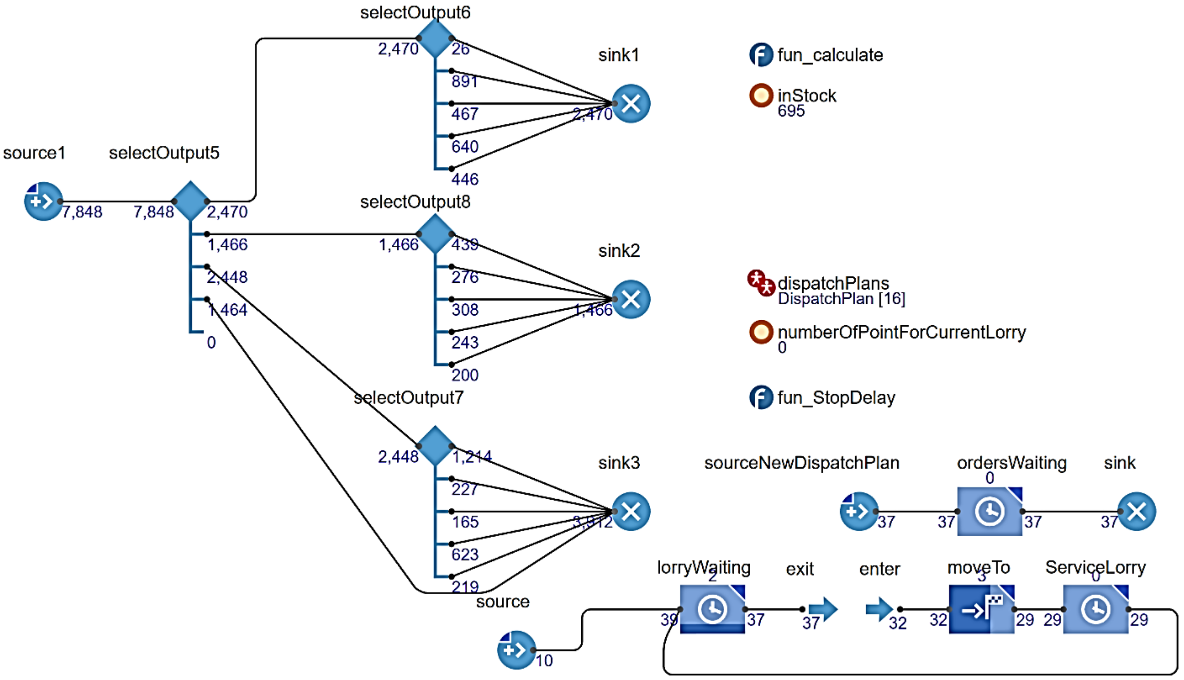


Fig. 4. Agent *Business Process* window

The key to this agent is three subprocesses:

1) accumulation of cargo mass for the formation of a new shipment to the trading network. It is carried out through the generation of requirements (block source1), where each requirement is one kilogram of commodity mass. Further, with the help of splitters (selectOutput blocks), the requirements are separated in accordance with the initial data on the receipt of cargo at destinations. The specified algorithm simulates the arrival of cargo in the logistics terminal and the formation of batches of cargo mass through the supermarket chain;

2) the process of forming an order and delivery route of small batches of perishable goods to points of sale (supermarket chains): discrete-event process «sourceNewDispatchPlan – ordersWaiting – sink». This process simulates the formation of an information message in case of accumulation of commodity mass to the norm of shipment;

3) truck turnover through process integration into the RetailPoint agent population: blocks «source – lorryWaiting – exit – {RetailPoint} – enter – moveTo – ServiceLorry».

This algorithm simulates following a route over the network along a unique route, which is developed each time according to new parameters.

Due to the certain complexity of the model and the lack of standard solutions in the AnyLogic environment special procedures were used to be able to implement the task.

When starting the model, Java-code is implemented, thanks to which the maximum volume of cargo in the truck body for each destination is set:

```
«for (int i=0; i < businessProcess.dispatchPlans.size();
i++){
businessProcess.dispatchPlans.get(i).
retailPointValueBig = businessProcess.dispatchPlans.
get(i).percentOfCargo * lorryCapasity;
}».
```

This algorithm implements the principle:

$$q_i = q_{truck} \cdot p_{t.i.}, \qquad (3)$$

where $q_i$ is the maximum cargo quantity for the *i*-th destination point in the groupage shipment batch, tons; $i$ – the number of destinations in the service network; $q_{truck}$ – technical standard of loading a truck, tons; $p_{t.i}$ – the share of the total volume over the network attributable to the *i*-th destination.

To calculate the conditions for forming a new order for organizing the distribution route of small consignments of perishable goods, an additional function *fun_calculate*() in the *Business Process* agent was used. The function is implemented for each receipt of requirements for blocks *sink* 1, *sink*2, *sink*3 (Fig. 4):

```
«inStock=0;
dispatchPlan="";
for (int i=0; i<dispatchPlans.size(); i++){
   inStock +=dispatchPlans.get(i).
retailPointActualValue;
}
boolean marker=true;
if ( inStock >=main.lorryCapasity){
   for (int i=0; i<dispatchPlans.size(); i++){
            dispatchPlans.get(i).readyToShip=false;
if (dispatchPlans.get(i).retailPointActualValue
>=hPlans.get(i).percentOfCargo * main.lorryCapasity &&
dispatchPlans.get(i).retailPointActualValue >=main.
minValueForDelivery){
                  dispatchPlans.get(i).
readyToShip=true;
                  if (marker){
                     sourceNewDispatchPlan.inject(1);
                     marker=false;
                  }
            }
}
}».
```

In this algorithm, for each receipt of cargo mass to the logistics terminal, the condition of a sufficient quantity of goods intended for delivery to points of sale is checked. If the quantity of cargo is sufficient for shipment (equal to the capacity of the car body), a new information message is generated on the availability of the goods ready for shipment («sourceNewDispatchPlan.inject(1);»).

During the experiments, data arrays of the following indicators were collected:

1) the time of stay of consignments at the logistics distribution terminal, as the difference between the moments of the model time of cargo departure from the terminal and the moment of time of cargo arrival at the terminal:

$$t_{log.term} = t_{dep} - t_{arr}, \tag{4}$$

where $t_{dep}$ is the moment of time of departure of the consignment from the terminal; $t_{arr}$ – the moment of arrival of the consignment to the terminal.

This indicator is formed when accumulating data to an element of type Histogram Data in the *BusinessProcess* agent:

```
«dataTimeInStock.add(time()–agent.timeIn);»;
```

2) the time of stay of consignments during transportation by cars, as the difference between the moments of delivery time to the final destination and departure of cargo from the terminal:

$$t_{del} = t_{del.ass} - t_{dep}, \tag{5}$$

where $t_{del.ass}$ is the moment of time of arrival of the goods to the destination.

This indicator is also formed for elements of the Histogram Data type when organizing the distribution of goods in the *BusinessProcess* agent:

```
«dataTimeTurnWorking.add(time()–agent.timeStart);»;
```

3) the average loading time of vehicles of the working fleet is defined as the proportion of vehicle engagement (taking into account downtime) relative to the total model time;

4) the average level of capacity utilization of the car;

5) the average number of delivery points on each route.

When accumulating to the norm of vehicle loading, the algorithm builds a unique delivery route that takes into account only those points for which there is the required amount of cargo. If there is a free vehicle, loading and dispatch along the route is carried out. In the absence of a vehicle, the party waits for the car to be released and loaded.

To build a mathematical model, the data are obtained from the trading network, which is represented by 112 trade establishments in 33 cities of Ukraine. The sample size was more than 2500 shipments. The structure of cargo flow, its dynamics, parameters of delivery routes and departures were studied. The following data sets were taken (Table 1):

– annual intensity of cargo receipt and its distribution across the trading network;

– minimum batch volume for shipment and variability of delivery routes;

– number and cargo capacity of vehicles;

– distance between delivery points, coordinates of geolocations of the temporary storage point and end points of implementation.

Set up your experiment and collect statistics. To be able to analyze the results of experiments, a mechanism is employed for collecting and systematizing data on:

– arithmetic mean;

– maximum and minimum values of the indicator;

– variance of the indicator;

– coefficient of variation of the indicator;

– interval series of the density distribution of the indicator.

When modeling the basic values, the results were established (Table 2).

The density of distribution of the time of delivery of goods is close to the exponential distribution (Fig. 5). This indicates a completely natural process of queuing systems and indicates a sufficient number and capacity of production resources of the transportation process – the number of cars and their cargo capacity.

Imitation of the process of storing consignments at the logistics terminal and delivery to trade establishments showed obvious problems in the organization of delivery. A significant share of time, namely 81 %, is the average waiting time for the formation of a shipment batch. Given that the goods have limited terms of sale, it is necessary to minimize storage time at the logistics terminal. The relatively large average time of cargo accumulation and its significant dispersion ($M(x)$=49.6 hours, $\sigma(x)$=25.3 hours) indicates a low intensity of departure of the delivery route. The insufficiently high intensity of the organization of new routes is evidenced by the relative high importance of car turnover. When operating one machine, the turnover will be equal to the departure interval, namely 81.6 hours (Fig. 6, *a*). Moreover, most of the turnover is the waiting time for the car cargo ($M(x)=66.7$ hours, $\sigma(x)=2.8$ hours) (Fig. 6, *b*). To reduce the interval, it is necessary to use another car, while their cargo capacity is permissible less than the installed one.

Table 2

Initial parameters and simulation results for the basic experiment

| Indicator/parameter | Units of measure | Value |
|---|---|---|
| Initial parameters | | |
| Number of cars | units | 1 |
| Cargo capacity of the car | kg | 3,000 |
| Annual cargo volume | thousand tons | 291 |
| The minimum amount of cargo to form a shipment | tons | 100 |
| Average (route) speed | km/h | 20 |
| Simulation results | | |
| The average load of the car park | NA | 0.182 |
| The average waiting time for cargo to be shipped at the logistics terminal | hour | 49.5 |
| Average time of cargo delivery | hour | 4.7 |
| Car load capacity utilization factor | NA | 0.9 |
| The average number of delivery points on the route | NA | 11.9 |
| The average time the car is on the route | hour | 14.8 |
| The average waiting time for a car to form a batch for shipment | hour | 66.8 |
| The average duration of a car turnover | hour | 81.6 |

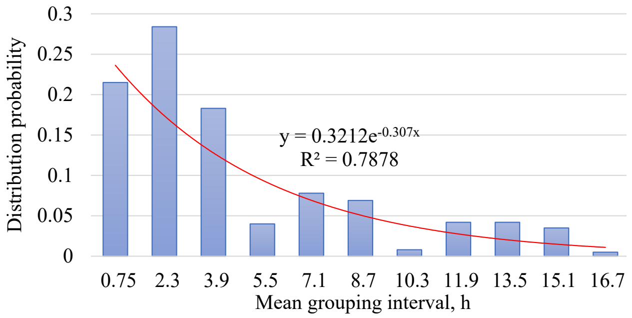
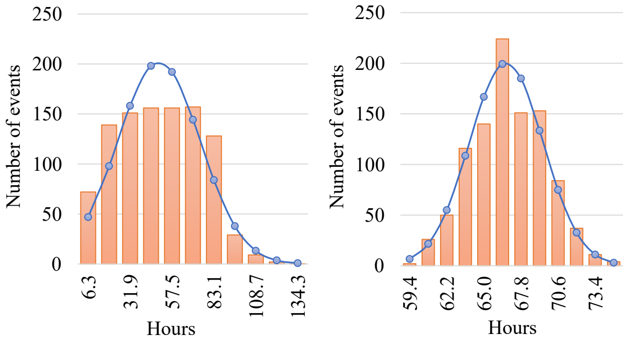


Fig. 5. Density of distribution of cargo transportation time



*a* *b*

Fig. 6. Distribution density: *a* – time of location of goods at the transit terminal; *b* – waiting time by car forming a consignment of cargo for the delivery route to destinations

The model is implemented on the basis of one of the trading networks selling perishable goods. With a relatively short transportation time of an average of 4.7 hours, the number of points of delivery of goods varies from 9 to 14, the goods are much of the time at the transit cargo terminal under accumulation to the cargo capacity of vehicles. The cargo capacity of vehicles that are available is not always used efficiently. Therefore, it is necessary to optimize the existing transportation and technological process.

### 5. 2. Experimental optimization of the parameters of the distribution route of small batches of perishable goods

As a result of the construction and implementation of the optimization simulation model, the optimal parameters of the distribution route of small batches of perishable goods are established: terminal capacity, cargo fleet, and its characteristics. The main technical and operational indicators of functioning of the transport system are established: mathematical expectation of the time of turnover of cars, delivery of goods, taking into account delays during accumulation to the norm of vehicle capacity, fluctuations in the volume of cargo mass in the warehouse.

To simulate the value of a groupage shipment, it is necessary to set the masses of the shipment to one recipient and their quantity in the consignment shipment. By their nature, these characteristics are discrete. Fluctuations in the volume of cargo mass in the warehouse for 181 days are shown in Fig. 7.

Delivery of small orders takes place in trade establishments located in different cities of the country. On delivery routes, it provides for the establishment of route characteristics in the city of deployment of the warehouse, intercity transportation and in transit cities, where partial unloading of the car is also performed.

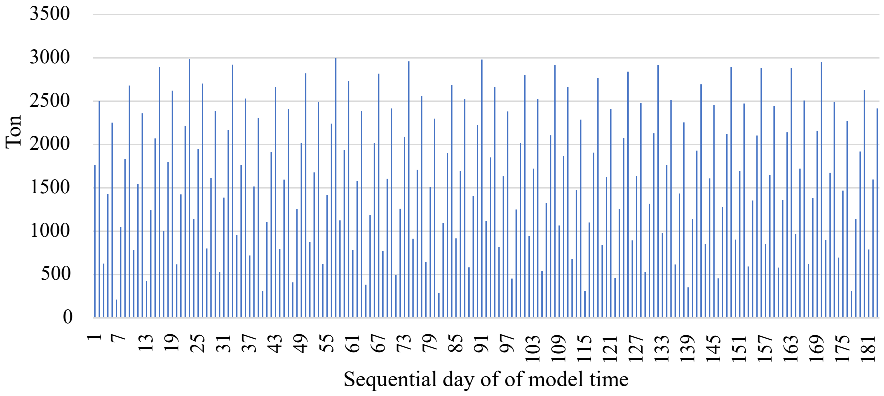
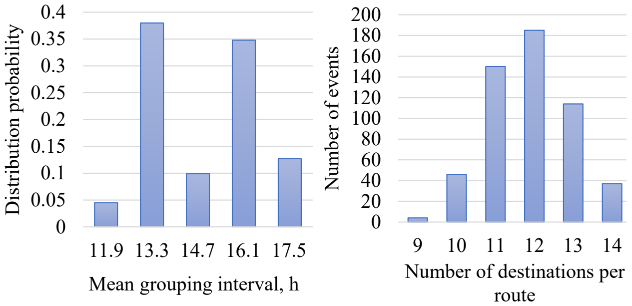


Fig. 7. Fluctuations in cargo mass volumes at the logistics terminal

To describe the distribution route in the city that has a warehouse of goods, it is necessary to establish mileage from the warehouse to the first recipient of the shipment and between adjacent recipients (Fig. 8).



*a* *b*

Fig. 8. Distribution density: *a* — time spent by cars on the route; *b* — the number of assignments in the route

The duration of the route ranges from 11.9 to 17.5 hours (Fig. 8, *a*), which is due to the large network of the distribution route (14 points) and the variability of routes (Fig. 8, *b*); the number of points during the experiment on the route ranges from 9 to 14.

## 6. Discussion of results of modeling and optimizing the parameters of the transport and technological process of delivery of perishable goods

Simulation makes it possible to create new or optimize existing logistics delivery systems. When developing the model, two analytical tools, such as the transport problem and the traveling salesman problem, were combined, so scientific articles do not use associations, they were solved separately. To build a simulation model, a discrete-situational and agent-based approach was used, that is, an assessment of the efficiency of moving objects within the entire trading network or at the terminal, as well as the transportation of goods between different geographical points (Table 1). The main agents of the model took into account the placement of coordinates, each chain of the distribution route, infrastructure, available rolling stock and its characteristics (Fig. 2), even the registration of the route sheet and the waybill for transportation. Also, to optimize the model, the average storage time of cargo at the logistics warehouse and the average delivery time of the delivery route of small consignments of perishable goods to the trading network are taken into account. Since this process is complex and has not been considered up to this point, we use an experimental simulation to solve it. The time for storage and delivery needs to be optimized because perishable goods have a limited shelf life, which affects the quality of the goods.

The advantage of modeling is the ability to assess the effectiveness of the interaction of agents with each other, namely: agents exchange the necessary information (number of orders, distribution of orders by days of the week, formation of traffic volume). Sometimes the shipment batch to the *i*-th point could be less than 100 kg (Fig. 8), and this affects the transportation time, route, and costs. Unlike existing models, this model makes it possible to: change the distribution route, depending on the actual availability of cargo, set the maximum minimum volume of cargo that can be added before shipment to the appropriate destination. When forming a route, the model algorithm takes into account the minimum allowable batch size to the first destination in order to use the vehicle more efficiently and optimize delivery time. You also need to upgrade the fleet of vehicles and purchase vehicles of different cargo capacity. Then each route will be unique and will be calculated each time to determine the optimal one.

When creating the model, it was not taken into account:

– the schedule of trucks. It is believed that the transportation process is carried out around the clock and during all days of the week;

– presence of failures, errors, technical failures in the operation of the transport and technological system. It is believed that all technical systems are operated in accordance with existing norms and procedures.

The simulation results are random variables whose value density has a normal distribution. Therefore, the reliability of the results at the level of 95 % (probability of error 0.05) was ensured through four replications of the simulation with a model time of at least 18 months.

When performing the experiment, we did not take into account the working hours of drivers on the route, the working hours of the logistics terminal, and the working hours of destinations, did not set restrictions, adopted 24 hours 7 days a week. The duration of the route ranges from 12 to 17.5 hours with a large number of destinations of the distribution route (14 points). It is advisable to consider using 2 drivers per flight, this will increase costs but may affect the transit time. For further calculations, the driver's working time must be taken into account, according to the requirements of the working and rest time of the driver and crew. At the same time, it is necessary to take into account the working hours of logistics terminals and warehouses, in order to make the results more accurate. Also, we did not take into account the impact of martial law on the transport and technological scheme of delivery of goods to the trading network since some stores do not work.

Our model differs from existing mathematical model for the retail network, which is described in [24] and takes into account the density of the trading network, static coefficient of cargo use, and technical speed of the car. The model built makes it possible to take into account the peculiarities of the distribution network, the minimum consignment for the *i*-th destination, and dynamically change the route in accordance with the available cargo. It also takes into account fluctuations in stocks of perishable goods in the warehouse and developing the optimal route for transportation, the cargo capacity of vehicles. The optimal parameters of the transport and technological system of distribution of small batches of perishable goods have been experimentally established: the required capacity of terminals, a fleet of trucks.

The scope of application of our results is the production activity of logistics companies, transport companies, and retail chains in the transportation of small consignments (including perishable). Transport companies, thanks to the constructed simulation model, will be able to optimize the fleet of vehicles – by fleet size and cargo capacity of vehicles; as well as planning their work.

For logistics companies, it is possible to develop a long-term logistics strategy for the supply of small batches of perishable goods at any area for cargo owners. In particular, the principle of «expediency» of order delivery will be taken into account. If the order is less than the minimum set size, it will not be executed, and the goods will await accumulation in stock. Refusal to fulfill the order can significantly affect costs and lead to a shortage of goods in retail chains. Therefore, in the future, to determine the economic efficiency of distribution, these studies will be continued since it is advisable to assess the economic risks from loss of goods or shortage of goods in the network.

## 7. Conclusions

1. A simulation model of distribution of small batches of perishable goods has been built. The construction of the model was based on agent-based and discrete-event principles. Unlike existing ones, our model combines the solution to the transport problem and the traveling salesman problem simultaneously taking into account the stochasticity of the duration of technological operations. In addition, when forming the delivery route, the model algorithm takes into account the minimum allowable batch size to the *i*-th destination, which makes it possible to build a new unique route of the vehicle each time.

The model is implemented on the basis of one of the retail chains selling perishable goods (frozen fish and seafood). With relatively short transportation times (an average of 4.7 hours), the goods spend a significant part of the time on the transit cargo terminal under accumulation to the norm of truck capacity (66.8 hours). This indicates insufficient efficiency of the existing transportation and technological process.

2. As a result of the experiment, according to the criteria for minimizing time, limit (rational and reliable) levels of fleet use and cargo capacity of vehicles, the optimal number of trucks were determined (1 with a capacity of 5 tons; 2 with a capacity of 3 tons). At the same time, fluctuations in the volume of cargo mass at the transit terminal are not critical and do not exceed two truck capacities (10 and 6 tons, respectively).

## Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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## Data availability

The data will be provided upon reasonable request.

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