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SHAPING SUSTAINABLE STRATEGIES OF FREIGHT FORWARDING COMPANIES IN THE ENVIRONMENT OF THE ROAD TRANSPORT MARKET

Purpose. The paper aims to propose an approach to shape the sustainable strategies of freight forwarders under uncertainty of the stochastic environment of the transportation market.

Methodology. The elements of the game theory were used to formalize the conflict situation, where the uncertainty of the transport market is considered as a game with nature. To design the model of the freight transportation market, the principles of the system's theory were used in the representation of a forwarding company operating as an element within the macro-logistic system of the transport market. The methods of object-oriented programming were applied to develop the dedicated software for computer simulations of the forwarder's operation within the market of transport services. The regression analysis was used as the main methodology to process the numeric results of experimental studies. The elements of functional analysis were applied to substantiate the sustainable strategy of a forwarding company in the considered example.

Findings. The results of the conducted experiment allowed for determining the high-quality dependencies between the number of serviced requests and the number of dispatchers involved in the requests' servicing for the case when the operators' decisions are supported by the specialized software and for the case when decisions are made conventionally.

Originality. The use of a game-theoretical approach in this study is based on the advanced simulations of a freight servicing process where the demand randomness and the servicing process stochasticity are integrally considered.

Practical value. The proposed methodological approach is proposed to be used by forwarding companies to evaluate sustainable strategies when servicing clients within the given market. The use of the developed approach in practice allows forwarders to decrease the operational costs achieving the minimal negative impact on the environment.

Keywords: *sustainable development, game theory, freight forwarding, stochastic demand*

Introduction. The activity of the transport sector of Ukraine under the conditions of the legal regime of martial law largely depends on the ability of domestic transport and freight forwarding (logistics) companies to quickly carry out all types of transportation in the necessary volumes. Industry representatives must rebuild logistics chains in critical conditions and look for comprehensive solutions necessary to meet the needs of the Armed Forces of Ukraine, the national economy, and the civilian population. The key levers of influence that give the transport industry the opportunity to adapt, function and develop belong to freight forwarders – transport market entities that provide intermediary services to other participants in the formation of delivery chains, including the selection of shippers and other counterparties. The activity of transport and forwarding companies is one of the strategic ones for ensuring the functions of the state, its legal and organizational foundations in Ukraine are regulated by the Law of Ukraine "On Transport and Forwarding Activities" dated 01/07/2004 No. 1955-IV. Also, chapter 65 of the Civil Code of Ukraine is dedicated to transport forwarding.

The main purpose of forwarding is the uninterrupted movement of cargo between interested parties. For this, freight forwarders must perform an extremely complex set of technological and organizational operations that ensure the continuous, reliable, and flexible functioning of supply chains [1, 2], as well as documentary support for the transportation process. In turn, logistics service providers usually work based on orders from cargo owners, which in most cases are unstable [3, 4], as they depend on various circumstances. For many logistics companies, random appearance or fluctuations of orders create serious complications since they are affected by many uncertainties and alternatives at different stages of decision-making. Accordingly, the efficiency of the transport and forwarding service decreases, which in turn causes the deterioration of the efficiency of the macro-logistic system of the transport market. Therefore, the problem of determining the adequate strategies of forwarders is the most important task for ensuring the stability of the entire system of the transport and logistics market.

According to the classic definition of the "World Commission on Environment and Development", the main principles of sustainable development are economic growth, social security, and environmental protection. Since modern freight transportation is the sphere of human activity that, on the one hand, leads to significant economic development, and on the other – notably contributes to environmental pollution, it should be considered from the point of view of the sustainable development paradigm.

Analysis of recent publications. The introduction of sustainability into the freight transportations constantly attracts global attention. The implementation of advanced sustainable development practices acts as the most important link between the modernization process and the sustainable activities of freight carriers. The study [5] is aimed at determining the relevance of modern technologies for environmentally oriented freight transport services, areas of its quality management and competitiveness. Data collected from 140 freight transport companies was thoroughly analyzed using exploratory factor analysis and Cronbach's alpha coefficient was used to assess factors consistency. As a result, the authors determined the interrelationships between factors and components characterizing the perception of selected modern technologies of sustainable-oriented freight transportation services, the spheres of quality management and the competitiveness of companies.

Fulzele and Shankar believe that it is extremely important to introduce sustainability values into freight operations to minimize the environmental and social consequences of cargo transportation process. In their study [6], the authors identified twenty-four advanced practices in the field of sustainable development, which were further divided into four main categories: organizational, process-oriented, technological, and collaborative. The peculiarity of the model proposed in [6] is that it evaluates both the positive and negative impact of the sustainable development practices on the carrier's economic, ecological, social, operational, and technological indicators.

One of the most widespread practices of sustainable development of transport and forwarding services is the integration, which is considered a key characteristic of creating improved logistics chains. Integration ensures purposeful coordination and coherence of actions of transport agents to improve the efficiency of transport services. The tactical capacity planning of an integrated multilateral freight transport system is covered in work [7]. The study examines revenue management concepts, including categorizing shippers, classifying demand, imposing penalties for exceeding established time windows for demand satisfaction, and offering packages for services. In work [8] a new conceptual scheme is proposed, which allows understanding the essence and mechanisms of integration in freight transport chains. The proposed concept is designed to assist transport agents in identifying untapped opportunities for strengthening integration or mitigating negative aspects.

One of the most important tasks of freight forwarders is the collection and consolidation of cargoes, the size of which does not allow to fully load the vehicle, as well as the selection of the appropriate transport organization for the transportation of these cargos, which makes the transportation process more efficient, and reduces transportation costs. A system of strategic planning for the freight forwarding sector using a co-loading shipment plan is proposed in [9]. Similarly, the study [10] examines the integrated transportation planning problem (ITPP) for the forwarding companies, considering external resources. External resources include the vehicle fleet of such subcontractors: closely related carriers in vertical cooperation, autonomous carriers in the distribution market, as well as collaborating partners in a horizontal coalition. The optimization criterion is the cost of resources when implementing vehicle routing with implemented subcontracting.

Krajewska and Kopfer [11] state that the ITPP expands the common vehicle routing and scheduling problem by engaging subcontractors to service part of the orders. The research [12] is devoted to the use of multi-agent systems in the freight forwarding industry. The authors present an intelligent mobile-agent-based system for working in a dynamic freight transportation environment, where freight consolidation and route planning are crucial.

However, integration leads to additional costs, so it is necessary to introduce restrictions on its use. Various theories and principles were applied to study the dynamics of integration [13]. System engineering methods were utilized to analyze the components and structure of transport chains, while principles of logistics and supply chains were applied to examine the performance and behavioral patterns of agents. Moreover, network and graph theories are widely used for representing and analyzing the structure of transport chains and networks. The new institutional economics (NIE) approach reveals issues and challenges of coordination, as well as points out the opportunities for introducing incentives to overcome these problems and obstacles.

Another extremely important practice in the field of sustainability of transport systems is the use of artificial intelligence. The intelligent service capacity allocation for logistics and forwarding operations, which considers the stochastic appearance of requests, is proposed in [14]. The authors of the article a deep learning-based one-step integration optimal decision-making approach (S2SCL), which combines inventory optimization and the demand forecasting techniques. The solution for overcoming the primary problems of using prescriptive analysis in freight transportation are presented in the paper [15]. The application of machine learning (ML) techniques in the field of transportation, logistics and supply chains can be seen in the extensive review of scientific sources carried out in the study [16]. The authors highlight the possibilities of applying ML to demand, location and traffic flow prediction, optimization processes, solving vehicle routing problem and detection of data anomalies. The article [17] presents the results of a study aimed at determining the preferences of shippers regarding the delegation of modal control to the logistics service providers (the practical testing of synchro modality).

The authors of the study [18] argue that the appearance of new digital platforms threatens to disrupt the logistics sector through the emergence of a new business models. However, it is still unclear whether these digital services could cause problems for the existing logistics domain. The article discusses the concepts of "disruption" and "disruptive innovation" in relation to logistics startups using digital platforms.

Most methods and concepts of sustainable transport appeared long before the term was introduced into circulation. Accordingly, there are different methodologies, approaches, and forms of transport that contribute to economic growth and competitiveness, while at the same time reducing the negative impact on the environment. In relation to the European Union, such form of transport as "door-to-door" service is considered one of the most suitable solutions capable of curbing the unsustainable growth of the transport sector. Solving such common problems as choosing the optimal shipment size and a freight vehicle (by using modeling approach [19]), selecting of a freight forwarder (by developing a multi-criteria decision-making system [20]), analysis of a shipper's decision to delegate the choice of transport mode to service providers (by carrying out a survey [17]), evaluating the quality of the transportation infrastructure (by utilizing navigation service data [21]), exploring the notion of monopolistic competition (by implementing an agent-based framework for freight market interactions [22]), etc. also contribute to increasing the level of sustainable transportation and mobility.

It should also be noted that the latest development of information technologies and artificial intelligence allows the use of innovative tools to solve both classic and modern transport problems and tasks. Some of the most popular techniques used by scientists include: agent-based modeling and goal programming [22, 23]; a hybrid system for strategic planning, which integrates mathematical models with knowledge principles [9]; covariance analysis, discrete choice and latent class analysis [17, 19]; tabu search heuristics [11]; deep and machine learning [8, 14–16]; mechanisms of fuzzy logic and simulated annealing [12]; methods based on the data of navigation services [21]; exploratory factor analysis [5]; innovative combination of intuitionistic fuzzy numbers with graph-theoretic and matrix approach [6]; models of commodity-based freight demand based on exogenous economic forecasts [24] and economics of transaction costs [8]; the theory of time windows [7], dynamic measurements [25], digital image correlation method [26] and the Bayesian approach for model estimation [27, 28].

Based on the conducted literature review, it can be stated that the stability of the transport system should be ensured at the stage of planning strategies of market entities. This gives the possibility to consider the stochasticity of demand parameters and technological processes and to eliminate obstacles caused by incorrect setting of tasks at the level of tactical planning.

Unsolved aspects of the problem. The review of the scientific literature in the field of sustainable development of the transportation market allows us to highlight the following disadvantages of existing approaches:

- most of the described approaches do not consider the randomness of the parameters of demand for freight transportation;
- many of the existing methods for choosing for choosing the proper strategies for transport companies are focused on the selected technological parameters.

In this paper, we contribute to the area of substantiation of the strategies of forwarding enterprises that ensure the sustainable development of the whole transportation market. We aim to fill the gap in the existing methodologies for the shaping of the strategies of transport companies by considering the stochastic nature of demand and forwarding operations.

Objectives of the article. The purpose of the presented work is to demonstrate the game theory approach, which is an element of agent modeling, to determine the strategy of a freight forwarding company under the conditions of the freight transportation market.

As the object in the current study, the process of processing the requests for forwarding from cargo owners is distinguished. The strategies of forwarding companies are considered within the basic technological process of servicing regarding the number of operators involved in the requests' servicing, and the use of the specialized software supporting the decision-making by dispatchers.

To achieve the research goal, we develop the game-theoretical approach to choose the optimal strategy of a forwarding company, implement the simulation model of the forwarder's operation within the market of freight deliveries, perform the simulation experiment to define the influence of the number of dispatchers on the result of servicing operations, process the results of the experiment using the regression analysis, and apply the obtained models for the case of servicing process performed by the Auto-Transit forwarding company that operates in Kharkiv, Ukraine.

A game theory approach to determining the freight forwarders' strategies. A game classically is defined as a conflict situation. The game takes place, if participants (decision-makers) are identified, the possibilities of the conflict actors (the set of all strategies) are known, the outcomes of the conflict (the situations) are defined, the parties defending some interests and the interests of the conflicting actors (goals) are identified. According to the game definition, the conflict situation $\Im$ formally could be presented in the following way

$$\Im = \left\langle \Re_a, \{r_K\}_{K\in\Re_a}, r, \Re_i, \{\succ_K\}_{K\in\Re_i} \right\rangle,$$

where $\Re_a$ is a set of all decision-making subjects (coalitions of actions in a game model); r_K is a set of all possible decisions (strategies) of a game participants, which are responsible for decisions; r is a set of all situations (outcomes) in the game; $\Re_i$ is a set all entities defending the certain interests (coalition of interests); $\succ_K$ is a set of all interests of entities interested in the conflict (relation of preference).

All the outcomes of a game form a set r, which is a subset of a set of all combinations of the action coalitions' strategies: $r \subset \prod_{K\in\Re_a} r_K$. It is generally accepted that the interests of the coalition are subsets of the same set of players, that form the coalition of actions. A set of all the interests $\succ_K$ is a binary relation on the set r

$$\succ_K \subset r \cdot r, \quad K \in \Re_i.$$

To determine the preference relation on the set of situations, the payoff function H_K of the coalition of interests K is used. This function is defined in the set of real numbers.

The problem of choosing the optimal strategy of a freight forwarder under transport market conditions in terms of game theory could be formulated as a game with nature (although the other formulations could be provided, i.e., a conflict between competing forwarding companies or a conflict between a client and a forwarder). The set of players, in this case, consists of two elements – a forwarding company and the transport services market (nature)

$$\Re_a = \left\{ FF^*, M'_{TS} \right\},$$

where FF^* is a forwarding company, for which the strategy is being defined; M'_{TS} is a part of the macro-logistics system of a transport market, which does not include the forwarding company FF^*.

For the proposed formulation, the game model applies to the models characterized by a stochastic uncertainty. In the case of stochastic uncertainty, each state of nature could be described by the corresponding probability of its occurrence. Naumov and Kholeva in the papers [29, 30] propose to define the optimal strategy r_{FF}^{opt} of the forwarding company in the following way

$$r_{FF}^{opt} = \arg\max_{r_{FF}\; i=1\ldots m} \sum_{j=1}^{n} (p_j \cdot H_{ij}) = \arg\max_{r_{FF}\; i=1\ldots m} H_i^*, \tag{1}$$

where m is the number of profiles for the forwarding company strategies; n is the number of possible states of the transportation services market; p_j is a probability of the market being in the j^{th} state; H_{ij} is the payoff function value for the case when the forwarder uses the i^{th} strategy and the market stays in the j^{th} state, [EUR]; H_i^* is the value of the integral payoff function for the i^{th} profile of the forwarder's strategy, [EUR].

The choice of the best profile for the freight forwarder's strategy is carried out based on the matrix of the payoff function values, in which the values in the rows correspond to the alternative profiles of the forwarding company's strategies, and the column values – to the considered states of the transport services market (Table 1).

Since the parameters of demand are not deterministic, their distribution must be considered while determining the possible states of nature. If the integral distribution functions of the numerical parameters characterizing the transport market states are known, then these states can be described based on the values of the parameters and the corresponding probabilities that the parameters would take that value. In the range of possible values of the parameter, several disjoint ranges can be identified, and, for a given distribution function, the probability, that the parameter will take a value in this range, could be estimated. If we divide the range of possible values into k equal subranges, then the probability that the parameter will take a value from the first subrange will be equal to the integral distribution function for the upper boundary of the subrange; the probability of falling into each subsequent subrange could be determined as the difference between the values of the integral function for the upper and lower boundaries of the subrange

$$\begin{bmatrix} p_x^{(1)} = F(x_h^{(1)}) - F(x_l^{(1)}) = F(x_h^{(1)}) \\ p_x^{(2)} = F(x_h^{(2)}) - F(x_l^{(2)}) \\ \ldots \\ p_x^{(k)} = F(x_h^{(k)}) - F(x_l^{(k)}) = 1 - F(x_l^{(k)}) \end{bmatrix},$$

Table 1

The matrix of a game with nature for choosing the strategy of a forwarding company

Profiles of the forwarder strategy	Strategies of nature (nature states)			
	$r_{TM}^{(1)}$	$r_{TM}^{(2)}$	...	$r_{TM}^{(n)}$
$r_{FF}^{(1)}$	H_{11}	H_{12}	...	H_{1n}
$r_{FF}^{(2)}$	H_{21}	H_{22}	...	H_{2n}
...	...	...	...	...
$r_{FF}^{(m)}$	H_{m1}	H_{m2}	...	H_{mn}

where $F(x)$ is the integral distribution function for some parameter x; $x_l^{(i)}$ and $x_h^{(i)}$ are lower and upper boundaries of the i^{th} subrange of the parameter x; $p_x^{(i)}$ is the probability of falling into the i^{th} bin.

It should be noted that the sum of probability values for all the possible states of nature equals 1.

Representation of the forwarding company's strategies. Let's define a set r_{FF} of all feasible decisions (strategies) of a forwarding company as a set of all possible combinations for the following key parameters:

1. N_d is the number of dispatchers, involved in a process of the incoming requests flow servicing.

2. T_{FF} is tariff for the provided services offered by the forwarding company to freight owners, [EUR/ton-km].

3. τ_{FF} is the technology of the logistics chains (delivery routes) forming accepted by a forwarding company: using the standard tools of logistics portals or using the specialized information tools.

The set r_{FF} of the forwarder strategies is defined as the Cartesian product of sets, containing the possible values for key parameters

$$r_{FF} = S(N_D) \cdot S(T_{FF}) \cdot S(\tau_{FF}),$$

where $S(N_D)$ is a set of possible values of the number of dispatchers, which serve the incoming requests flow; $S(T_{FF})$ is a set of possible values of the tariff on the forwarding services; $S(\tau_{FF})$ is a set of alternate variants of the technology used for the forming of the logistics chains structure (or delivery routes forming).

A wider range of key parameters defining the forwarder strategies could be considered in the model. The described representation of the set of forwarder strategies considers the very basic characteristics for the purposes of this paper.

Model of demand for forwarding services. The demand for transport services is the key characteristic of the transport market. Random parameters of demand substantiate a variety of the market possible states.

The demand-shaping core unit is a request for transport services, which is understood as the customer's need for services backed by its purchasing abilities and presented on the market to be satisfied. The request for service is the basis and the reason for the interactions between the transportation market actors. A set of current and potential requests for forwarding services shapes the demand for company services; correspondingly, a set of requests for services of all forwarding companies in the region represents the demand for freight transport services in the region, etc. Each request could be quantified based on a set of parameters, among which the most significant are the shipment volume, the delivery distance, and the time interval between requests in a flow. Since a set of ordered in time requests characterizes demand, the task of demand estimation could be defined as the problem of estimating numeric parameters of the requests flow. Data on the flow of requests for the studied enterprise can be obtained based on the parameters of previously processed requests.

In general form, the model of demand can be presented as an ordered set **D**

$$\mathbf{D} = \{r_1, r_2, ..., \rho_N\}, \quad (2)$$

where ρ_i is the i^{th} request in an ordered set: $\rho_i \prec \rho_{i+1}$, if $t_i \le t_{i+1}$, t_i is the time moment when the i^{th} request appears in the system; N is the total number of the analyzed requests.

A single request ρ is characterized on the grounds of the following parameters

$$\rho = \{\zeta, \omega, \tau, \theta\}, \quad (3)$$

where ζ is the time between moments of the appearance in the system of current and previous requests, [min.]; ω is the shipment volume, [tons]; τ is the time between the moment when the shipment is to be delivered and the moment when the order was placed in the system (acceptable waiting time), [days]; θ is a type of vehicle needed to service the request (box, van, dump, container, etc.).

For a single request, the presented parameters are deterministic characteristics, however, for the requests flow, numeric parameters (ζ, ω and τ) become random variables, and possible values of the variable θ are characterized by the respective probabilities.

The geographic location of consignors and consignees we propose to describe based on a two-dimensional set **L**, in which the rows characterize the regions of the consignors of goods (origin regions) and the columns – the regions of the recipients (destinations regions). The elements of the set **L** are sets of requests $\mathbf{r}_{ij}$, for which a consignor is located in the i^{th} region, and the consignee – in the j^{th} region (i and j are the row and column number respectively). For the requests flow with a finite number of elements, the set **L** could be replaced by a numeric characteristic – the origin-destination matrix **D**, which elements δ_{ij} reflect the ratio of the number of requests in the set $\mathbf{r}_{ij}$ and the total number N of requests in the flow

$$\delta_{ij} = \frac{\eta(\mathbf{r}_{ij})}{N},$$

where $\eta(\mathbf{r}_{ij})$ is the number of elements in the set $\mathbf{r}_{ij}$.

Thus, the final model of demand for the services of a forwarding enterprise can be shown as a set of the listed above characteristics depicted in (2)

$$\mathbf{D} = \left\{\Delta, \tilde{\zeta}, \tilde{\omega}, \tilde{\tau}, p_\theta\right\},$$

where $\tilde{x}$ is a stochastic variable characterizing the demand numeric parameter x; $\mathbf{p}_\theta$ is a vector, the i^{th} element of which is the probability that the i^{th} type of a vehicle will be needed to serve a given request.

Payoff function. Naumov and Kholeva in the papers [29–31] underline that the payoff function for choosing the strategies of a forwarding company should reflect the numerical characteristics of sustainable development indicators – productivity of dispatchers, a level of the clients' service, the total costs of forwarding operations (characteristics of an indicator of the productive resources use), the level of environment pollution (characteristics of the environmental impact indicator) and the number of the dispatchers (characteristics of the indicator reflecting the social component of the forwarding company operation). On the other hand, the payoff function should be determined by the numerical characteristics of the players' strategies – characteristics of a freight forwarder and the transport market.

To solve the problem of choosing the sustainable development strategies, we propose to use the following payoff function that satisfies the described requirements

$$H = I_{FF} - E_{FF} - H_E,$$

where I_{FF} is an income of a freight forwarder, [EUR]; E_{FF} is the total operating costs of a forwarding company, [EUR]; H_E is an economic expression of a harmful impact of transport on the environment, [EUR].

If tariff T_{FF} for freight forwarding services is some constant value per a request, the forwarder's income could be defined in a following way

$$I_{FF} = \mathrm{T}_{\mathrm{FF}} \cdot n_{sr},$$

where n_{sr} is the number of serviced requests.

The freight forwarder operating costs in a simplified form could be expressed as the linear dependence on the number of dispatchers serving the incoming requests flow

$$E_{FF} = c_0 + c_d \cdot N_d,$$

where c_0 and c_d are constant and specific costs of freight forwarding operations, [EUR] and [EUR/dispatcher].

Evaluation of environmental impacts of transport could be provided by using average specific indicators. Such indicators allow estimating the harmful impact of transport on the grounds of resulting technological indicators (total transport work, total delivery distance, total cargo volume, etc.). Using average costs of environmental pollution, the harmful impact of transport on the environment could be defined based on the total distance L_Σ covered by vehicles servicing clients of a forwarder

$$H_E = L_\Sigma \cdot c_e,$$

where c_e are the mean costs of a harmful impact per 1 km of a delivery distance, [EUR/km].

Thus, the payoff function takes the following form

$$H = T_{FF} \cdot n_{sr} - L_\Sigma \cdot c_e - c_d \cdot N_d - c_0. \quad (4)$$

The resulting parameters characterizing the servicing process (such as the number of satisfied requests and the total distance covered by vehicles) depend on the number of dispatchers assigned to the servicing process and the characteristics of the existing demand for forwarding services. On the other hand, the costs of provided services depend on the selected servicing technology. The value of the payoff function (4) can be determined if the dependencies $n_{sr} = f(N_d)$ and $L_\Sigma = f(N_d)$ are known. To study the mentioned dependencies and define their shape, the simulation experiment should be carried out yielding the set of input data that would allow determining of the mathematical models for the number of serviced requests and covered distance.

The simulation experiment on determining the functions of $n_{sr}=f(N_d)$ and $L_\Sigma=f(N_d)$. To implement the simulations for the processes of requests' servicing by a forwarding company, the dedicated library of base classes was developed in Java programming language. The implemented classes allow describing of the base elements of the described mathematical models:

- the *Request* is dedicated for simulations of requests for services of freight forwarders based on (3);
- the *Request Flow* class represents the model (2) of demand based on the set of ordered requests;
- the *Forwarder* class provides a template for modeling of a freight forwarder as an element within the system of the freight transportation market;
- the *Dispatcher* class allows simulating of an operator who process the requests for freight forwarding;
- the *Transport Market* class is designed to implement the simulation models of the macro-logistic system of a freight transportation market, where the operation of a forwarding company is considered.

To define the mathematical models describing the influence of the number of operators processing the existing demand on the final number of successfully processed orders and the total covered mileage, the dedicated simulation experiment was carried out.

To simulate the demand for forwarding services, the set of requests from the lardi-trans.com portal was processed: the distributions of the numeric characteristics were fitted, and the respective parameters of distributions were estimated for the time interval and the consignment weight. The intensity of requests sent to the logistics portal is around 500 orders per minute, for that reason, the sample of requests that appear for 1 minute was used for data processing. In the series of the simulation experiment, the number of operators available for demand service was accepted as an exponentially distributed stochastic variable with an average equal to 1.

Within the simulation experiment, two alternative approaches to servicing the requests by dispatchers were studied:

- the service with the use of the specialized software that pair the requests to ensure the load of vehicles in both direct and back directions;
- the traditional requests' processing, without the use of the decision-support software.

The processing time for servicing the requests was considered the variable with normal distribution; for the first of the described processing technologies, the mean servicing time was taken equal to 2 minutes per request, and for the conventional technology of processing – to 10 minutes per request.

To guarantee the high adequacy of the data obtained within the experiment, 500 launches of the simulation model were done for each set of the input parameters. Such the number of the model runs ensures a significance level of 0.05 for the simulation results.

Based in the obtained data, by performing the regression analysis, the linear and power dependencies were fit to functions $n_{sr} = f(N_d, \delta, \varsigma)$ and $L_\Sigma = f(N_d, \delta, \varsigma)$ for the considered approaches to process the demand for forwarding services.

For the option of servicing based on the decision-support system ($\tau_{FF} = ST$), the following models were obtained as the best possible solutions

$$n_{sr}^{\tau_{FF}=ST} = \delta^{0.416} \cdot N_d^{0.982}; \quad (5)$$

$$L_\Sigma^{\tau_{FF}=ST} = 302.921 \cdot \delta^{0.365} \cdot N_d^{0.994}. \quad (6)$$

For the situation of servicing without the use of the decision-support system ($\tau_{FF} = TT$), the similar dependencies take the following form

$$n_{sr}^{\tau_{FF}=TT} = \delta^{0.501} \cdot \varsigma^{0.066} \cdot N_d^{0.979}; \quad (7)$$

$$L_\Sigma^{\tau_{FF}=TT} = 266.654 \cdot \delta^{0.366} \cdot N_d^{0.991}. \quad (8)$$

The models (5–8) represent almost functional dependencies, as the values of the determination coefficients characterizing these models are greater than 0.99. On the other hand, the obtained dependencies can be considered valid only under the conditions of the Ukrainian market of freight transportation. In other cases, similar experimental studies should be carried out to estimate the corresponding regression models.

Case Study: Strategy of a forwarding company in the environment of Ukrainian transport market. Using the proposed method and results of the demand studies presented in [29], the strategy for the freight forwarding company Auto-Transit (Kharkiv, Ukraine) was defined as an example of the described game theory approach.

A set of alternative states of nature is determined by the ranges of values for the parameters δ and ς, which describe the state of the Ukrainian freight forwarding market in the road transport segment. The number of possible market states is defined as a product of the subranges number for all demand parameters. For example, if 3 subranges were selected for each of the parameters δ and ς, then the number of possible market states equals 9. The probability of the market being in a certain state is estimated as the product of the probabilities of the demand parameters falling into the corresponding ranges

$$p_{ij} = p_\delta^{(i)} \cdot p_\varsigma^{(j)},$$

where p_{ij} is the probability of nature being in a state when the parameter δ is in the i^{th} subrange of values and the parameter ς is in the j^{th} subrange; $p_\delta^{(i)}$ is the probability of the parameter δ falling into the i^{th} range of values; $p_\varsigma^{(j)}$ is the probability of the parameter ς falling into the j^{th} range of values.

Table 2 shows the possible strategies of nature for a normal distribution of the requests share δ and the scale parameter ς when 3 subranges of possible values are selected for each demand parameter.

Due to the non-linearity of the payoff function dependence on the parameters defining the profiles of the forwarder possible strategies, for a fixed state of nature there exists a strategy profile in which the functional dependence $H(N_d)$ has an extremum.

Figure, *a* shows an example of this dependence calculated on the grounds of c_0, c_d and c_e values, characteristic for the Auto-Transit company. The given example allows us to conclude that in the considered range of the dispatchers' number there's such a value of this parameter at which the payoff function has the maximum possible value, and this value does not necessarily lie on the range boundaries. However, it should be borne in

Table 2

The possible states of nature

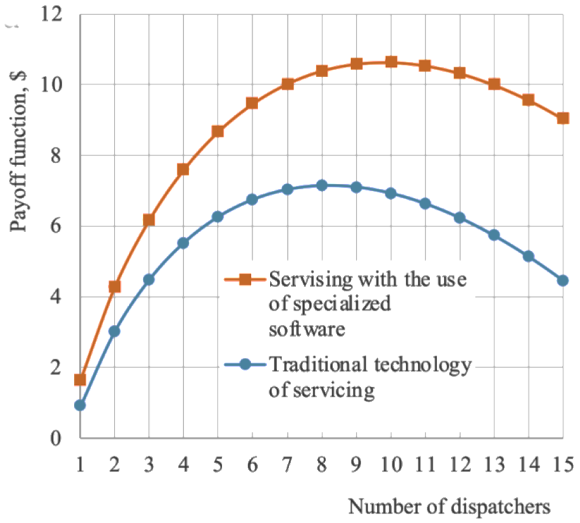
State of nature	Range of the parameter values		Probability of the parameter falling into the range		Probability of nature being in the state
	δ	ς, h^{-1}	$p_δ$	$p_ς$	
$r_{TM}^{(1)}$	(0; 0.1846]	(0; 0.403]	0.157	0.157	0.025
$r_{TM}^{(2)}$	(0; 0.1846]	(0.403; 0.807	0.157	0.683	0.107
$r_{TM}^{(3)}$	(0; 0.1846]	(0.804; 1.210]	0.157	0.157	0.025
$r_{TM}^{(4)}$	(0.1846; 0.3692]	(0; 0.403]	0.683	0.157	0.107
$r_{TM}^{(5)}$	(0.18446; 0.3692]	(0.403; 0.807]	0.683	0.683	0.466
$r_{TM}^{(6)}$	(0.1846; 0.3692]	(0.807; 1.210]	0.683	0.157	0.107
$r_{TM}^{(7)}$	(0.3692; 0.5538]	(0; 0.403]	0.157	0.157	0.025
$r_{TM}^{(8)}$	(0.3692; 0.5538]	(0.403; 0.807]	0.157	0.683	0.107
$r_{TM}^{(9)}$	(0.3692; 0.5538]	(0.807; 1.210]	0.157	0.157	0.025

mind that the extremum of the payoff function characterizes only the given state of nature and does not necessarily correspond to the best strategy of the freight forwarder. The choice of the optimal strategy profile is carried out in accordance with (1) based on the integral payoff function H^*. Figure, *b* presents the results of the evaluation of the integral payoff function for 30 profiles of Auto-Transit strategies, which was carried out based on the set of possible states of nature presented in Table 2.

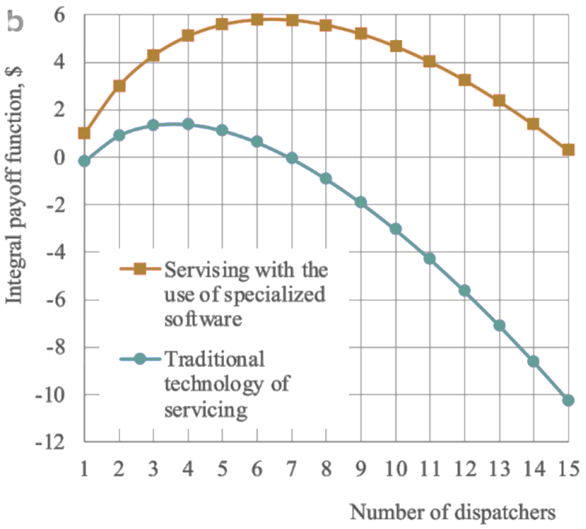
Analysis of the dependencies presented in Figure, allows to determine the optimal forwarder's strategies:

- for stationary parameters of demand: the optimal strategy of the company is the use of specialized software for servicing the flow of requests by 10 dispatchers (the strategy profile $\tau_{FF} = ST$, $N_d = 10$);
- for stochastic parameters of demand (in accordance with the states of nature identified in Table 2): the optimal strategy of the forwarder is to service the incoming flow by 6 dispatchers using specialized software (the strategy profile $\tau_{FF} = ST$, $N_d = 6$).

It should be noted that when using traditional tools of logistics portals (the servicing technology $\tau_{FF} = TT$), the optimal number of dispatchers for the Auto-Transit forwarding company is 8 people if the evaluation of the strategy does not take into account the alternative states of the transport market, or 4 people if the stochastic nature of the transportation services market is taken into account.



a



b

Fig. Estimates of the freight forwarder strategies:

a – payoff function for the state of nature $r_{TM}^{(5)}$; *b – integral payoff function for all the possible states of nature*

Conclusions. The proposed game-theory-based approach to determining the strategies of freight forwarding companies considers the sustainable development principles of the forwarders' operation under conditions of stochastic demand parameters. The described model considers the limited number of parameters defining the strategy profiles and is confined to the listed characteristics of demand for transport services. However, it could be widened without changing the proposed principle for the substantiation of the forwarder's sustainable strategy.

The proposed models implemented as the library of base classes are dedicated to the development of programming models of interactions between the entities within the macro-logistic system of a freight transportation market. Simulation models obtained based on the proposed tools can be used to study the stochasticity of demand for freight deliveries and the random nature of the technological operations implemented by forwarding companies.

As future research direction, expansion of the number of parameters defining profiles of the forwarder strategies, considering strategies of competitive companies, and use in the model of more indicators characterizing the demand for forwarding services should be mentioned. The other significant direction of future research is checking out if the strategies substantiated with the proposed approach would not decrease the competitiveness of a forwarding company. The proposed class library is available on open access; thus, the developed classes could be adjusted accordingly to reflect the changes provided in the mathematical model.

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Формування сталих стратегій експедиторських компаній у середовищі ринку автомобільних перевезень

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Мета. Запропонувати методологію формування стійких стратегій транспортно-експедиторських компаній в умовах невизначеності стохастичного середовища транспортного ринку.

Методика. Для формалізації конфліктної ситуації використані елементи теорії ігор, де невизначеність транспортного ринку розглядається як гра із природою. Для побудови моделі ринку вантажних перевезень використані принципи теорії систем для моделювання діяльності експедиторської компанії як елементу макрологістичної системи транспортного ринку. Методами об'єктно-орієнтованого програмування розроблене спеціальне програмне забезпечення для комп'ютерного моделювання роботи експедитора на ринку транспортних послуг. В якості основної методики обробки числових результатів експериментальних досліджень використано регресійний аналіз. Для обгрунтування сталої стратегії транспортно-експедиторської компанії в розглянутому прикладі застосовані елементи функціонального аналізу.

Результати. Результати проведеного експерименту дозволили визначити якісні залежності між кількістю обслуговуваних заявок і кількістю диспетчерів, залучених до обслуговування заявок, для випадку, коли рішення операторів підтримуються спеціалізованим програмним забезпеченням, і для випадку, коли рішення приймаються традиційно.

Наукова новизна. Використання теоретико-ігрового підходу у цьому дослідженні базується на розширеному моделюванні процесу обслуговування вантажів, де випадковість попиту та стохастичність процесу обслуговування враховуються комплексно. Це дозволило обгрунтувати нову стратегію оптимального функціонування транспортно-експедиторських компаній.

Практична значимість. Запропонований методологічний підхід пропонується використовувати транспортно-експедиторським компаніям для оцінки стійких стратегій при обслуговуванні клієнтів на даному ринку. Використання розробленого підходу на практиці дозволяє експедиторам знизити експлуатаційні витрати, досягнувши мінімального негативного впливу на навколишнє середовище.

Ключові слова: *сталий розвиток, теорія ігор, експедирування вантажів, стохастичний попит*

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