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DEFINITION OF THE OPTIMAL STRATEGIES OF TRANSPORTATION MARKET PARTICIPATORS

Summary. A generalized model of the transportation services market is presented. The models of conflict situations between transportation services market participators are developed. The payoff functions are defined to assess the optimal strategies of market participators.

OKREŚLENIE OPTYMALNYCH STRATEGII UCZESTNIKÓW RYNKU TRANSPORTOWEGO

Streszczenie. Przedstawiono uogólniony model rynku usług transportowych. Opracowano modele konfliktowych sytuacji między uczestnikami rynku usług transportowych. Dla oceny optymalnych strategii uczestników rynku określone są odpowiednie funkcje wypłat.

1. INTRODUCTION

A large number of scientific publications and methodical guidelines are dedicated to the problem of improving the transportation process organization. Basically, their essence is in improvements of technological nature, which are reached by some optimization measures: transportation routing [1], the coordination of vehicles and loading/unloading stations joint work [2], the choice of optimal capacity of vehicles [3], etc. Similarly, in works, which authors develop methods of market participants' optimal strategies definition, these strategies are considered in the economical and technological planes: a strategy for managing the development of rolling stock [4], the strategy of inventory management
[5, 6], the pricing strategy of the enterprise [7], etc. However, the transportation companies operate in the market of logistics services, and what is significantly – they interact with each other. Hence, speaking about their market behavior strategies, the links between market players, as well as the existence of different interests, should be taken into account.

The activities of modern freight forwarding companies have mostly mediating character [8], and therefore are characterized by the presence of conflicts appearing from the need to harmonize the interests of various parties. In this paper the author offers a model for determining the optimal strategies for participants of the transportation market, based on the methodology of game theory. Also a numerical example of practical use of the model is briefly discussed.

2. THE BACKGROUND OF THE MATHEMATICAL MODEL

The generalized model assumes three levels: upper (macrologistics) – transportation services' market as a whole, the middle – the interaction of the subjects of three types – freight forwarders, carriers and cargo owners, and the lowest (micrologistics) – the level of individual enterprises.

2.1. The principal model of the transportation market

Transportation market currently is characterized by a large number of participants – both cargo owners and carriers and intermediaries – freight forwarders (FF), who organizationally provide the process of cargo delivery. Transportation market is macrologistic system (a large material management system, covering enterprises and industrial organizations, agencies, trade and transport organizations [9]), so the simulation must be implemented with the systems theory methodological approach, which the realization principle is fundamental in the concept of logistics [10].

The subjects of the transportation market – freight forwarders FF_n, $n = 1…N$, carriers C_m, $m = 1…M$, and freight owners FO_k, $k = 1…K$, are the subsystems of market system (its components). Groups of one type elements form appropriate sets:

$$S_{FF} = \{FF_1,\ FF_2,\ ...,\ FF_N\},$$
$$S_C = \{C_1,\ C_2,\ ...,\ C_M\}, \qquad (1)$$
$$S_{FO} = \{FO_1,\ FO_2,\ ...,\ FO_K\},$$

where: S_{FF}, S_C, S_{FO} – sets of all the freight forwarders, carriers and freight owners at the transportation services market.

It should be noted that in this context a freight forwarder means a market participant that performs the complex of intermediary operations, which supports the delivery of cargo from the shipper to the consignee. In more detail the issue of terminology in the field of the transport market modeling is described in [7].

The interaction of market entities (subsystems) is caused by the needs of the cargo owners on the one side – in the movement of goods, and by the needs of the carriers on the other side – in the availability of orders for transportation. Therefore, the forwarding service (FS) is a process of meeting the needs of carriers and cargo owners. Requests for FS (demand) and the process of their servicing form streams that connect elements of the system. The FS process is provided by the flows of the three types circulating between system elements – material, information and financial.

The flows can be represented as matrices for the n-th forwarder: $F_M^{(n)} = (Q_{M\,ij}^{(n)})_{i=1,\,j=1}^{K,M}$, $F_F^{(n)} = (Q_{F\,ij}^{(n)})_{i=1,\,j=1}^{K,M}$, $F_I^{(n)} = (Q_{I\,ij}^{(n)})_{i=1,\,j=1}^{K,M}$, where F_M, F_F and F_I – material, financial and information flows; Q_M, Q_F and Q_I – set of values of parameters that characterize the material, financial and information flows, respectively.

Indicators that characterize the material and information flows, are the parameters of the flow of requests for FS – from the cargo owner to the forwarder (the need for FS), from the carrier to the FF (the need for orders) and from the forwarding agent to the carrier (component of the client service process). Parameters of the flow of requests for each of these types are described in [7]. Financial flows, circulating between forwarders and shippers, as well as between FF and carriers, are formed on the basis of individual requests, and are obviously described by the amount of money paid by the freight owner to the forwarder and by the FF to the carrier, respectively.

Thus, the transportation market (M_{TS}) is a set of considered objects:

$$M_{TS} = \langle S_{FF},\ S_{FO},\ S_C,\ F_M,\ F_F, F_I \rangle . \qquad (2)$$

This expression is a general view of the model of freight forwarding market.

2.2. The model of conflict situation

Basing on the content and features of the process of forwarding service, we can make a conclusion about the feasibility of using the apparatus of game theory while selecting the optimal strategies of FF on the market of transport services.

In [11, 12] the game is defined as a conflict situation, and the game takes place, if the parties, who are the decision making subjects, the possibilities of the conflict parties (the set of all strategies), the outcomes of the conflict (situations), the parties, who defend some interests, and interests as themselves (goals) of parties, concerned in the conflict, are identified.

According to the definition of the game [12], the conflict situation can be formally represented as follows:

$$\Gamma = \left\langle \Re_A, \{r_K\}_{K\in\Re_A}, r, \Re_I, \{\succ_K\}_{K\in\Re_I} \right\rangle, \qquad (3)$$

where: $\Re_A$ – the set of all decision-making subjects (coalitions of action); r_K – the set of all feasible solutions (strategies) of the game players, who make decisions; r – the set of all situations (outcomes) of the game; $\Re_I$ – the set of all subjects defending the interests of certain entities (coalitions of interests); $\succ_K$ – the set of all interests of the parties concerned in the conflict (relation of preference).

The H_K function, which takes real values, – the payoff function of coalitions of interests (K), is defined to determine the preference relation on the set of situations.

Let us consider an elementary situation of the interaction of market entities (Fig. 1).

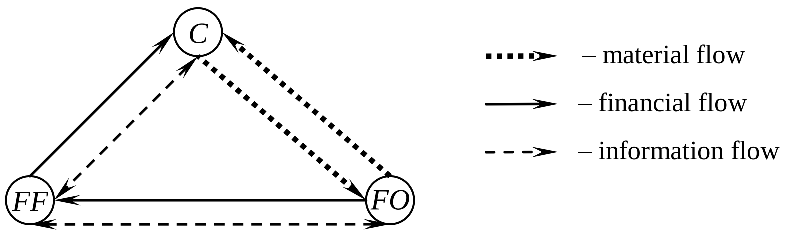

Fig. 1. Interaction between subjects of the transportation market
Rys. 1. Interakcje między podmiotami rynku transportowego

The following types of situations of interaction, characterized by the presence of different interests, are possible for the transport market subjects' operating process:

1. The interaction between forwarder and carrier (Γ_1).
2. The interaction between forwarder and freight owner (Γ_2).

The interaction of carrier and cargo owner is carried on a level of technological process, i.e., a conflict of interests is not considered for this pair.

The coalitions of interests are at the same time the coalitions of action in the Γ_1 conflict situations. Moreover, the main purpose of the FF, as well as of the carrier, is to increase its profit, and therefore the corresponding payoff functions can be specified on the set of real numbers. In this case, the game can be formalized as follows:

$$\Gamma_1 = \left\langle I_1, \{r_i\}_{i\in I_1}, \{H_i\}_{i\in I_1} \right\rangle, \qquad (4)$$

where: I_1 – the set of players; r_i – the set of strategies of i-th player; H_i – the payoff function of i-th player.

The I_1 set, obviously, consists of two elements: $I_1 = \{FF; C\}$.

Similarly to (4) the Γ_2 conflict can be presented:

$$\Gamma_2 = \left\langle I_2, \{r_i\}_{i\in I_2}, \{H_i\}_{i\in I_2} \right\rangle, \qquad (5)$$

where: I_2 – the set of players, $I_2 = \{FF; FO\}$.

2.3. The model of the choice of forwarder strategies

It is necessary to determine the elementary actions of forwarder and cargo owner while the interaction on the FS market to formalize the strategies of the conflict situation participants. The services
A_k (k = 1…5), provided by FF, can be assigned to FF elementary operations:

A_1 – provision of services of technological character;
A_2 – provision of information and referral services;
A_3 – provision of commercial services;
A_4 – provision of maintenance services;
A_5 – provision of organizational services.

The level of detalisation while the formalization of the A_k elements can be changed (this is determined by the purpose of simulation). Moreover the dimension of the payoff matrix will be changed.

Different combinations of A_k represent the FF strategies. In accordance with the terminology of game theory [11], the set of all combinations of A_k elements is the set r_{FF} of FF strategies. The element of the set of all possible strategies can be conveniently represented as a vector $\Phi_A \in r_{FF}$:

$$\Phi_A = \begin{vmatrix} A_1 & A_2 & A_3 & A_4 & A_5 \\ \varphi_1 & \varphi_2 & \varphi_3 & \varphi_4 & \varphi_5 \end{vmatrix}, \tag{6}$$

where: φ_1, φ_2, ..., φ_5 – probabilities of respective services usage, $\sum_{k=1}^{5} \varphi_k = 1$.

The elementary actions of the cargo owner in the conditions of competition at the market of transport services are to use services (B_1) or to deny services of certain freight forwarder (B_2).

As the payoff function of a forwarder as a business entity it is appropriate to define the profit from servicing a particular request of the cargo owner:

$$P_{FF} = D_{FF} - E_{FF}, \tag{7}$$

where: P_{FF} – forwarder's profit, \$/request; D_{FF} – forwarder's income, \$/request; E_{FF} – costs of the forwarder, \$/request:

$$D_{FF} = \sum_{k=1}^{5} T_k \cdot \varepsilon_k, \tag{8}$$

where: T_k – an amount paid for forwarding services, \$/request; ε_k – indicator, which takes the value 1, if the service is ordered by the client, and 0 otherwise;

$$E_{FF} = D_{FF} \cdot \delta_D + E_{ut} + E_{lease} + E_{connect}, \tag{9}$$

δ_D – the share of the dispatcher wage costs; E_{ut} – expenses for payment of utility bills, \$/request; E_{lease} – the cost of rent payments for office premises, \$/ request; $E_{connect}$ – costs for communication services (telephone, Internet services, mobile communication), \$/request:

$$E_{ut} = \frac{E^{ut}_{month} \cdot t_{ser}}{T^{h}_{month}}, \tag{10}$$

where: E^{ut}_{month} – monthly expenses for utilities, \$/month; t_{ser} – service time of one request, h/request; T^{h}_{month} – total working time of the forwarder per month, h/month.

It is obvious that the optimal value of the payoff function (7) for the freight forwarder is its maximum.

The payoff function for the customer (for the cargo owner) is defined as costs E_{FO} of satisfying its requirements in freight forwarding services and has the following form:

$$E_{FO} = E_{FFS} + E_f, \tag{11}$$

where: E_{FFS} – costs of FS, \$/request; E_f – costs of finding the optimal service option, \$/request:

$$E_{FFS} = D_{FF} = \sum_{k=1}^{5} T_k \cdot \varepsilon_k. \tag{12}$$

Costs of finding the optimal service option can be accepted as a value that is linearly dependent on FF service fees (the correlation between E_{FFS} and E_f, and the type of dependence definition are perspective directions of research):

$$E_f = \delta_f \cdot E_{FFS} , \tag{13}$$

where: δ_f – share of expenses for FF search depending on the FS cost (on average δ_f = 0,05).

The optimal option for the cargo owner is the minimum possible value of the (11) payoff function.

The integral (resulting) payoff function H is appropriate to be defined as the difference between the forwarder and the cargo owner payoff functions, because in this case the maximization of the payoff function satisfies both sides of the conflict situation:

$$H = P_{FF} - E_{FO} . \tag{14}$$

Since the tariffs for the A_2 – A_5 services do not depend on the parameters of demand, then we can say that T_k = const for k = 2 ... 5. The A_1 technological services include shipping and handling operations. Technological services payment is determined by the basic parameters of the demand – the volume of the shipment and distance of delivery.

2.4. The model of the choice of carrier strategies

The set r_C of carrier strategies is a set of M models of vehicles, which the fleet of transportation company contains, or which may be purchased: $r_C = \{B_1; B_2; ...; B_M\}$. The set r_{FF} of forwarder strategies contains two elements ($r_{FF} = \{C_1; C_2\}$): the C_1 strategy – to use the carrier for executing the request and the C_2 strategy – to refuse the carrier services. Payoff functions for sides of the conflict reflect the result of one strategy, of the pair of strategies, or of the multiple of strategies. The payoff function for each of the participants in a conflict situation is the profit from the request realization.

The forwarder payoff function H_{FF} is calculated by the formula

$$H_{FF} = D_{FF} - E_{FF}^{e} , \tag{15}$$

where: E_{FF}^{e} – costs of the FF for request performing, \$/request:

$$D_{FF} = P \cdot C_T , \tag{16}$$

C_T – market rate for 1 tkm of performed transportation activities, \$/tkm; P – transportation activities done when request performing, tkm/request;

$$E_{FF}^{e} = T_C + E_{FF}^{f} + E_{FF}^{in} , \tag{17}$$

T_C – amount paid to the carrier in accordance with the agreed fares for delivery services, \$/request; E_{FF}^{f} – costs of the FF on the carrier searching, \$/request; E_{FF}^{in} – costs on the primary processing of information, \$/request.

The costs of primary processing are linked with the consideration of the desirability of the carrier proposal and include the carrier's costs on the dispatcher wages and communications services. Value E_{FF}^{in} can be defined as follows:

$$E_{FF}^{in} = E_{FF}^{e} \cdot \delta_{in} , \tag{18}$$

where: δ_{in} – coefficient, indicating which part of the freight forwarder operating costs the costs of primary processing constitute (on average δ_{in} = 0,01).

Currently, the existing databases for the choice of rolling stock, provided by specialized Internet portals, allows minimizing of the search time. In these circumstances, the FF costs on searching of rolling stock much less than T_C, so it may not be taken into account.

The payoff function H_C of the carrier is defined similarly to (15):

$$H_C = T_C - E_C^{e} - E_{oth} - E_C^{f} , \tag{19}$$

where: E_C^{e} – operational costs of the carrier for the performed request, \$/request; E_{oth} – other carrier costs, \$/request; E_C^{f} – carrier costs on the request searching, \$/request:

$$E_C^{f} = E_C^{e} \cdot \delta_{app} , \tag{20}$$

δ_{app} – coefficient, indicating which part of the carrier's operational costs the costs of request searching constitute (on average δ_{app} = 0,01).

The carrier's services costs for the FF are determined by market rates (C_T), and for a given level of carrier's profitability R the T_C value is calculated according to the dependence

$$T_C = (E_C^e + E_{oth}) \cdot (1 + R) . \tag{21}$$

Carrier's operational costs are calculated on the basis of the rate for 1 tkm C_{tkm}, \$/tkm:

$$E_C^e = P \cdot C_{tkm} . \tag{22}$$

Other costs can be calculated on the basis of the rough norm δ_{oth}, which indicates what part of the operational costs all other items of expenditure constitute:

$$E_{oth} = E_C^e \cdot \delta_{oth} . \tag{23}$$

For example, for motor transport enterprises of Ukraine in average δ_{oth} = 0,42 (http://www.lardi-trans.com).

The integral payoff function H_Σ represents the difference between carrier and FF payoff functions:

$$H_\Sigma = H_C - H_{FF} . \tag{24}$$

For the C_1 strategy the integral payoff function in accordance with (15)-(24) has the next form:

$$H_\Sigma^{C_1} = -P \cdot (C_T + C_{tkm} \cdot \delta_{app}) + P \cdot C_{tkm} \cdot (1 + \delta_{oth}) \cdot (1 + 2 \cdot R + R \cdot \delta_{in} + \delta_{in}) . \tag{25}$$

For the C_2 strategy the payoff function reflects the processing costs, under this D_{FF} = 0 and T_C = 0:

$$H_{FF}^{C_2} = -E_{FF}^{in} . \tag{26}$$

The carrier payoff function in the case of FF refusal from its services, obviously, reflects only the cost of searching:

$$H_C^{C_2} = -E_C^f . \tag{27}$$

The integral payoff function for C_2 strategy takes the next form:

$$H_\Sigma^{C_2} = P \cdot C_{tkm} \cdot [\delta_{in} \cdot (1 + R + \delta_{oth} + R \cdot \delta_{oth}) - \delta_{app}] . \tag{28}$$

3. STUDYING THE CASE

3.1. Forming the FF optimal strategy

The following experimental studies were conducted on the basis of Fursenko forwarding company (Kharkiv). Taking into account rates of the enterprise and average market indicators for the average values of the cargo sending and delivery distance for this enterprise the payoff matrix is composed. On the basis of dependence (14) the integral payoff matrix is obtained (Tab. 1).

Table 1

Base rates of the freight forwarder and payoff matrix

Type of service	Strategy code	Rate, \$/request	Payoff matrix elements, \$/request	
			B_1 strategy	B_2 strategy
Services of technological character	A_1	100	-15	-41
Information and referral services	A_2	138	-21	-9
Commercial services	A_3	163	-24	12
Maintenance services	A_4	125	-19	-20
Organizational services	A_5	113	-17	-30

There is no saddle point in the obtained integral payoff matrix, i.e. pure strategies in this game do not exist. For games of two persons, which can be described by matrices of 2×n type (i.e., one player has 2 strategies, and the other one – n strategies), the search of optimal strategies can be represented graphically (Fig. 2). The carrier B_1 and B_2 strategies match to the left and right ordinate axis, on which the values of the payoff function for all forwarder strategies are postponed. Pairs of points, corresponded to the certain strategies, define the straight lines, which are the graphical mapping of the FF alternatives.

In game theory it is proved that any finite game $m \times n$ has a solution, in which the number of useful strategies of one of the side does not exceed the lesser of m and n numbers. In particular, this implies that the game $2 \times n$ has always a solution, in which no more than two useful strategies are involved [13]. The optimal strategies for player with the n basic alternatives (in the considered game – for the forwarder) are a couple of strategies that correspond to lines intersecting at the lowest point of the upper polygonal line.

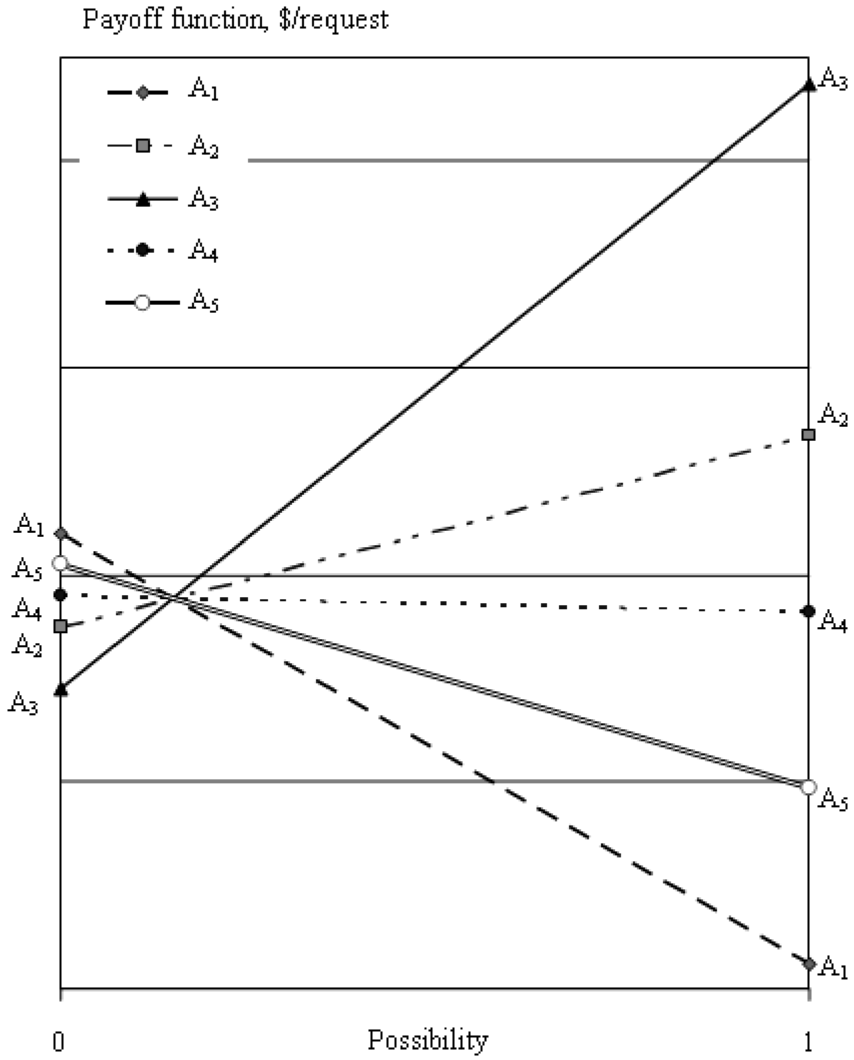

Fig. 2. Numerical simulation results of FF strategies choice
Rys. 2. Wyniki symulacji numerycznej przy wyborze strategii spedytora

At Fig. 2 the forwarder optimal strategies are reflected by A_1A_3 polygonal line, which corresponds to the maximum value of the payoff function. Consequently, the optimal mixed strategy of the FF is to provide A_1 and A_3 services. For determining the optimal ratio of A_1 and A_3 services it is necessary to determine the coordinates of the intersection point of the A_1A_1 and A_3A_3 lines.

A_1A_1 line contains (0, -15) and (1, -41) points, and A_3A_3 line – (0, -24) and (1, 12), respectively. To determine the coordinates of the point of lines intersection, the A_1A_1 and A_3A_3 equations must be determined from the general equation of the line:

$$\frac{x-x_1}{x_2-x_1}=\frac{y-y_1}{y_2-y_1}. \quad (29)$$

The equation of A_1A_1 line in accordance with (29) has the following form:

$$\frac{x-0}{1-0}=\frac{y+15}{-41+15}, \quad (30)$$

The equation of A_3A_3 line, respectively:

$$\frac{x-0}{1-0}=\frac{y+24}{12+24}. \quad (31)$$

Transforming (30) and (31), we obtain the following dependence:

$$\begin{cases} y_{A1A1}=-26\cdot x-15, \\ y_{A3A3}=37\cdot x-24. \end{cases}. \quad (32)$$

Considering that at the point of intersection y_{A1A1} = y_{A3A3}, we obtain: $-26\cdot x-15=37\cdot x-24$. From where the abscissa of the intersection point x_M = 0,15. Consequently, for optimal mixed strategy of FF the share of A_1 services (technological services) would be 0,15, while the share of services of A_3 type (commercial services) – 0,85, respectively.

3.2. Forming the carrier optimal strategy

To illustrate the method of determining the carrier optimal strategies, we consider the models of vehicles used for delivery of goods in international transport (Tab. 2). Providing the specific vehicle model for servicing of the request is the carrier strategy B_j, $j = 1\ldots11$. In this case a mixed strategy is a variant of the structure of the carrier's fleet. Probability φ_j of j-th strategy use corresponds to the proportion of vehicles of this model in the total number of the rolling stock fleet.

Table 2

Carrier strategies and payoff matrix

Vehicle model	Strategy code	Cost value, \$/tkm	Payoff matrix elements, \$/request	
			C_1	C_2
Volvo FH12	B_1	0,0103	22,25	24,47
МАЗ-МАН 543268	B_2	0,0109	8,74	26,05
Iveco AS440S43	B_3	0,0111	3,34	26,62
МАЗ-544069	B_4	0,0113	0,63	26,95
DAF-XF105.460 SSC Intarder Mega	B_5	0,0110	6,04	26,36
MAN-TGA 18.540 XXL	B_6	0,0106	14,14	25,46
FREIGHTLINER-Columbia	B_7	0,0105	16,84	25,16
MERCEDES BENZ-Actros 2641 LS	B_8	0,0099	30,35	23,66
KENWORTH-T2000	B_9	0,0103	22,25	24,47
RENAULT-Premium 420	B_{10}	0,0109	8,74	26,05
SCANIA-R124L 400	B_{11}	0,0111	3,34	26,62

Based on the data of www.etractor.ru, della.ua, www.lardi-trans.com and www.avtodispetcher.ru network resources, the delivery self cost for each of the models of vehicles were determined (Tab. 2), these data are relevant to the September 2010. Using proposed formulas, the integral payoff functions were defined. The results of calculations for the mathematical expectation of the cargo volume in the 20 tons and the delivery distance of 650 km with an average market price of 0,02 \$/tkm are represented in the integral payoff matrix (Tab. 2).

The payoff matrix must be checked for the presence of pure strategy. The pure strategy (i.e. the use of the same vehicle model for cargo owners servicing) is absent for the obtained variant, because the minimum in rows and maximum in columns elements do not match. Thus, the optimal strategy for the carrier belongs to the set of mixed strategies. The search for the optimal balance of trucks models in the structure of the carrier's fleet is illustrated graphically at Fig. 3.

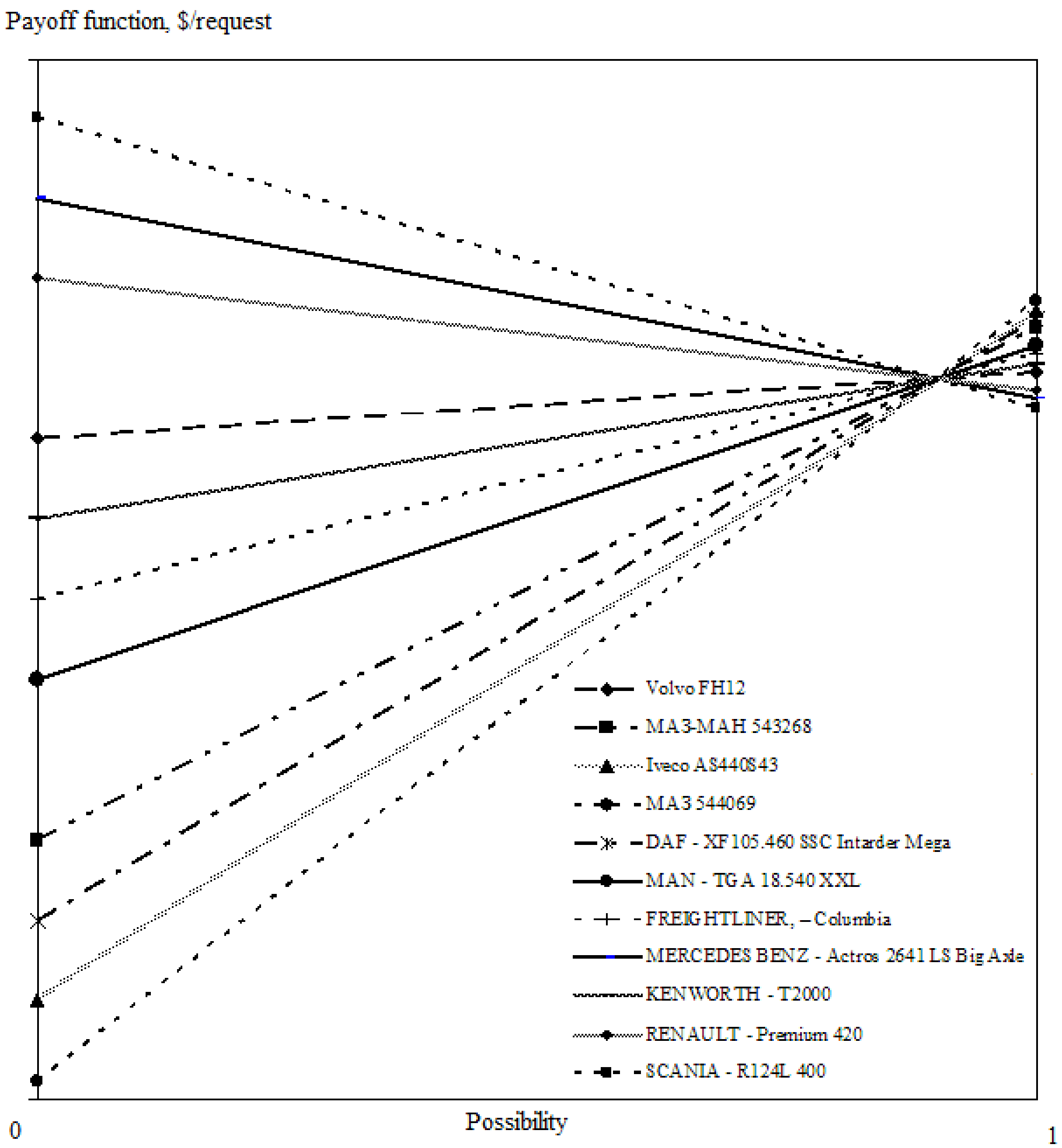

Fig. 3. Graphical interpretation of the method of determining the carrier strategies
Rys. 3. Graficzna interpretacja sposobu określania strategii przewoźnika

As we see, the lines, reflecting the maximum values of the integral payoff function, corresponds to B_4 and B_{11} strategies, i.e. – to MA3-544069 and SCANIA-R124L 400 models. It should be noted, that these strategies form the optimal strategy for a variety of considered alternatives of vehicle models. The optimum ratio of truck operating time for these models (in the case of the same work time – the ratio of vehicles in the fleet structure) is defined similarly – as the abscissa of the point of the lines intersection.

For the considered example МАЗ-544069 line equation has the $y_{MA3} = 26,32 \cdot x + 0,63$ form, and for SCANIA-R124L 400 line – $y_{SCANIA} = -9,69 \cdot x + 33,07$, respectively. The abscissa of the lines intersection point is 0,89. Thus, when cargo owners servicing the carrier's optimal strategy is to use SCANIA-R124L 400 vehicle model at 89% of the total time of rolling stock work and МАЗ-544069 model – in remaining 11% of the working time.

4. CONCLUSIONS

1. The proposed method is effective and relatively simple tool of selecting the optimal strategies of freight forwarders and carriers on the market of forwarding services under condition of the availability of information about the parameters of the forwarding service demand.

2. The conducted research suggests the advisability of providing for clients primarily of such forms of forwarding services as technological (re-processing and storage of goods, receipt and delivery of cargo, documentation forming, transportation of goods) and commercial (performance of calculations, recording and reporting, cargo insurance, sales of package, leasing of equipment).

3. The solution of the problem of choosing the optimal strategies of the carrier using described approach allows us to conclude that the carrier should use no more than two models of vehicles from a number of alternatives, those two, which are characterized by the lowest and highest cost of the transport operations implementation. Further development of the proposed method is in detailing of the components of the market entities payoff functions – the cost of primary processing and of the search for forwarding service request.

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