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Article

Mathematical and experimental research of the shopping centers' managers' strategic behavior

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Abstract: The managers' strategic behavior of commercial real estate in a competitive environment is discussed. The means of this research are methods of mathematical and experimental game theory. Illustrates an example of a decision-theoretic game problem with two players engaged in the management of competing shopping centers. The strategies of these players are determined by the costs of the development. Since the number of visitors is constantly and changing the quality of shopping centers, managers actually pull visitors from each other, the game-theoretical formulation of the problem of management of shopping centers corresponds to the zero-sum game. The model example shows that with the help of mathematical modeling it is possible to determine the theoretical expected behavior of agents. The model of the software module created specifically for experimental research is described. The experiments are designed to compare the theoretically predicted behavior with the real actions of people. The novelty is that at significant costs of the Manager for the development and promotion of shopping and entertainment centers, the strategies of managers are resistant to each other's actions, in contrast to changes in the external environment is shown.

Keywords: experimental economy; mathematical game theory; experimental game theory; behavioral experiment; business game; shopping centers; property management.

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1. Introduction

The task of management of shopping and entertainment complexes (SEC) has a high degree of uncertainty associated with the complexity of forecasting the results of management and business activities of management entities, increasing the number of heterogeneous economic entities and the implementation of their business activities autonomously [1-3].

The desire of the subjects to make individual decisions only in their favor (egoistic behavior) can lead to a decrease in the overall results of their activities, since the results of the activities of some depend on the actions of others, and vice versa [4]. This phenomenon in experimental and behavioral Economics is referred to as public good problem and free rider problem. Usually the complexity of research and forecasting of economic processes associated with incomplete or asymmetric information of participants of socio-economic systems, however, as the results of studies show, people behave sometimes irrationally, which is an inevitable source of error of any mathematical modeling [5]. Uncertainty is heightened by the fact that even rational people who are prone to strategic behavior do not always follow balanced and/or optimal strategies. In addition, equilibrium strategies are not always sustainable, that is, the erroneous action of one participant (or conscious action to destabilize the equilibrium) can lead to unexpected consequences, for example, due to the cascade effect.

This confirms the fact that the key source of uncertainty is the human factor and requires a study of the strategic behavior of SEC management entities. Detailed mathematical formulation of the SEC control problem and its justification are given in the paper [6]. Below are the main provisions used in the organized experiment.

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2. An example of a decision theoretic game problem with two players engaged in the management of a competing SEC

2.1. Raw data for solving the problem of competing SEC management

The internal parameters characterizing the shopping and entertainment complex for the consumer include: x_1 – square, x_2 – range of goods, x_3 – transport availability, x_4 – aesthetic parameter, x_5 – promotions and discounts, x_6 – quality of goods, x_7 – availability of brands and x_8 – events (here are the data obtained in the course of sociological (marketing) research of the SEC of the city of Perm[1], in which respondents were asked to assess how important each of the SEC parameters is to them). Among the above internal parameters describing the SEC, we can distinguish managed (y = 4, 6, 7, 8) and unmanaged at the tactical and operational level (ny = 1, 2, 3, 5).

Let there be two competing SEC ($j \epsilon J$, $J=\overline{1,2}$), each of them has three pedestrian-transport zones and their intersection forms ten sectors (K). The task of SEC management is formulated as a conditional optimization problem, where profit (1) or profitability (2) can be used as a target function (OF), while limiting the ownership of the costs of SEC development and promotion to a set of acceptable values $c_y \epsilon C_y$, $y \epsilon Y$, where Y – multiple managed parameters.

$$OF = P_j(c_{jy};c_{-jy}) = \mu \cdot Ar \cdot n_j\left(c_{jy};c_{-jy}\right) - \sum_{y\in Y} c_{jy} - TFC_j, \tag{1}$$

$$OF = RR_j\left(c_{jy};c_{-jy}\right) = \frac{\mu \cdot Ar \cdot n_j\left(c_{jy};c_{-jy}\right)}{\sum_{y\in Y} c_{jy} + TFC_j} - 1, \tag{2}$$

where TFC_j – total fixed costs of the Manager of the j-th SEC; μ – customer conversion ratio (the percentage of visitors who purchase something); Ar – the average amount of purchases that visitors make; c_{jy} – costs of managing j-th SEC for the development of managed parameters of the object; n_j – the number of attracted visitors in the j-th SEC, determined by the expression:

$$n_j = \sum_{k=1}^{10} N_k \cdot \frac{\prod_{y\in Y} Q_j(c_y)^{q_y} \cdot \prod_{ny\in NY} Q_j(c_{ny})^{q_{ny}} \cdot T_k^{-\lambda_k}}{\sum_{j=1,2}\prod_{y\in Y} Q_j(c_y)^{q_y} \cdot \prod_{ny\in NY} Q_j(c_{ny})^{q_{ny}} \cdot T_k^{-\lambda_k}}, \tag{3}$$

where $Q_j(c_y)$ – quality of managed parameters of object j; $Q_j(c_{ny})$ – quality of unmanaged parameters of object j; T_k – correspondence time to I-th SEC of visitors to I-th sector; λ_k – power parameter that affects the importance of correspondence time for visitors; N_k – number of inhabitants in sector k, k={1,…,10}; ny – parameters not controlled at the tactical and operational level; q_y, q_{ny} – power parameters. Since the number of visitors is constantly $n_1+n_2=const$, and by changing the quality of SEC, managers actually pull visitors from each other, the game-theoretical formulation of the management problem SEC corresponds to the zero-sum game.

The solution of the optimization problem is the cost distribution for SEC management, defined by the expression:

$$c_{jy}^{*} = \arg\max_{c_y \in C_y}\left(OF\left(c_{jy}, c_{-jy}\right)\right), \tag{4}$$

which corresponds to the game-theoretic formulation of the control problem, taking into account that the result of the Manager's activity depends on the actions of the competitor, and vice versa. The game situation is denoted by a $-j$ according to the theory of games [7]. Accordingly, in the expression (4) c_{-jy} is the cost of a competitor to manage his SEC.

The data presented below are the initial ones, at which the authors conducted theoretical and experimental research of strategic behavior of SEC managers.

[1] Advantages the Results presented in tablet form. Retried from https://goo.gl/enasqb (creation date: 18.09.2013)

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Table 1. Evaluation of quality parameters SEC and values their importance, compiled by the authors based on the results of a survey of visitors SEC

i	Parameter	Q_1	Q_2	q_i
1	Area	0,947	0,740	0,12
2	Range of goods	0,853	0,648	0,15
3	Transport accessibility	0,851	0,887	0,15
4	Aesthetic parameter	0,861	0,842	0,12
5	Promotions, discounts	0,660	0,516	0,11
6	Quality of goods	0,789	0,759	0,15
7	Availability of brands	0,884	0,748	0,12
8	Events, concerts	0,681	0,605	0,08

Because the only some of the parameters are controlled, it is advisable to group the unmanaged ones and calculate the constant factors used in the expression (3).

Table 2. Initial values of quality of unmanaged parameters and their importance for consumers, necessary for the model

	Q_1	Q_2	q	Q_1^q	Q_2^q
ny=1	0,947	0,740	0,12	0,993	0,965
ny=2	0,853	0,648	0,15	0,976	0,937
ny=3	0,851	0,887	0,15	0,976	0,982
ny=5	0,660	0,516	0,11	0,951	0,924
			$Q_{remaining}$	0,885	0,803

Table 3. The values of the power parameter λ, the time correspondence to the SEC and the number of residents, depending on the sectors

Sectors (K)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Value of parameter λ:	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_9	λ_{10}
for SEC_1	0	0	0,5	0,5	0,5	0	1	0,5	1	1
for SEC_2	0	0,5	0	0,5	0,5	1	0	1	0,5	1
N_k	5182	8292	8292	6215	6215	20729	20729	31094	31094	50000
T_1	45	45	80	80	80	45	160	80	160	160
T_2	45	80	45	80	80	160	45	160	80	160

In the discrete case, the total number of control strategies will be determined by the formula:

$$U=\prod_{m=1}^{M}\bar{u}_m, \qquad (5)$$

where m is the ordinal number of the parameter that can be controlled by the SEC Manager; M – total number of parameters to be managed; $u_m=\{1,2,\dots,\bar{u}_m\}$, $\bar{u}_m$ – the maximum number of options for changes to the criterion m.

Consider an example where the strategy of SEC managers depends on four cost options for changing four managed criteria. In this case ($\forall m$: $\bar{u}_m=\bar{u}=4$) the number of strategies of each manager will be determined by the formula:

$$U=\bar{u}^M=4^4=256\,. \qquad (6)$$

In a study made an assumption that the function that determines the quality of the private parameter, depending on its content cost, is linear and is given by (7):

$$Q(C_y) = \begin{cases} \dfrac{c_y - \underline{c}_y}{\underline{c}_y - \overline{c}_y}, & c_y \in C_y \\ 0.001, & \text{если } c_y = \underline{c}_y \end{cases} \qquad (7)$$

where $\underline{c}_y$ – the minimum value of C_y, and $\overline{c}_y$ – the maximum value. Expression (7) is a logic to avoid a situation $Q_j(c_y) = 0$, since it is according to the expression (3) will lead to zero attendance facility.

Under the above assumptions and the initial data, the set of SEC quality values can be represented in the following form (Figure 1), by ranking in ascending order. The type of the graph depends on the values of the importance factors q_y of the controlled parameters. The figure shows 4 areas that characterize the importance of these parameters for visitors of the shopping and entertainment complex (on a scale from 0 to 1, where 0 is not an important parameter, 1 is a very important parameter).

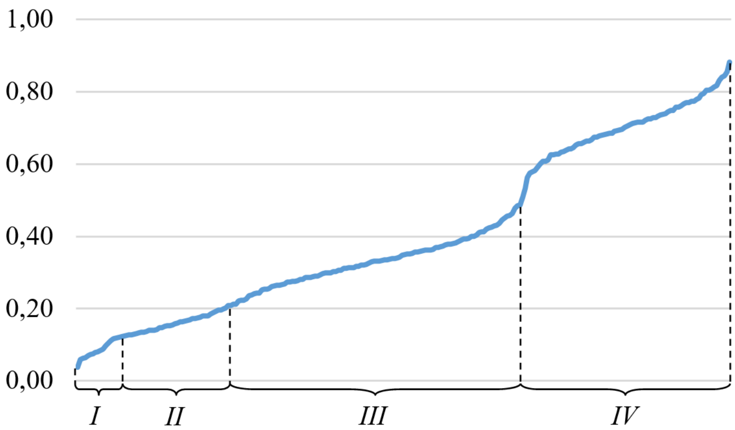

Figure 1. Schedule Quality SEC values ranked by ascending

Let the costs for the development of individual SEC parameters be set as follows (Table 4).

Table 4. Example of cost distribution options to manage the four criteria

Variants of distribution of management costs	advertising / brands y=7	aesthetic appearance y=4	quality of goods y=6	events y=8
u=1	40	0	100	25
u=2	60	120	200	40
u=3	90	250	300	55
u=4	120	500	400	70

In this case, we can construct graph SEC quality depending on costs (Fig. 2). As can be seen, the quality function for given cost functions is non-monotonic.

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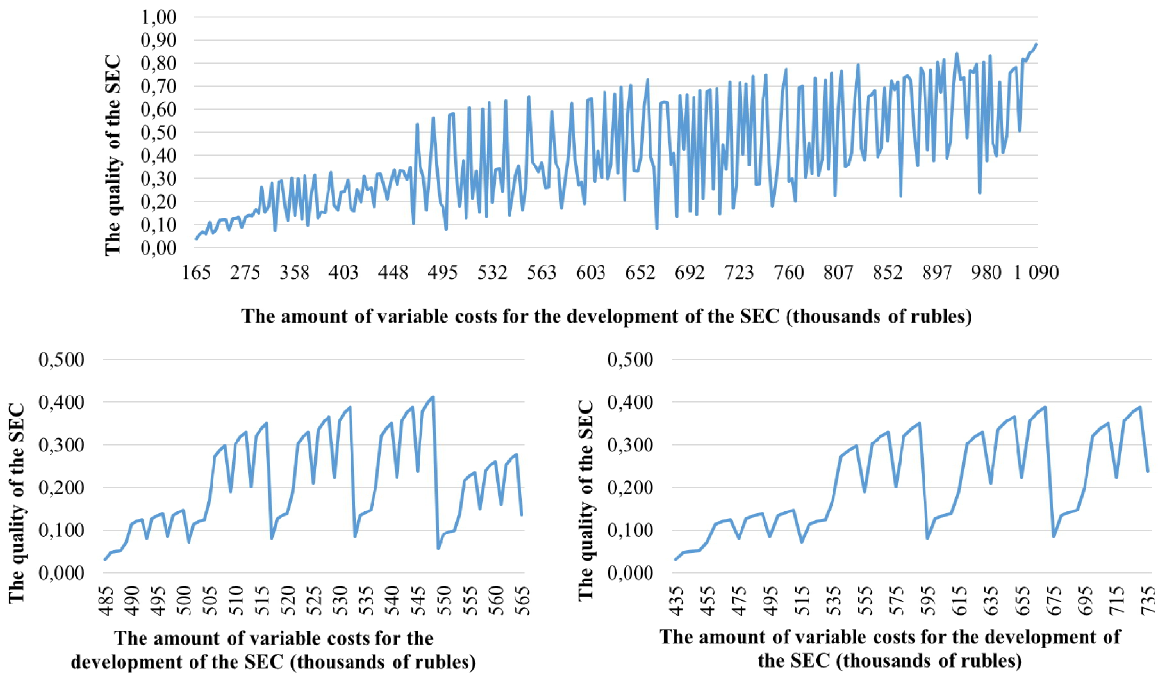

Figure 2. Graph of quality values shopping and entertainment complexes (SEC): with a full set of cost options for its development (top graph); at changing advertising costs and fixed costs c_4=120, c_6=300 и c_8=25 (lower left graph); at changing costs for the quality of goods and fixed costs c_7=60, c_4=250 и c_8=25 (lower right graph).

According to expression (4), the optimal solution to the management problem of the SEC is to allocate the management budget to change the controlled parameters, which provides the maximum of their personal profit [6] or profitability. The optimal strategy of the SEC Manager by profit maximization criterion (orange columns) and profitability maximization (gray columns) is shown below (Figure 3).

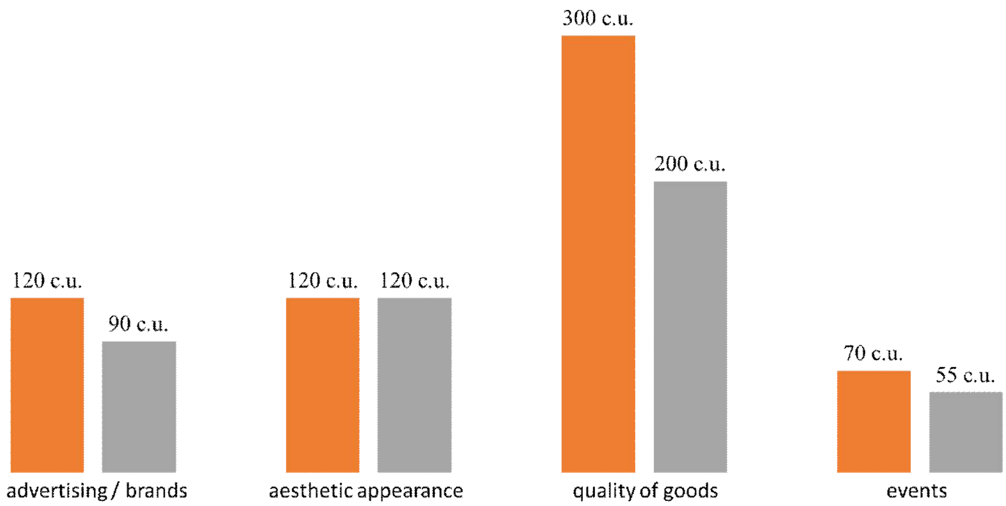

Figure 3. The optimal strategy for the first player. Note: at μ=0.1, the purchase is made every tenth visitor SEC; AR-0.5 c.u.; competitor's quality SEC (Q) - 0.663, in relative scale [0;1].

It is worth noting that these solutions are obtained with a known strategy of the second player and a given level of consumption. The level of consumption is characterized, on the one hand, the share of visitors, making purchases in the SEC (the conversion rate - μ), and, on the other hand, the

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average amount of purchases that make visitors SEC (size of the average check - AR). These parameters describe changes of the environment. However, for the purposes of this study, devoted to the study of strategic behavior of competing entities, the impact of the external environment is ignored, and the level of consumption is considered constant. Examples of the dependence of the optimal strategy of the SEC management on the changing environment are given below (Fig. 4, 5).

Distribution costs for SEC development shows (Fig. 4, 5) that, when the rate of consumption becomes profitable to invest money in the development and promotion of SEC, which is almost obvious. However, the task of searching for the optimal allocation of resources at the SEC's management is not a trivial task and its solution is quite time-consuming, making the creation of demand management decision-making support system. It should also be noted that the most sensitive strategy is precisely to changes in the external environment.

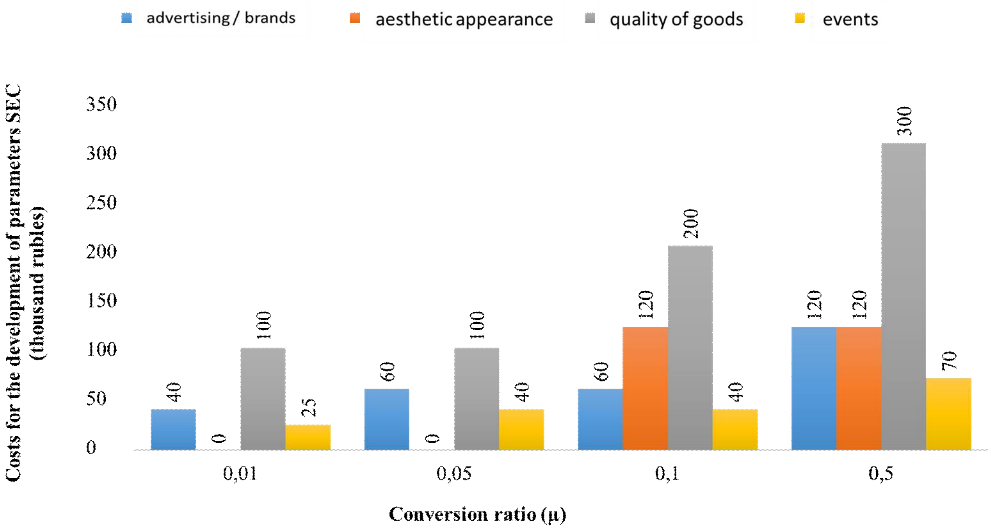

Figure 4. The optimal strategy distribution of development costs SEC when the target profit function and the average bill is equal to 0.1 c.u. at different conversion ratios. *Note:* at μ=0.01, the purchase is made by every hundredth visitor of SEC; at μ=0.05, the purchase is made by every twentieth visitor of SEC; at μ=0.1, the purchase is made by every tenth visitor of SEC; at μ=0.5, the purchase is made by every second visitor of SEC.

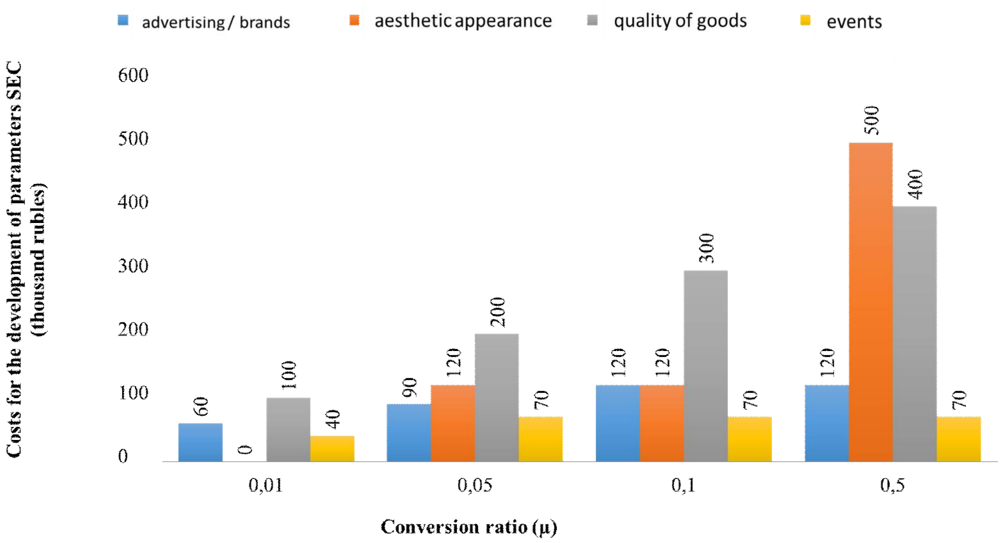

Figure 5. The optimal strategy distribution of development costs SEC when the target profit function and the average bill is equal to 0.5 c.u. at different conversion ratios. Note: at μ=0.01, the purchase is

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made by every hundredth visitor of SEC; at μ=0.05, the purchase is made by every twentieth visitor of SEC; at μ=0.1, the purchase is made by every tenth visitor of SEC; at μ=0.5, the purchase is made by every second visitor of SEC.

2.2. An example of solving a game-theoretic problem with two players managing the competing SEC

In this paper, we illustrate an example of the solution of the game-theoretic problem in the simplest formulations, where the participants in the game are two entities that manage the competing SECs and their strategies are determined by the costs of their development.

In a situation where the player does not know the opponent's strategy, it is suggested to search for strategies according to the concept of the maximum guaranteed result (MGR). This situation is typical for players with the first rank of strategic reflection. The second rank of reflexion means that the player calculates his Best Response (BR), knowing the opponent's strategy. The third rank of reflexion means that the player uses the strategy corresponding to Double Best Response (DBR), with the known Best Response enemy [8]. Comparative analysis strategies obtained based on these concepts is presented in Table 5.

The decision game-theoretic formulation of two SEC players-managers shows that with an increase in grade of reflection, the players share the same strategies (Table. 5). It is important to note that the decision depends on the level of consumption, which in this study deliberately not investigated.

Table 5. Matrix of strategies of players in the formulation of a game with two managers when using profit as an objective function

Strategies		**2nd player**		
		MGR2	*HO2*	*ДНО2*
1st player	*MGR1*	151 (MGR1) 87[1] (MGR2)	151 (MGR1) 151 (HO2(MGR1))	151 (MGR1) 151 (ДНО2(HO1(MGR2)))
	BR1	151[2] (BR1(MGR2)) 87 (MGR2)	151 (BR1(MGR2)) 151 (BR2(MGR1))	151 (BR1(MGR2)) 151 (DBR2(BR1(MGR2)))
	DBR1	151 (DBR1(BR2(MGR1))) 87 (MGR2)	151 (DBR1(BR2(MGR1))) 151 (BR2(MGR1))	151 (DBR1(BR2(MGR1))) 151 (DBR2(BR1(MGR2)))

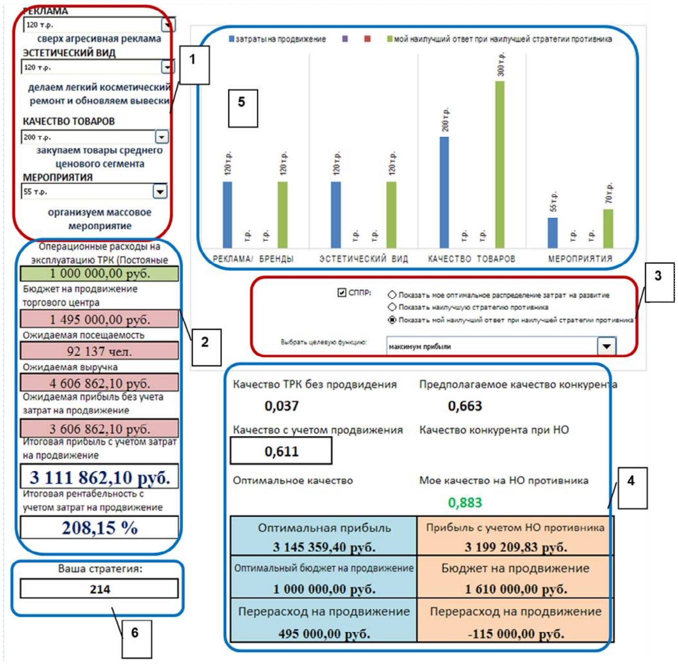
[1]The player's choice of strategy **87** corresponds to the following costs: for advertisement 60 c.u., for aesthetic appearance – 120 c.u., for the quality of goods – 200 c.u. and for holding events – 55 c.u.; [2]strategy **151** corresponds to: an increase in advertising costs – 90 c.u., costs for aesthetic appearance – 120 c.u., costs for the quality of goods – 200 c.u. and increase the cost of events up to 70 c.u.. Strategy number is determined according to the expression $1\cdot\left(u_{y=8}-1\right)+4\cdot\left(u_{y=6}-1\right)+16\cdot\left(u_{y=4}-1\right)+64\cdot\left(u_{y=7}-1\right)$

Thus mathematically possible to determine the theoretically predicted behavior of the SEC management subjects and becomes relevant experimental study of strategic behavior through a series of business games. An experimental study of the above problem in the form of a business simulation game will make it possible to find out – to which strategy the players will come.

The purpose of the organization of the experiment is to test the reachability people strategies, which provide the balance of the system.

2.3. A model of the software module created for the implementation of the pilot study

To organize the experiment, the authors created a layout of a software module based on MS Excel, which is shown in the figure below (Figure 6).



	changeable parameters
	automatically calculated parameters
1	options cost of management the four criteria that were implemented as drop-down lists
2	numerical data expressing quantitative parameters of the SEC optimality of the player
3	strategy performance dashboard
4	quantitative characteristics of a quality SEC
5	bar chart of the current distribution of costs for the player's promotion, as well as implemented decision support system (DSS) with the ability to select the target function of the player (profit or profitability)
6	automatically determined sequence number of the player's strategy in the current allocation of costs for SEC management

Figure 6. The display form of the player – Manager SEC.

Players act as managers of two SECs competing with each other. The goal of the players is to maximize personal profit or profitability in managing the costs of developing their SEC. It is worth noting that the optimal allocation of costs depends on the objective function, and may be different (see Figure 3).

The rules of the game provide for the possibility of scenario modeling, during which the player searches for the optimal, in his opinion, or the so-called acceptable pseudo-optimal solution [2] on the distribution of costs for the management of the SEC (see Figure 6, area 1). When searching, the changes of the resulting parameters are analyzed (see Figure 6, areas 2 and 4).

When a player makes a decision on the allocation of costs for the SEC development, he can use the DSS (see Figure 6, area 3, "DSS" checkbox) to compare your solution with the optimal one. During the experiment, the control is carried out so that the DSS is turned on by the player only after the decision he made.

When connecting the DSS, players can use the strategy switches that show:

«My optimal allocation of development costs» (it is calculated without taking into account the actions of the enemy, with the settings of the game as a competitor); in this case, the optimal distribution is determined by the following expression:

$$c_{1y}^{*} = c_{1y}^{*}\Big|_{Q_{2_0}} = \arg\max_{c_{1y}\in C_y}\left(OF\left(c_{1y}\,\Big|\,\prod_{y\in Y} Q_2\left(C_y\right)^{q_y}\cdot\prod_{ny\in NY} Q_2\left(C_{ny}\right)^{q_{ny}} = Q_{2_0}\right)\right), \tag{8}$$

where Q_{2_0} – this is the quality of the opponent's SEC given by the game conditions.

«The best strategy of the enemy» (is determined under the assumption that the strategy of the player will correspond to the optimal allocation, see the previous strategy; this mode is designed to see what quality SEC competitor it is beneficial); The best strategy of the enemy is described as follows:

$$c_{2y}^{*} = \arg\max_{c_{2y}\in C_y}\left(OF\left(c_{2y}\,\Big|\,c_{1y} = c_{1y}^{*}\Big|_{Q_{2_0}}\right)\right). \tag{9}$$

«My best answer at the best answer of the opponent» (determined by the assumption that the opponent walks according to his best answer; this mode is implemented as double best response); the double best response is described as:

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$$DBR_1 = c_{1y}^* \Big|_{c_{2y}^*} = \arg\max_{c_{1y} \in C_y} \left(OF\left(c_{1y} \middle| c_{2y} = c_{2y}^* \right) \right). \quad (10)$$

According to the authors of the experiment, these switches are necessary to visualize the optimal distribution of costs for the development of SEC, as well as comparing the strategies of players at different levels of reflection (see table 5). When switching, the histogram visualizes the calculated data for the corresponding mode, and in the area 4 the optimal values of the quality of the player and his opponent are displayed. Also in the layout there is a switch showing the optimal distribution of the target function OF (profit maximization (1) or profitability (2)) selected by the rules.

At the end of the turn, each player tells the experimenter the serial number of the strategy he selected and the value of the quality of his SEC in the implementation of this strategy. At the beginning of the next turn, each player replaces the quality of the competitor on the value that reached the opponent on the last turn.

The end of the game is the situation when a certain number of moves ends in the game or the players do not change their strategies for the second consecutive move. The latter also takes into account the situation in which players would be beneficial (advisable) to change their strategy. This will show the difference between theoretically predicted and actual player behavior.

Before starting the experiment, players are informed of all the theoretical information about the essence of the game and methods of solving the SEC management problem. The experimenter must be convinced that each player correctly understood the rules of the game and his role, through feedback.

During the preliminary experiments, two aspects were found: with the apparent cognitive complexity of the problem, players were able to find the optimal distribution without using the DSS in a fairly short period of time, in other words, players came to a theoretically predicted strategy; the optimal strategy, in turn, was resistant to the actions of the enemy, and therefore the players did not change their strategies, which led to a very rapid completion of the experiments.

The stability of the optimal strategy is explained by the experimental assumptions, including the values of the development and promotion costs of the SEC controlled parameters (see table 4) and about the type of expensive functions (see expression (6)). As it turned out, the costs are too large a change step and when the enemy tries to attract additional consumers to itself, the player's costs for their preservation in its SEC exceed the expected economic effect, determined by the product of the average check (AR) on the number of visitors (n_j) and the conversion rate (μ). This determines the need for additional theoretical study of the SEC control problem with different cost functions.

2.4. Change of functions of costs for development and promotion of controlled parameters of SEC in a computational experiment

To conduct the experiment in the mathematical model, the ranges of cost functions were increased (table 6). The conversion ratio is changed by 0.05, the average check is assumed to be 500 c.u.

Table 6. Example of allocation of increased cost options to manage four criteria

Variants of distribution of management costs	advertising / brands y=7	aesthetic appearance y=4	quality of goods y=6	events y=8
u=1	100	100	100	100
u=2	200	200	200	200
u=3	300	300	300	300
u=4	400	400	400	400

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By increasing the range of costly functions, a stable strategy of player behavior and optimal resource allocation was revealed (optimal strategy – 0, in which y=4, y=6, y=7, y=8 correspond to the level of costs u=1). The resulting optimal strategy can be interpreted as follows: at the maximum cost functions should adhere to the minimum investment in the development and promotion of the SEC.

The next step was to reduce the range of cost functions (table 7). The conversion rate and the average check are the same.

Table 7. An example of the distribution of reduced variants of the cost of four criteria

Variants of distribution of management costs	advertising / brands y=7	aesthetic appearance y=4	quality of goods y=6	events y=8
u=1	5	0	3	8
u=2	10	10	6	16
u=3	15	20	9	24
u=4	20	30	12	32

When reducing the range of cost functions, it was also revealed a stable strategy of player behavior and optimal allocation of resources (optimal strategy – 255, in which y=4, y=6, y=7, y=8 correspond to the level of costs u=4). The resulting optimal strategy can be interpreted as follows: with minimal cost functions should adhere to the maximum investment in the development and promotion of the SEC.

The last step was the replacement of the quality evaluation function from geometric to arithmetic in the mathematical model, with the cost functions adopted in section 2.2 (see table 4). As a result, the optimal strategy (without reflection) was for the first player – 5, for the second (with the first rank of reflection) – 196, for the first (with the second rank of reflection) – 151. As it turned out, the strategies of the players are resistant to the actions of competitors and, accordingly, to the quality of competing secs, that is, the stability of strategies does not depend on the function describing the quality of the object.

With the costs that were taken in the computational experiment, it turned out that there is a distribution that shows their optimal value. We can assume that the adopted objective function, the model adopted to assess the consumer attractiveness and quality of the SEC, adopted in the experiment, the cost functions are adequate. Thus, it can be said that if in real practice of management the quality of SEC, which affects the choice of the consumer object to visit, would be described using a geometric weighted model, the strategy of the Manager would be resistant to the action of his competitor, but not resistant to changes in the environment, in the form of conversion ratio and average check. Previously, the authors [1] showed on the number of SEC of Perm city that the geometric model gives more accurate results of forecasting the consumer flow to real data than other recommended weighted models.

3. Conclusion

In the course of the described experiment it was revealed that the function determining the relationship between the quality of the factor essential for the consumer when choosing SEC and costs does not affect the result of management, in the case of two players managing competing SEC. In this example, the strategy of the players is resistant to changes in the cost functions (decrease or increase values) and to change the function describing the quality of the changed parameters of the SEC.

It should also be noted that the described experiment is a game with full awareness, that is, the player knows all the information about his opponent, which allows to determine the optimal distribution both without taking into account the strategic behavior of the enemy according to (8), and taking into account (10). The transition to the game with incomplete awareness is a promising area of research. In addition, in the future, the authors plan to conduct additional experiments with the possibility of scaling the cost function.

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