Analysis of the Effectiveness of the Successive Concessions Method to Solve the Problem of Diversification

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Abstract

The subject of the paper is multicriteria problems that arise when modeling the complex diversification of a centralized pharmacy network**. The purpose** of the work is to analyze the peculiarities of solving the three-criteria problem of pharmacy network diversification by the method of successive concessions in the MATLAB package. The paper solves the following problems: research of the advantages of the proposed three-criteria model of pharmacy network diversification in relation to the classical two-criteria model of portfolio theory; construction of the relation of dominance on a set of criteria; determination of the area of stability in the space of the parameters of the concessions method; evaluating the effectiveness of the method for problems of different sizes. **The following methods** are used: classical portfolio theory, multicriteria optimization, the successive concessions method, computer modeling of the Pareto set. The results obtained: a study of the processes of complex diversification of the pharmacy network by building portfolio models and solving the relevant multicriteria problems by the successive concessions method. Acceptable sets and sets of pareto-optimal portfolios for the risk management are graphically found, taking into account the activity of the network itself and the client portfolio. **Conclusions:** The results of computer modeling and numerical analysis of solutions by sequential concessions will be useful for automating the business processes of pharmacy networks, risk management, analysis of market data to improve their efficiency.

Keywords 1

multicriteria problem, entropy, optimal portfolio problem, successive concessions method, Pareto set, pharmacy network

1. Introduction

The successive concessions method is used to solve multicriteria problems, in which all partial criteria are arranged in the order of importance. It is considered that each criterion is much more important than the next that it is possible to be limited to consideration of only pairwise connection of criteria and to choose the acceptable concession for the next criterion taking into account behavior of only one following criterion. The disadvantages of the method include the complexity of the appointment and coordination of the size of concessions, the need for a priori ranking of criteria. The complexity increases with the dimension of the problem and the number of criteria. The result does not necessarily belong to a subset of Pareto-efficient solutions. Therefore, the work of the method of concessions is combined with dialogue - by multiple solutions of the optimization problem, graphs of the dependences of the solution at the next stage from the concession of the previous stage obtained. The expert selects the assignments based on the analysis of such diagrams and the assessment of the gains or losses appropriate to the assignment. This paper considers the problem of the effectiveness of the concessions method to solve the problems of portfolio optimization, which are known due to the

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research of H.M. Markowitz [1] and his modern followers [2]. Such tasks are characterized by multicriteria and prevalence, both in the financial and non-financial spheres.

2. Literature review

When applying the methods of multicriteria optimization, traditional definitions of the dominance relation, effective boundary, Pareto set, etc. were used. In particular, in the work of M.Ehrgott [3] the basic definitions, different approaches and methods of multicriteria optimization are systematically stated.

The group of publications of the short literature review devoted to portfolio optimization unites the use of evolutionary methods in research, which is a promising area because the tasks of portfolio optimization belong to the class of complex NP tasks. In [4], a genetic algorithm was constructed to solve the problem of the optimal loan portfolio, where a specific entropy criterion was used as a measure of the degree of portfolio diversification. Paper [5] presents several two-criteria formulations for the optimization of the molecules portfolio, taking into account the limited budget and fixed size of the portfolio. The computational diversity of the set associated with the covariance matrix is presented in this paper by the Solow-Polaski measure. The proposed approach is tested in experimental conditions using accurate and evolutionary approaches. The authors [6] consider the problem of optimizing the product range in conditions of uncertainty.

Another group of publications of the literature review consists of works devoted to the study of the peculiarities of the methods of multicriteria optimization, especially the method of successive concessions. [8] considered various issues of solving multicriteria problems of discrete optimization and proposed the method of equivalence sets; investigated the advantages of this method in comparison with other popular methods of solving multicriteria problems, in particular with the successive concessions method, for the class of discrete optimization problems. In [9] the existing achievements in the application of multicriteria optimization methods are considered to solve problems of evaluating the activities of enterprises, a comparative analysis of modern methods is made, which includes optimization methods both without the participation of decision maker and with the participation of decision maker . In the analysis of the successive concessions method, a class of tasks was indicated for which this method is recommended - optimization of the values of indicators of the enterprise with the definition of sustainability. The advantages of the method also include the implementation of the concept of restrictions that are imposed on the value of the criteria. The disadvantage of this method is that the solution requires verification of its belonging to the area of compromises. Improving the successive concessions method in solving problems of multicriteria optimization in logistics is proposed in [10]. The author's approach is based on the introduction of special formats for the task of choosing a city for the warehouse and the form of ownership. The possibility of analytical determination of the order of certain criteria at the request of decision maker is discussed, the influence of different variants of their ordering on the ranking of alternatives is analyzed.

The variety of subject areas in which researchers solved multi-criteria problems by classical and modern methods indicates the relevance of scientific research in this direction. The authors of this paper in [11, 12] built multicriteria models of complex diversification of the centralized pharmacy network, where the successive concessions method was used to solve the corresponding multicriteria problems. Giving the advantages and disadvantages of this method, identified by other authors [8, 9] for their problems, it is necessary to analyze the effectiveness of the successive concessions method to solve diversification problems. The purpose of the work is to analyze the effectiveness of solving the three-criteria problem of pharmacy network diversification by the successive concessions method in the MATLAB package [13]. To achieve this goal, the following tasks are solved in the paper.

- Research of the advantages of the proposed three-criteria model of pharmacy network diversification over the classical two-criteria model of portfolio theory.
- Construction of the dominance relation on a set of criteria.
- Determination the area of stability in the space of the parameters of the method of concessions.
- Evaluation the effectiveness of the method for tasks (networks) of different sizes.

3. Problem statement and results

The paper [11] proposes a mathematical model of diversification in the form of a three-criteria optimization problem. Solving multicriteria optimization problems is not trivial, and requires special methods and definition of decision maker of certain parameters. One of the classic methods is the method of concessions.

We present one of the tasks of complex diversification, which is formalized as a portfolio model for optimizing the distribution of finances between the outlets of the centralized pharmacy network. Optimally distributing goods among outlets, the network gets the maximum profit in time to respond to the circulation of medications in a certain period, because the demand for medications in a particular pharmacy is not constant and goods not sold in one outlet can be sold on time in another and bring profit without increasing the length of the composition.

The turnover of the pharmacy network is the sum of the turnover of its pharmacy establishments. The turnover of an individual pharmacy is estimated to be sufficient at the level of UAH 2 million, which defines additional limitations in Model 1.

Let, x_i- the share of the i -th pharmacy in the turnover of the pharmacy network, which is equal to the share of distributed financial resources for the i -th pharmacy;

a_i - the expected turnover of the pharmacy (UAH);

n - number of pharmacies in the network.

The model of the optimal portfolio considered in the paper has a composition of the vector objective function, consisting of three criteria. The first two criteria correspond to the classical portfolio theory: risk criterion - *Risk*, which decreases; *Sum* criterion - the profitability on the portfolio, which is desirable to increase.

The third criterion - entropy - *Entropy*, is introduced by us as a value that characterizes the level of diversification of the portfolio and the assessment of the diversity of its components, which the pharmacy network is trying to increase in its activities. In addition, the model has its own specific system of constraints, which is determined by the business process of the pharmacy network in the structure of its activities.

In this model, the *Risk* criterion - structural risk - is the risk of irrational distribution of financial resources of the centralized pharmacy network between outlets. Structural risk is defined as the covariance of the turnover of i -th and j -th pharmacies.

So, we have such multi-criteria problem of quadratic programming.

$$\begin{cases} Risk = \sum_{i=1}^{n} (a_i - \bar{a}) \cdot (a_j - \bar{a}) \cdot x_i \cdot x_j \to min \\ Sum = \sum_{i=1}^{n} a_i \cdot x_i \to max \\ Entropy = -\sum_{i=1}^{n} x_i \, ln(x_i) \to max \\ \sum_{i=1}^{n} a_i \cdot x_i \geq 2 \cdot 10^6 \cdot n \\ \sum_{i=1}^{n} x_i = 1; x \in [0..1] \end{cases} \quad (1)$$

The solution of problem (1) is a vector $\overline{X}^* = (x_1, x_2 .. x_n)$- the optimal plan for the distribution of financial resources of the centralized pharmacy network between outlets.

Solving multicriteria problems of complex diversification will be considered in detail on the example of the successive concessions method [14, 15].

The successive concessions method for solving multicriteria problems is applied when partial criteria can be ordered in ecrease of their importance. To choose a diversification strategy, we first choose the following order: *Entropy-Risk-Sum.*

In the first stage, we determine the optimal value of the first most important Entropy criterion in the field of acceptable solutions.

$$Entropy = -\sum_{i}^{n} x_i \, ln(x_i) \to max$$

$$\begin{cases} \sum_{i}^{n} \bar{a}_i \cdot x_i \geq 2 \cdot 10^6 \cdot n \\ \sum_{i}^{n} x_i = 1, \\ 0{,}001 \leq x \leq 0{,}9 \end{cases} \quad (2)$$

The optimal solution for the first partial criterion is $Entropy^*$.

In the second stage, we solve the conditional optimization problem by the next most important Risk criterion, adding to the conditions that determine the acceptable solutions, the conditions for the deviation of the first Entropy criterion from the found optimal value by $Entropy^*$ no more than the acceptable concession $\delta_1 > 0$. So we have the formalization of the second stage:

$$\begin{cases} Risk = \frac{2}{n} \sum_{i=1}^{n} \sum_{j=i+1}^{n} (a_i - \bar{a}_i) \cdot (a_j - \bar{a}_j) \cdot x_i \cdot x_j \to min \\ \sum_{i=1}^{n} x_i \, ln(x_i) + \delta_1 Entropy^* \leq 0 \\ \sum_{i}^{n} \bar{a}_i \cdot x_i \geq 2 \cdot 10^6 \cdot n \\ \sum_{i}^{n} x_i = 1 \\ 0{,}001 \leq x \leq 0{,}9 \end{cases} \quad (3)$$

The optimal solution according to the second criterion $Risk^*$ is obtained.

The procedure is repeated for the next most important criterion Sum adding to the conditions that determine the acceptable solutions, the conditions for the deviation of the first criterion $Entropy^*$and the second criterion $Risk^*$from the found optimal values $Entropy^*$, $Risk^*$ ot more than the values of the acceptable concessions $\delta_1 > 0$ and $\delta_2 > 0$.

$$Sum = \sum_{i}^{n} \bar{a}_i \cdot x_i \to max$$

$$\begin{cases} \sum_{i=1}^{n} x_i \, ln(x_i) + \delta_1 Entropy^* \leq 0 \\ \sum_{i}^{n} \bar{a}_i \cdot x_i \geq 2 \cdot 10^6 \cdot n \\ Risk \leq (1 + \delta_2) \cdot Risk^* \\ \sum_{i}^{n} x_i = 1 \\ 0{,}001 \leq x \leq 0{,}9 \end{cases} \quad (4)$$

The solution obtained in the third stage is the solution of the three-criteria conditional optimization problem (1).

4. Experiments

Experiments with the models were conducted on real data of one of the pharmacy chains operating in Zaporizhzhia. All calculations were performed in the MATLAB package [13].

Here are some useful definitions for analyzing the effectiveness of solving the three-criteria problem of diversification the pharmacy network by the successive concessions method in the MATLAB package, which are taken from sources [14, 15].

Definition 1. Stability of the algorithm - the ability to perform calculations and obtain the final result with a given accuracy when changing the parameters of the algorithm and input data in some area, which is called the area of stability.

Definition 2. Convergence is a property of an algorithm by changing its parameters to perform calculations with an arbitrarily small error for a given class of input data (i.e. when increasing the number of iterations for matching algorithms, the error will tend to zero). Moreover, the increase in accuracy is achieved by changing the internal parameters of the algorithm (for example, the maximum acceptable difference between the previous and next approximation).

Definition 3. The correctness of the computational method is a property of the indisputable existence of the solution the problem and ensuring stability of the computational algorithm that implements this method.

Let's consider the parameters that affect the results of solving the three-criteria problem of diversification by the successive concessions method.

The method of concessions requires the decision maker to determine the relation of dominance on multiple criteria.

The criteria are: total income of the pharmacy network for a certain period $SUM \rightarrow max$, the risk of income loss, which is defined as covariance on the set of income of pharmacies $SUM \rightarrow max$ and the degree of diversification, which is estimated by the entropy of the investment portfolio of the pharmacy network $ENTROPY \rightarrow max$.

Therefore, the first parameter of the method is the order of solving optimization problems according to one of the three criteria.

The vector of deviation values is the second parameter of the method. After solving the first one-criteria problem, the system of constraints is supplemented by a new criterion, which limits the deviation from the found of the optimal solution at the previous stages.

The number of pharmacies in the network, which determines the size of the problem, is the third parameter of the method.

The fourth parameter concerns the initial approximation and accuracy of the method. In this study, its characteristics are the accuracy of algorithms implemented by standard functions OPTIMIZATION TOOLBOX MATLAB, as the authors have developed a software product for solving research problems in the MATLAB package. Such function is the exitflag, which describes the conditions of the exit. If the value of exitflag is greater than zero, it means that the function matches the desired solution by X. If it is zero, then the maximum value of the function estimate or iteration has been exceeded. But if the value of exitflag is less than zero, then the function does not match to some solution.

Therefore, to analyze the effectiveness of the method of concessions on certain parameters, it is necessary to perform four steps that meet the objectives of this paper.

Step 1. Research of advantages of the offered three-criterion model of diversification of a pharmacy network concerning classical two-criterion model of the portfolio theory.

The initial approximation of the first stage is fixed as 0.1 from the lower limit of the admissibility interval. For each subsequent stage, we take the optimal value of the previous stage as the initial approximation.

Let's compare the solutions obtained using the classical two-criteria approach and the proposed three-criteria approach.

Consider the five modifications of problem (1), which are formed due to the different sequences of consideration of the criteria of profitability (*SUM*), risk (*Risk*) and the degree of diversification (*Entropy*) by the successive concessions method.

So we have two two-criteria problems, which we denote according to the sequence of criteria: $SUM - Risk$ and $Risk - Sum$ The results of solving these problems for a small network (the number of pharmacies in the network n = 5) with estimates of the main parameters are given in Table 1.

Table 1

The results of solving two-criteria problems for a small network

	RISK_SUM n=5	SOLUTION	SUM_ RISK n=5	SOLUTION
Stage of the method	1 level	2 level	1 level	2 level
SUM	25.271	30.038	141.489	25.271
Risk	15.724	17.296	641.734	15.724
ENTR	1.499	1.515	0.0944	1.499
exitflag	1	5	1	5
X=	0.394	0.196	0.001	0.394
	0.001	0.001	0.007	0.001
	0.001	0.001	0.990	0.001
	0.164	0.321	0.001	0.164
	0.439	0.481	0.001	0.439

According to the data in Table 1, we can see that the best result among the two-criteria modifications is achieved for the model RISK_SUM, n = 5.

When adding the third criterion $Entropy$ the vector objective function, you can get a total of 3! = 6 combinations to consider the sequence of criteria by the method of concessions. But the purpose of the third criterion is to increase the degree of diversification of the portfolio, so we consider it the most important and put in the first place (in addition, a number of experiments have confirmed that such arrangement gives better results than others).

Therefore, we will consider two three-criteria problems, which we will also denote according to the sequence of consideration of criteria by the method of concessions: $Entr - SUM - Risk$ and $Entr - Risk - SUM$. The results of solving three-criteria problems (n = 5) with estimates of the main parameters are given in Table 2, where an inefficient modification $Risk - SUM - Entropy$ is also given for comparison.

Table 2

Results of solving three-criteria problems for a small network

	ENTROPY_RISK_SUM n=5			ENTROPY_ SUM_ RISK n=5			RISK_SUM_ENTROPY n=5		
			SOLUTION			SOLUTION			SOLUTION
	1 level	2 level	3 level	1 level	2 level	3 level	1 level	2 level	3 level
SUM	60.149	38.320	42.049	60.149	87.512	78.761	25.271	30.038	28.172
Risk	92.970	31.926	35.119	92.970	214.102	154.047	15.724	17.296	17.296
ENTR	2.322	2.089	2.0897	2.322	2.089	2.089	1.499	1.515	1.690
exitflag	1	5	5	1	4	4	1	1	5
X=	0.200	0.289	0.219	0.200	0.105	0.062	0.394	0.196	0.355
	0.200	0.092	0.067	0.200	0.198	0.106	0.001	0.001	0.017
	0.200	0.056	0.086	0.200	0.437	0.377	0.001	0.001	0.005
	0.200	0.245	0.285	0.200	0.143	0.259	0.164	0.321	0.240
	0.200	0.318	0.344	0.200	0.118	0.196	0.439	0.481	0.384

According to the estimates given in Table 2, it can be stated that the ENTROPY_RISK_SUM model n = 5 has the best result. Comparing the results of calculations from tables 1 and 2, we obtain experimental confirmation that the introduction of the entropy criterion allows to increase the income of the pharmacy network, but also increases the risk in different proportions.

Step 2. Construction of the dominance relation on the set of criteria.

The dominance ratio on the set of criteria, based on the significance of a particular criterion for the optimal decision-maker solution and the results of the experiments in step 1, is most successful in the ENTROPY_RISK_SUM model, where the criteria are ranked in descending order of importance. So this is the best result recommended for decision-maker, so Figures 1, 2, and 3 below show the computer simulation results for the the results of computer modeling of the domain of acceptable solutions, Pareto set and effective solution (red triangle) ENTROPY_RISK_SUM model.

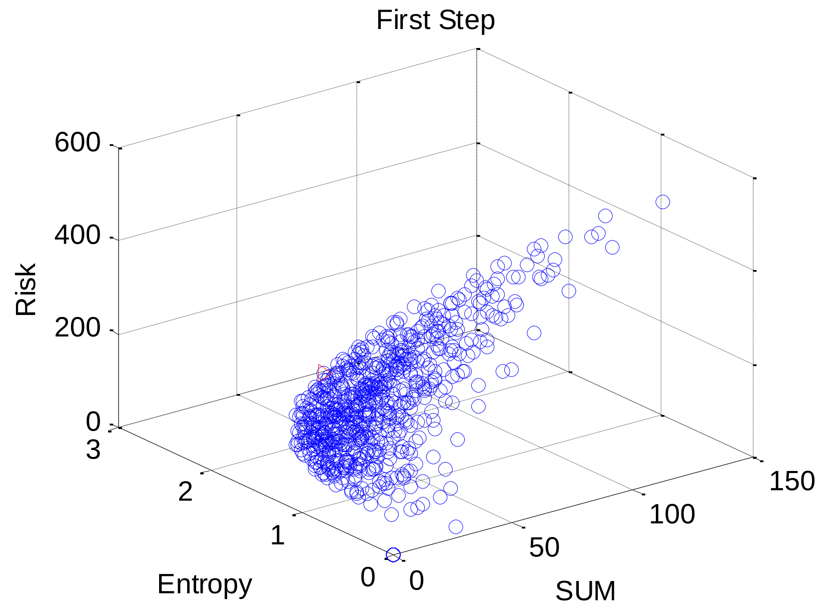

Figure 1: The result of computer simulation of the first step of the concessions method for the model ENTROPY_RISK_SUM

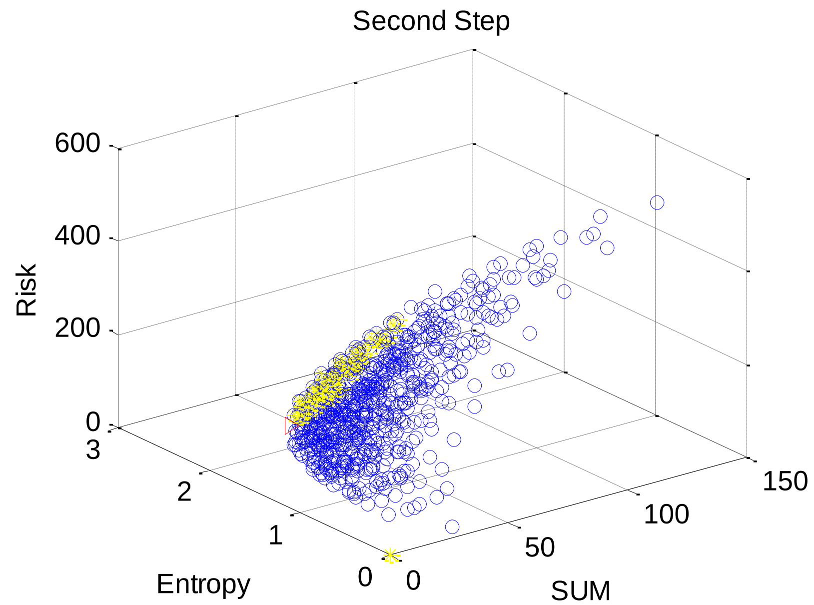

Figure 2: The result of computer simulation of the second step of the concessions method for the model ENTROPY_RISK_SUM

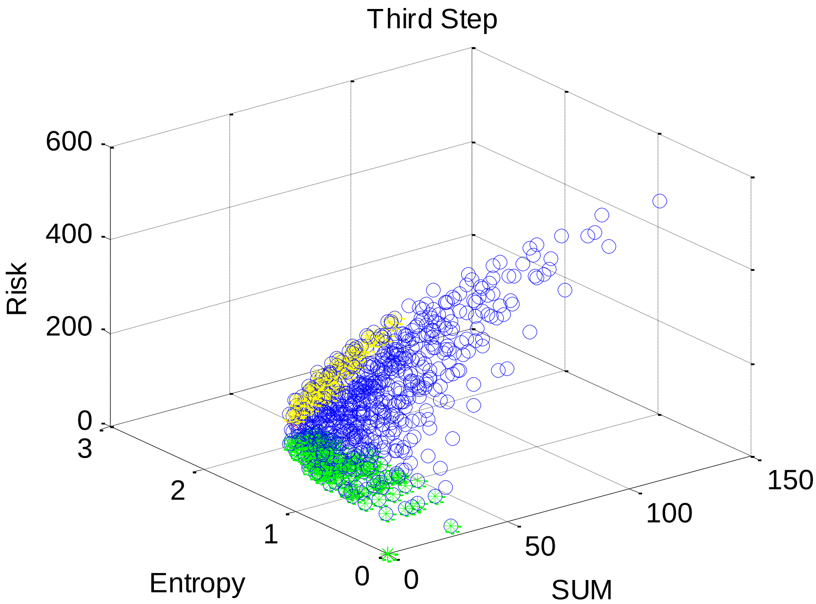

Figure 3. The result of computer simulation of the third step of the concessions method for the model ENTROPY_RISK_SUM

As can be seen from Figures 1, 2 and 3, the visualization of solutions using computer modeling eliminates the previously mentioned disadvantage of the concessions method that the result does not necessarily belong to a subset of Pareto-efficient solutions, and therefore requires verification of its membership compromises. Thanks to the graphical interpretation, the check is performed automatically.

Step 3. Determination the area of stability in the space of the parameters of the concessions method

Construct n area of stability in the space of parameters of the concessions method $\delta_1 > 0$ and $\delta_2 > 0$. The color will indicate the end conditions of the algorithm. Red color indicates the successful completion of the algorithm with the value exitflag=1 (First order optimality conditions satisfied). Marked in green Exitflag = 4 (Computed search direction too small). Marked in blue exitflag = 5 (Predicted change in objective function too small).

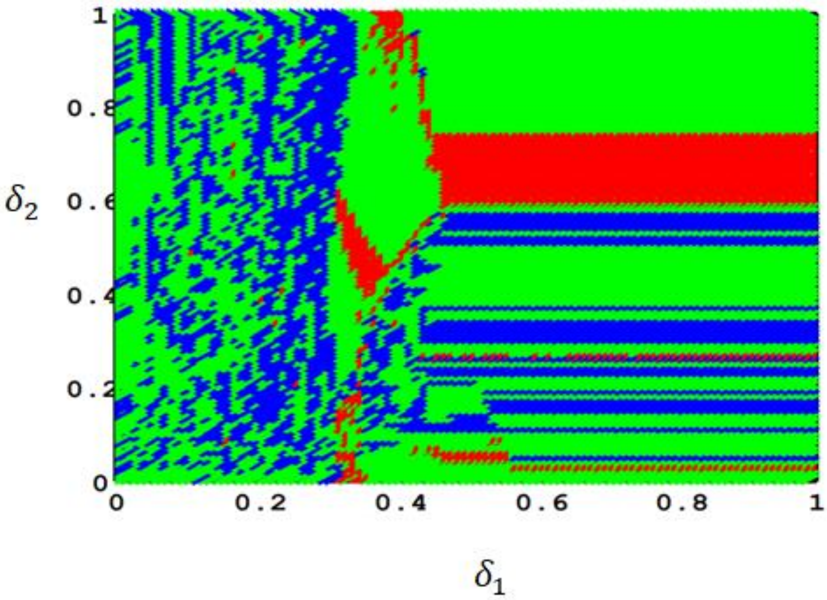

Figure 4: The area of stability in the space of parameters of the method of concessions δ_1 and δ_2 for the model ENTROPY_RISK_SUM, n=5

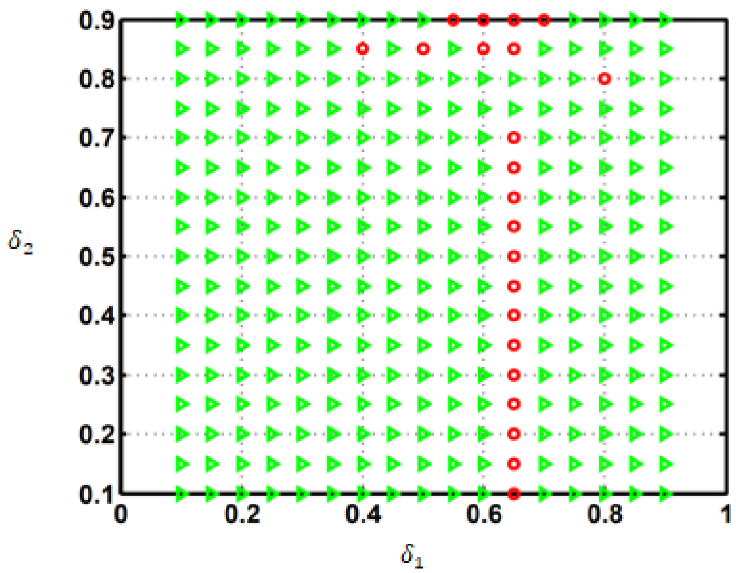

Figure 5: The area of stability in the space of parameters of the method of concessions δ_1 and δ_2 for the model ENTROPY_SUM_RISK, n=5

For the ENTROPY_SUM_RISK model, experiments have shown that the concessions method is resistant to parameter changes for both small and medium networks (n <33) and large networks with n = 65 objects.

Step 4. Evaluation the effectiveness of the method for tasks (networks) of different sizes.

Let us evaluate the efficiency of the method application for networks of different size n = 5, 33, 65 and problems with different composition of the vector objective function.

Previously, Table 1 and 2 presented the results of solving two-criteria and three-criteria problems for small networks n = 5. Similar experiments were performed with medium networks, the results of which are presented in Table 3 and 4.

Table 3

Results of solving two-criteria problems for a medium-sized network, n=33

	RISK_SUM n=33	**SOLUTION**	**SUM_RISK n=33**	**SOLUTION**
	1 level	2 level	1 level	2 level
SUM	33.064	42.227	146.461	47.646
Risk	11.112	12.223	866.358	13.449
ENTR	2.843	3.233	0.364	3.411
exitflag	**5**	**5**	**1**	**5**

Table 4

Results of solving three-criteria problems for a medium-sized network, n=33

	ENTROPY_RISK_SUM n=33		**SOLUTION**	**ENTROPY_SUM_RISK n=33**		**SOLUTION**
	1 level	2 level	3 level	1 level	2 level	3 level
SUM	86.535	60.892	66.475	86.535	127.774	114.996
Risk	104.181	26.347	28.981	104.181	308.114	123.268
ENTR	5.044	4.486	4.539	5.0444	3.985	3.985
exitflag	**1**	**0**	**0**	**1**	**5**	**5**

The results of experiments with large networks (n = 65) are shown in Table 5 and 6.

Table 5
The results of solving two-criteria problems for a large network, n=65

	RISK_SUM n=65	SOLUTION	SUM_RISK n=65	SOLUTION
	1 level	2 level	1 level	2 level
SUM	40.425	50.334	200.644	85.064
Risk	10.659	11.725	2302.353	27.226
ENTR	2.943	3.208	0.727	3.487
exitflag	**5**	**5**	**1**	**5**

Table 6
The results of solving three-criteria problems for a large network, n=65

	ENTROPY_RISK_SUM n=65		SOLUTION	ENTROPY_SUM_RISK n=65		SOLUTION
	1 level	2 level	3 level	1 level	2 level	3 level
SUM	60.598	66.851	93.322	180.035	162.032	60.598
Risk	26.015	28.969	124.682	749.963	210.482	26.015
ENTR	5.245	5.342	6.022	3.312	3.312	5.245
exitflag	**1**	**0**	**0**	**1**	**5**	**4**

Evaluation of the effectiveness of the method of concessions for networks of different sizes is performed by the value of the exitflag function of the MATLAB package, which describes the exit conditions. Therefore, pay attention to the resulting column of each SOLUTION table, which corresponds to the last stage of the method of concessions.

For all problems of dimension n = 5 the value of exitflag is greater than zero, ie this function coincides with the desired solution by X. For the problem with the objective function of the model ENTROPY_RISK_SUM at n = 33 and 65 the value of exitflag is zero. This indicates that the maximum value of the function or iteration estimate was exceeded. But in no case was the exitflag value less than zero when the function did not match some solution.

Therefore, there is always a solution for the considered problems, and its belonging to the acceptable area is checked graphically thanks to the developed software in the MATLAB package.

5. Discussion and Conclusion

This work continues the study diversification models of the centralized pharmacy network, which was started in [11] and [12]. In the article [12], the authors developed four main models of complex diversification, which focus on various aspects of risk management: financial allocation, customer relations, supply and individual outlets. The model of pharmacy portfolio management is considered in more detail in [11]. Recommendations for different initial conditions are developed on the basis of [11], which are determined by variations in the ratio of customers of three types: loyal, random and online customers.

In contrast to [11] and [12], this paper is devoted to the study of effectiveness tool used by the authors to solve the relevant multicriteria tasks - the successive concessions method. Evaluation of the effectiveness of the method was performed on four parameters. For the first the parameter of the method is the sequence of solving optimization problems for one of the three criteria. The experiments were conducted on different arrangements of risk, income and entropy, as well as a comparison of the results of solving classical two-criteria tasks (risk-income) with three-criteria. The second parameter of the method is the vector of deviation values, which is determined by the size of the assignment. There are a number of pharmacies in the network that determine the size of the problem the third parameter of the method. The fourth parameter concerns the initial approximation and accuracy of the method. The acceptable sets and sets of pareto-optimal portfolios were found graphically for all cases of parameter values.

Thanks to the developed software in the MATLAB package it is solved the task of studying the advantages of the proposed three-criteria model of pharmacy diversification networks relative to the classical two-criteria model of portfolio theory, built the relation of dominance on a set of criteria; determining the area of stability in the space of the parameters of the concessions method - which is the scientific novelty of this paper.

The results of computer simulation and numerical analysis performed in this paper successive concessions will provide investors with an appropriate tool decision support will be useful for automating pharmacy business processes networks, risk management, analysis of market data to improve their efficiency functioning.

Among the areas of further research - a comparative analysis of the effectiveness of other methods solving diversification problems and taking into account the dynamic factors that affect the degree of the risk.

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