Multi –Criteria Choice and Ranking of the Objects for Socio-Economic Studies

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Abstract:- Socio-economic studies of rural areas due to their natural and economic heterogeneity combined with the territorial dispersion of the population require the involvement of sufficiently large resources. As a rule, the resources for socio-economic studies are limited. Those facts raise the question of choosing objects from a variety of similar ones. The choice of a pilot object for research and testing of various socio-economic programs is a multi-criteria task. The aim of the study is to develop a chain of methodological techniques and procedures that provide the selection of the most suitable objects for social studies based on a set of criteria. Methods and procedures of mathematical and statistical analysis are used. Well-known methods based on the calculation of normalized distances of feature values to the corresponding "reference" values, as well as the method of the analytical hierarchical process, were subjected to critical analysis. A method has been developed which combines the advantages of currently available approaches. It is concluded that the method allows taking into account the objective and subjective components of the choice problem as effectively as possible and strengthens the scientific validity of the selection of appropriate rural territories for the implementation of pilot socio-economic projects. The method has been developed and tested on the materials of the region of Northern Kazakhstan; and it allows ranking the territories according to any set of criteria.

Key-Words: methodology, model, criterion, multi-criteria choice, ranking, socio-economic objects.
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1 Introduction

In countries such as Kazakhstan, the population is geographically scattered over a large area with extremely different natural and climatic conditions. The population of Kazakhstan is dispersed over an area of more than 2.7 million square kilometers. A huge part of the country's population - 41.6% of the total - still lives in rural areas [3]. At the same time, the incomes of those employed in the agricultural sector are the lowest: 57.4% of the average level for all sectors [4]. Socio-economic studies of rural areas due to their natural and economic heterogeneity combined with the territorial dispersion of the population require the involvement of sufficiently large resources. The limited resources for research inevitably raise the question of the selection of objects for study. Moreover, the selection process is complicated by the need to take into account a number of criteria. And, for example, in order to develop and implement adequate, effective socio-economic programs in rural regions, it is first necessary to accurately determine the place and severity of depression and poverty. The main source of income for rural residents of Kazakhstan is agricultural entrepreneurship. The success of entrepreneurship is determined by a number of factors, primarily the availability of natural agricultural resources, as well as the state of human capital [2], [7], [8], [10]. The formation of a viable economic model of a rural territory involves, first of all, taking into account the quality and characteristics of human capital. Well-known studies of researchers during the soviet period on this issue reflected the problems of the Soviet period and mainly concerned the consolidation of state farms-collective farms, the liquidation of "unpromising" villages [6]. The modern publications on the problem consider various scientific and practical aspects of the socio-economic development of the village [1], [9], [12]. However, the methodological aspects of multi-criteria selection and ranking of socio-economic objects to test various socio-economic programs, as a rule, remain without due attention. In short, the practical impossibility of a thorough continuous study of socio-economic systems due to limited resources raises the question of choosing objects from a variety of similar ones. And, the method which allows to take into account the objective and subjective components of the choice problem and strengthens the scientific validity of the selection process is in need. The aim of the study is to develop a chain of methodological techniques and procedures that provide the selection of the most suitable objects for social studies based on a set of criteria.

The topic under discussion has not only theoretical value - it is significant primarily in a practical sense. It should be noted that in this article the task of multi-criteria selection of objects for research is considered in the context of the problem of identification of potentially depressed rural areas in the conditions of Northern Kazakhstan. However, the developed methodological techniques and procedures can be used to solve other similar problems.

2 Materials and Methods

Currently, there are two approaches to solving this problem in the literature. Each of them is based on ideas that are quite disputable. The first approach is based on the formation of some ideal reference options; the best values of the criteria are taken as reference options [11]. Then the distances between the values of the criteria in each of the considered options $C_{ij}$and their corresponding values of the reference option $C_{ie}$are measured. Further, the found distances are "normalized", that is, they are reduced to a relative indicator by dividing the distances by the corresponding reference values:

$$\alpha_{ij} = \left|\frac{C_{ij}-C_{ie}}{C_{ie}}\right|, \quad (1)$$

where $\alpha_{ij}$the normalized distance between the value $C_{ij}$of the criterion i and its reference value C_{ie}according to the option$j$.

The option that has the smallest sum of the absolute values of the normalized distances is considered to be the closest to the “etalon” and therefore is considered optimal. The methodology finds its application in solving multi-criteria tasks in which (a) the search for the best (most promising) alternatives is conducted and (b) different criteria taken into account in the selection process have equal priorities.

Another approach to solving the problems of multi-criteria selection of the best option is called the analytical hierarchical process; the method became famous abroad, mainly in the United States of America (the calculation procedure is given in. The method allows us to find a solution to the problem in several stages. At the first step, the weights of the criteria are evaluated. To do this, a matrix of numbers is constructed, representing pairwise estimates of the preference of criteria relative to each other. Moreover, the weights are calculated so that in total they turn out to be equal to one. Further, numerical estimates of alternatives relative to each of the criteria are given on a certain scale. Then the estimates of alternatives relative to each criterion are "normalized" so that for each criterion in total they give one. At the third stage, the sum of normalized estimates weighted by the importance of the criteria (found at the first stage) is calculated for each alternative. Alternatives are ranked according to weighted sums of estimates. The key feature of the methodology is the calculation of weights of criteria and "normalized" estimates of alternatives based on an arbitrarily taken point scale. In other words, the calculation procedure is based solely on subjective estimates of preferences. Another feature of the approach is that there may be some incompatibility of estimates in the matrix of comparative estimates of criteria.

The methodological techniques and calculation procedures proposed below combine the advantages of the above approaches to solving the problem and allow (a) to significantly level subjectivity in the evaluation of choice options and (b) are applicable when choosing the most problematic alternatives that require studying and finding ways to improve their “condition”. As well as the considered first method of choosing the best option, the methodology is based on the "normalization" of the distances between the actual (observed) values of the criteria and their critical (reference) values. However, further calculations are carried out taking into account the weights of each of the criteria. The weights of the criteria are determined using the following calculation procedure:

(1) a matrix of numbers is formed, representing pair-wise comparative estimates of the criteria. The comparison is carried out on a scale from 1 to 9 (you can take another interval, say, from 1 to 100: the essence of the method will remain unchanged). These numbers indicate a quantitative assessment of how much one criterion is more important than another for a given expert or a decision-maker. Let's denote these numbers by a_{ij}, where i and j are the numbers of the criteria being compared. In this case, $a_{ij} = 1$ means that the criteria i and j are equally important; $a_{ij} = 9$ means the absolute superiority of criterion i over criterion j. The interpretation of the values of a_{ij} is given in Table 1. If it turns out that criterion i is less important than criterion j then the inverse value of the corresponding index from Table 1 should be used to numerically reflect the ratio. For example, if criterion i is noticeably less important than criterion j, then $a_{ij} = \frac{1}{5}$. The a_{ji} score of the ratio of criteria j and i is equal to $\frac{1}{a_{ij}}$, that is

$$a_{ji}=\frac{1}{a_{ij}} \ . \quad (2)$$

The interpretation of the values of a_{ij} in the matrix of pair-wise comparisons is as follows: $a_{ij} = 1$ means that criteria i and j are equally important, $a_{ij} = 3$ means that criterion i is slightly more important than criterion j, $a_{ij} = 5$ means that criterion$i$is noticeably more important than criterion j, $a_{ij} = 7$ means that criterion$i$ is significantly more important than criterion j, $a_{ij} = 9$ means that criteria $i$absolutely prevails over criterion j.And finally, comparing each criterion with itself gives 1; in other words, $a_{ii} = 1$.

Thus, the matrix of coefficients of pair-wise comparisons of criteria (let's denote it A) in general looks like this:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1m} \\ \dfrac{1}{a_{12}} & a_{22} & \dots & a_{2m} \\ \dots & \dots & \dots & \dots \\ \dfrac{1}{a_{1m}} & \dfrac{1}{a_{2m}} & \dots & a_{mm} \end{bmatrix}; \quad (3)$$

(2) using the given matrix of comparative estimates, we calculate the weights of each of the criteria according to the following scheme:

- calculate the sum of the numbers for each column of the matrix A:

$$S_j = \sum_{i=1}^{m} a_{ij}, j = \overline{1,m}; \quad (4)$$

- divide the numbers a_{ij} from column j by their corresponding sumS_j, $i = \overline{1,m}$. Thus, we get a normalized matrix A_{norm}, consisting of the elements

$$a_{ij}^{norm} = \frac{a_{ij}}{S_j}, j = \overline{1,m}, i = \overline{1,m}, \quad (5)$$

that is,

$$A_{norm} = \begin{bmatrix} a_{11}^{norm} & a_{12}^{norm} & \dots & a_{1m}^{norm} \\ a_{21}^{norm} & a_{22}^{norm} & \dots & a_{2m}^{norm} \\ \dots & \dots & \dots & \dots \\ a_{m1}^{norm} & a_{m2}^{norm} & \dots & a_{mm}^{norm} \end{bmatrix}. \quad (6)$$

In this case, the sum of the numbers in the columns of the normalized matrix is equal to one, that is,

$$\sum_{i=1}^{m} a_{ij} = 1, j = \overline{1,m}; \quad (7)$$

- calculate the average of the numeric elements for each row of the normalized matrixA_{norm}:

$$w_i = \frac{\sum_{j=1}^{m} a_{ij}^{norm}}{m}, i = \overline{1,m}. \quad (8)$$

The obtained valuesw_i, $i = \overline{1,m}$, are the numerical values of the weights of the corresponding criteria.

Further analysis is based on the fact that for each object, the sum of the normalized distances between the values of the criteria to their corresponding critical values is calculated, taking into account the weights. The resulting total distances are then used to rank objects: the greater the total distance, the greater the priority of the object for research. After calculating the weights of the criteria, the procedure for ranking and selecting the most priority object for analysis is carried out in the following order:

(a) we calculate the total normalized distance between the values of the features and their critical values for each object, taking into account the weights of the criteria according to the formula

$$D_j = \sum_{i=1}^{m} \alpha_{ij} w_i, \quad j = \overline{1,n}, \quad (9)$$

whereα_{ij} is the normalized distance between the criterion value $i$and its critical value for the object j; m isnumber of criteria; n isnumber of options to choose from; w_i is weight of the criterion i; the value α_{ij} is calculated by the formula (1), in this case, the reference value of the criterion is replaced by the critical value in the context of a specific problem;

(b) from the obtained values D_i, $i = \overline{1,m}$, the largest one is selected. The corresponding object should be considered the highest priority for the purposes of the project.

The data reflecting the number of rural population, the share of youth aged 16-29 years in the structure of the rural population, the volume of agricultural products produced in the rayons of Akmola and North-Kazakhstan oblasts of the Republic of Kazakhstan for 2014-2020 have been used (Table 1). The presence of urban-type settlements in certain rural areas suggests a breakdown of the totality of the considered rayons into groups according to the degree of ruralization of the population. To assess the ruralization of the rayon, such a characteristic as the share of rural residents in the total population of the territorial unit has been used. These groups of rayons are considered separately in the calculations. Techniques and procedures based on the normalization of the distances of the values of each of the criteria to the corresponding critical values, pair-wise comparison of the priority of the criteria and calculation of the weights of each of them have been applied.

There are 17 rural rayons in Akmola oblast. The task is to rank the rayons in accordance with a set of criteria, followed by the selection of the highest priority as an object of research to find ways to improve the economic prospects of the rural population. The calculations were carried out using 4 types of data: the ruralization of the rayon population, the number of rural population, the share of youth (16-29 years old) in the number of rural population, the volume of agricultural products produced in the rayon. Data of the first type were used to classify rayons according to their degree of ruralization. The second and third types of data allow us to assess the state and prospects of human capital in the rayons in general terms. The fourth one reflects in an integrated form the agro-economic conditions (quantity, quality and availability of resources, market infrastructure). These data correspond to the year of 2020.

3 Results and Discussion

It follows from the data in Table 1 that there are two types of rural areas in the region: (a) with the presence of urban settlements, and (b) absolutely rural, where there are no urban settlements of any form.

For each of the two groups, we make calculations on the ranking of rayons according to three criteria: the number of rural population, the share of youth aged 16-29 in the total number of rural population, the volume of agricultural production. The *minimum* values of the first two criteria and the *maximum* value of the third criterion are accepted as critical for use in the analysis.

Table 1. Rural rayons of Akmola oblast and criteria for their assessment.

No.	Rural rayon	Assessment criteria			
		Ruralization of the rayon*, %	The number of rural population, people	Percentage of youth aged 16-29 years, %	The volume of agricultural production, thousand tenge
1	Akkol	46,1	11838	19,1	25 697 600
2	Arshaly	100,0	27613	17,9	33 499 900
3	Astrakhan	100,0	23393	18,2	45 528 900
4	Atbasar	39,8	18925	20,3	45 594 100
5	Bulandy	47,9	16177	20,4	54 722 900
6	Burabay	37,5	28095	17,7	39 137 400
7	Egindykol	100,0	6008	18,3	28 725 300
8	Enbekshilder	75,0	10449	19,4	31 154 700
9	Yereimentau	65,6	17127	20,1	21 521 600
10	Essil	56,2	13282	18,9	39 207 900
11	Zhaksy	100,0	18768	20,3	46 052 400
12	Zharkaiyn	57,3	7776	18,6	43 683 300
13	Zerendi	100,0	38097	18,9	52 600 800
14	Korgalzhyn	100,0	8660	19,6	16 236 400
15	Sandyktau	100,0	17951	17,5	48 497 400
16	Tselinograd	100,0	79949	19,1	57 445 500
17	Shortandy	100,0	29223	17,6	32 447 700
* the share of the rural population					

In accordance with the methodology, we first calculate the distances between the values of the criteria and their corresponding critical values in each of the considered areas. The calculation results are shown in Table 2.

Table 2. Distances to the critical values of the criteria by rural rayons.

No.	Ruralrayon	Criteria		
		The number of rural population, people	Percentage of youth aged 16-29 years, %	The volume of agricultural production, thousand tenge
Rayons of the first type (with the presence of urban settlements)				
1	Akkol	4062	1,4	29 025 300
2	Atbasar	11149	2,6	9 128 800
3	Bulandy	8401	2,7	0
4	Burabay	20319	0,0	15 585 500
5	Enbekshilder	2673	1,7	23 568 200
6	Yereimentau	9351	2,4	33 201 300
7	Essil	5506	1,2	15 515 000
8	Zharkaiyn	0	0,9	11 039 600

	The critical value	7776	17,7	54 722 900
Rayons of the second type (with the absence of urban settlements)				
1	Arshaly	21605	0,44	23945600
2	Astrakhan	17385	0,74	11916600
3	Egindykol	0	0,81	28720200
4	Zhaksy	12760	2,76	11393100
5	Zerendi	32089	1,45	4844700
6	Korgalzhyn	2652	2,10	41209100
7	Sandyktau	11943	0,00	8948100
8	Tselinograd	73941	1,62	0
9	Shortandy	23215	0,05	24997800
	The critical value	6008	17,5	57 445 500

Then, the distances found must be "normalized", that is, reduced to a relative indicator by dividing the distances by the corresponding critical values according to the formula (1). The results of the calculations are presented in Table 3.

Table 3. “Normalized” distances to the critical values of the criteria by rural rayons.

No.	Rural rayon	Criteria		
		The number of rural population, people	Percentage of youth aged 16-29 years, %	The volume of agricultural production, thousand tenge
Rayons of the first type (with the presence of urban settlements)				
1	Akkol	0,343	0,075	1,129
2	Atbasar	0,589	0,128	0,200
3	Bulandy	0,519	0,134	0,000
4	Burabay	0,723	0,000	0,398
5	Enbekshilder	0,256	0,089	0,756
6	Yereimentau	0,546	0,120	1,543
7	Essil	0,415	0,062	0,396
8	Zharkaiyn	0,000	0,049	0,253
Rayons of the second type (with the absence of urban settlements)				
1	Arshaly	0,782	0,025	0,715
2	Astrakhan	0,743	0,041	0,262
3	Egindykol	0,000	0,044	1,000
4	Zhaksy	0,680	0,136	0,247
5	Zerendi	0,842	0,076	0,092
6	Korgalzhyn	0,306	0,107	2,538
7	Sandyktau	0,665	0,000	0,185
8	Tselinograd	0,925	0,085	0,000
9	Shortandy	0,794	0,003	0,770

To assess the priority of the criteria, local experts from rural areas were involved. Pair-wise comparative estimates of the criteria are shown in Table 4.

Table 4. Pair-wise comparative estimates of the criteria.

Criterion	The number of rural population	Share of youth aged 16-29 years	The volume of agricultural production
The number of rural population	1,00	0,33	0,14
Share of youth aged 16-29 years	3,00	1,00	0,20
The volume of agricultural production	7,00	5,00	1,00

It follows from table 4 that, according to experts, the criterion "Volume of agricultural production" has priority over two other criteria: to a greater extent over the total population and to a lesser extent over the proportion of young people in the rayon. In turn, the criterion "The proportion of youth aged 16-29 years" takes precedence over the criterion for the total population. This prioritization is consistent with common sense, since (a) agricultural production is the main source of income, (b) the proportion of young people in the total population indicates the prospects of the rayon: the more young people, the greater the prospects of the rayon, and vice versa. Of course, with a different formulation of the task, the prioritization would be different.

Further, based on the estimates obtained, it is necessary to form a normalized matrix and calculate the weights of the criteria. For this, a scheme is used, represented by a sequence of formulas (4) - (8). Table 5 presents the results of the corresponding calculations. The last column of Table 5 contains the estimated weights of the criteria: agricultural production received the highest priority (0.724), followed by the share of young people aged 16-29 in the total rural population (0.193) and the rural population (0.083).

Table 5. Normalized matrix of estimates of pairwise comparisons of criteria by priority.

Criterion	The number of rural population	Share of youth aged 16-29 years	The volume of agricultural production	Row average – criterion weight, w_i
The number of rural population	0,091	0,052	0,104	0,083
Share of youth aged 16-29 years	0,273	0,158	0,149	0,193
The volume of agricultural production	0,636	0,790	0,746	0,724

According to the methodology, the rayon with the largest total normalized distance enjoys the highest priority. The results of calculations according to the proposed method are shown in Table 6 (the ranking is carried out in descending order).

Table 6. Total normalized distances taking into account weights (ranked in descending order) across rayons of the Akmola oblast.

No.	Rural rayon	Distance	No.	Rural rayon	Distance
Rayons of the first type (with the presence of urban settlements)			Rayons of the second type (with the absence of urban settlements)		
1	Yereimentau	1,19	1	Korgalzhyn	1,88
2	Akkol	0,86	2	Egindykol	0,73
3	Enbekshilder	0,59	3	Shortandy	0,62
4	Burabay	0,35	4	Arshaly	0,59
5	Essil	0,33	5	Zhaksy	0,26
6	Atbasar	0,22	6	Astrakhan	0,26
7	Zharkaiyn	0,19	7	Sandyktau	0,19
8	Bulandy	0,07	8	Zerendi	0,15
			9	Tselinograd	0,09

As for the group of rayons with the presence of urban settlements, Yerementau rayon is the most priority for the concentration of measures to improve the economic conditions of rural rayons. As to the group of rayons that do not have urban settlements, Korgalzhyn rayon is given the first-degree priority.

As already noted, the matrix of pairwise comparative estimates (3) may have some incompatibility. Obviously, the degree of incompatibility will tend to increase as the number of criteria taken into account increases. The question is how acceptable the weights of the criteria calculated on their basis will be in terms of reliability. Therefore, there is a need for a preliminary check of the matrix for the incompatibility of estimates. Some researchers suggest introducing the *CI* incompatibility index into the analysis [13]. The verification procedure consists of the following steps:

(a) the vector Aw is calculated by multiplying the matrix of estimates A and the vector of weights w_i:

$$Aw = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1m} \\ \frac{1}{a_{12}} & a_{22} & \dots & a_{2m} \\ \dots & \dots & \dots & \dots \\ \frac{1}{a_{1m}} & \frac{1}{a_{2m}} & \dots & a_{mm} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_m \end{bmatrix} = \begin{bmatrix} v_1 \\ v_2 \\ \dots \\ v_m \end{bmatrix}; \quad (10)$$

(b) find the value

$$\gamma = \frac{\frac{v_1}{w_1}+\frac{v_2}{w_2}+\dots+\frac{v_m}{w_m}}{m}; \quad (11)$$

(c) calculate the incompatibility index

$$CI_{calc} = \frac{\gamma - m}{m-1}; \quad (12)$$

(d) find the ratio of the calculated index CI_{calc} to its tabular value CI_{table} for a given number $m$of criteria:

$$R = \frac{CI_{calc}}{CI_{table}}. \quad (13)$$

The CI_{table} tabular index is calculated as the average of the indexes calculated as follows:

(e) using a random number generator, the matrix A is repeatedly formed under the conditions that $a_{ii} = 1$ for all i and $a_{ij} = \frac{1}{a_{ji}}$;

(f) on the basis of each randomly generated matrix, in accordance with the above procedure, the CI incompatibility indices are calculated, which are then averaged.

Note that the index size depends on the number m of criteria in the problem: the larger m, the higher the index.

As can be seen from the formula for calculating the incompatibility index, at *R=0*, there is no incompatibility at all. This is achieved when the equality $\gamma = m$ takes place. The greater the R, the more significant the incompatibility. The general rule for choosing the threshold level of incompatibility: the closer the value of R is to zero, the more reliable the matrix of comparative estimates is. The recommended threshold value is R<0.1.

As one can see, the procedure for analyzing estimates for consistency is very time-consuming. At the same time, it should be emphasized that the presence of some inconsistency of estimates does not affect the procedure for further calculations in any way. It is also obvious that the degree of incompatibility of the assessment matrix directly depends on the qualification and thoroughness of the work of experts who conduct such assessments. Therefore, it is very important to involve qualified experts in the analysis from the very beginning.

Thus, the advantage of the proposed methodological techniques and procedures in comparison with the existing approaches is that they allow considering both objective and subjective components of the selection process. Moreover, they make it possible to impart more objectivity to the subjective component by quantifying subjective assessments.

The presented scheme and procedures for solving the problem of multi-criteria selection claim to be universal in the sense of applicability to a variety of conditions in which rural socio-economic systems (county, rayon, etc.) function. The methodology allows using a variety of criteria, and their number is in principle unlimited. However, considerations of practicality and convenience of calculations may require limiting the number of criteria used, depending on the natural, economic and social conditions of the territories. Therefore, further research is of interest to identify the most important criteria and their typification by natural and economic zones of the countries and regions concerned.

4 Conclusion

The resources allocated for socio-economic research and the implementation of pilot projects are usually limited. Therefore, when implementing such projects in regions characterized by heterogeneity of rural territories and scattered population, it is important to have a methodology that allows assessing and selecting the most appropriate socio-economic systems.

Selection of a pilot object for research and approbation of various socio-economic programs is a multi-criteria task. The proposed methodology allows us to take into account any numerically representable characteristics of socio-economic systems in the analysis. It combines the advantages of currently available approaches to solving the problem of multi-criteria choice and allows us to level out subjectivism and strengthen the objective component and scientific validity of the process of ranking and selecting the systems.

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