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MULTI-CRITERIA MODEL FOR DETERMINING THE URGENCY OF CONSOLIDATION WORKS (ON THE EXAMPLE OF THE MONIECKI COUNTY)

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ABSTRACT: The article proposes the use of one of the methods of multi-criteria decision analysis (AHP method) to determine the urgency of consolidation works in the area of the Moniecki county. To this end, an appropriate set of criteria was adopted for the mutual comparison of precincts in the considered area. The calculations include a non-typical for AHP method, a large number of considered ranges. The analysis covered 201 precincts, and as a result, the areas with the greatest urgency of merging works were indicated.

KEY WORDS: consolidation, planning, multi-criteria decision analysis

Introduction

Very important for the proper development of the agricultural production space and the possibilities of effective management is the development of the proper area structure of farms, as well as the land distribution within these farms. The means leading to this purpose are consolidation and interchange work. In Poland, the related issues are regulated by two legal acts, which are: the Act on Merging and Exchange of Lands and the Act on Real Estate Management.

The rank of problems concerning the shaping of the area structure of agricultural land and the land distribution and their impact on the efficiency of management are perceived by many researchers, which is reflected in various publications on this subject. As examples, mention may be made of such studies as: (Harasimowicz, 2001; Sobolewska-Mikulska, Pułecka, 2007; Szafrańska, 2011; Wierzchowski, 2007; Woch 2007).

In any case, the starting point for planning the consolidation work should be the assessment of the current area structure of farms, which allows assessment of needs and opportunities in this area. This problem was analyzed, among others by the authors of this article at work (Kobryń, Tekień, 2016), the subject of which was to identify the needs and possibilities in the field of consolidation works in the Moniecki county, located in the Podlaskie District. Among other studies dealing with this type of issues, mention may be made in works: (Banat, Janus, 2002; Gniadek, 2013; Jędrzejek et al., 2014; Leń, Noga, 2010; Leń, 2013).

An inseparable element of research aimed at optimization of spatial structures in rural areas are analyses and methodological proposals concerning the development of procedures and tools to facilitate solving problems related to the planning of consolidation and changeover works. Various proposals in this area have been described, among others in the works: (Ayranci, 2009; Cay, Iscan, 2006; Harasimowicz et al., 2009; Janus, 2011; Leń, 2013; Noga, 1990; Woch, 2008).

This study is also part of the above research trend. This work is a development of the threads undertaken by the authors in the study (Kobryń, Tekień, 2016). The area structure of agricultural holdings in the Moniecki county and the merits of changing it through consolidation works were analyzed there. Currently, the authors intend to propose appropriate analytical tools that may be useful at the level of planning of merging and exchange work by facilitating decisions regarding determining the urgency of these works in a given area.

At this point it can be mentioned that similar problems were taken up at work (Leń, 2013). It proposes appropriate solutions for agricultural lands in

the Brzozowski county, located in the Podkarpackie Voivodeship, using tools derived from taxonomic methods in the analysis. In the opinion of the authors of this article, multi-criteria decision analysis (MCDA), also known as multi-criteria decision making (MCDM), can be very useful in solving such problems.

MCDA / MCDM methods constitute a very intensively developing field of research, which is supported by broad application possibilities in solving multi-criteria decision problems in various areas. This is confirmed in many publications describing various practical applications of these methods. Many MCDA / MCDM methods are known from the literature (Figueira et al., 2005; Hwang, Yoon, 1981; Triantaphyllou, 2002; Tzeng, Huang, 2011; Zopounidis, Pardalos, 2010), the most popular ones include the following methods:

- AHP (Analytic Hierarchy Process) (Saaty, 1980, 2005),
- PROMETHEE (Preference Ranking Organisation METHod for Enrichment Evaluations) (Brans 1982; Brans et al., 1984),
- TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) (Hwang, Yoon, 1981).

their popularity is evidenced and developed by (Behzadian et al., 2010, 2012; Sipahi, Timor, 2010), providing an overview of the different uses of these methods.

Below, the proposal of a methodology for determining the urgency of consolidation works using the AHP method will be described, which will be illustrated on the example of the Moniecki county. This choice results from the fact that agricultural activity within the analyzed area is an important production base for Polish dairy moguls, which are „Mlekovita" and „Mlekpol" production cooperatives.

Identification of decision-making criteria

An important role in solving any decision problems is played by the adoption of a coherent set of criteria that should guarantee a comprehensive evaluation of the alternatives considered, and should be characterized by transparency and precise definition of their scope of avoiding redundancy. It should be added that individual criteria can be used to evaluate alternatives in terms of benefits or costs. They are referred to respectively as a stimulant (criterion of the nature of an advantage) or a deterrent (a criterion of a cost nature).

In establishing a set of decision criteria in relation to the analyzed decision problem, which is to determine the urgency of consolidation works in

a given area, the provisions contained in the Instruction No. 1 of the Minister of Agriculture and Food Economy on land consolidation and exchange (dated March 24, 1983) may be helpful. According to them, the classification of villages for consolidation should result first of all from the analysis of the state of land management, and when undertaking consolidation works, the villages which are characterized, among others, should be taken into account:

- a particularly arduous checkerboard of land for both family farms and the inconvenient land development of the Agricultural Property Agency,
- a relatively high average area of farms,
- an extensive checkerboard of land between villages,
- high level of saturation with means of production,
- a wide range of needs and possibilities of making necessary accompanying investments in the field of after consolidation development,
- the need to adjust the holdings to disruptive production conditions of line investments (motorways, express roads, pipelines, gas pipelines, canals, railway lines, windbreaks, anti-erosion devices, etc.),
- a significant possibility of concurrent consolidation of the enlargement of existing family farms at the expense of land of the Agricultural Property Agency or land obtained from persons who agree to sell all or part of their land.

Additional information that may be helpful in adopting the appropriate set of criteria, is included in Appendix 2 to the above instruction, which indicates how to analyze the land integration needs of a given village. Factors of significant importance included:

- total surface area,
- number of farms,
- total number of plots,
- average farm area,
- average plot area,
- average number of plots on the farm.

There is no doubt that – in addition to the substantive correctness of the set of decision criteria – it is important to have the necessary data to assess the decision alternatives in the light of the adopted criteria. Therefore, guided by the possibility of obtaining the necessary data on the basis of public records (such as land and building records), the authors of this study proposed a set of 6 criteria describing the area structure of agricultural land and thus characterizing the quality of agricultural production space. A summary of these criteria is provided in table 1.

Table 1. Decision criteria for determining the urgency of consolidation work

Criteria	Name	Nature
K1	Area of the precinct	stimulant
K2	Number of plots	stimulant
K3	Number of land registry units	stimulant
K4	Average area of the plot	deterrent
K5	Number of the plots per 1 land registry unit	stimulant
K6	Area of the land per 1 land registry unit	stimulant

Source: author's own work.

AHP as analysis method

The description of the AHP method has been included in many studies, including in works (Saaty, 1980; Kobryń, 2014), therefore it will be omitted in this publication. Only the most important issues related to the use of the AHP method will be indicated here. As is known (Saaty, 1980), the AHP method is based on the mutual comparison of the pairs of considered alternatives. The results of pairwise comparisons are determined using the so-called a relative, 9-grade rating scale. An integral part of the AHP analysis is the assessment of the coherence of the pairwise comparison matrix. Obtaining the required level of consistency is quite problematic for a greater number of compared items. Therefore, an important practical recommendation in the AHP method with regard to the compared elements is the Miller rule, according to which the number of these elements should be in the range of 7 ±2 (Miller, 1957). This rule is related to the limited human information processing abilities, and its consequence is the fundamental principle that is in force in the AHP method and is based on the hierarchical structuring of any decision problem.

This does not mean that – using the algorithm of the AHP method – it is not possible to consider a greater number of elements at a given hierarchical level, which is especially true for the compared alternatives. Limitations resulting from the Miller rule become less important if the pairwise pairing procedure is based on the use of appropriate mathematical formulas. The use of the following formulas gives this possibility (Szłapczyńska, 2009):

- in case of stimulant (benefit nature criteria)

$$p_{i,j} = \frac{Q_i^{(k)} - Q_j^{(k)}}{Q_{max}^{(k)} - Q_{min}^{(k)}} \cdot 8 + 1, \quad \text{for} \quad Q_i^{(k)} \geq Q_j^{(k)} \tag{1}$$

and

$$p_{i,j} = \frac{1}{p_{j,i}}, \qquad \text{for} \qquad Q_i^{(k)} < Q_j^{(k)}; \tag{2}$$

- in case of deterrent (costs nature criteria)

$$p_{i,j} = \frac{Q_j^{(k)} - Q_i^{(k)}}{Q_{max}^{(k)} - Q_{min}^{(k)}} \cdot 8 + 1, \qquad \text{for} \qquad Q_i^{(k)} \leq Q_j^{(k)} \tag{3}$$

and

$$p_{i,j} = \frac{1}{p_{j,i}}, \qquad \text{for} \qquad Q_i^{(k)} > Q_j^{(k)}, \tag{4}$$

where:
$Q_i^{(k)}$, $Q_j^{(k)}$ – alternative result (i-th and j-th) in the light of the k-th criterion.

The result of the implementation of the above formulas are the elements of the pairwise comparison matrix **P**, which assume values corresponding to the Saaty scale.

In the assessment of the consistency of the matrix of comparisons in pairs, the so-called Consistency Index *(CI)* and consistency ratio *(CR).* According to (Saaty, 1980), the consistency index is calculated using the formula:

$$CI = \frac{\lambda_{max} - n}{n-1}, \tag{5}$$

where:
n – dimension of the matrix **P** (corresponding to the number of criteria or alternatives being compared),
λ_{max} – the maximum custom value of matrix **P**.

On the basis of the *CI* index, the *CR* is calculated, which is the quotient:

$$CR = \frac{CI}{RI}, \tag{6}$$

where:
RI – is a reflection of the non-conformity rate of assessments, being the average value of *CI* for a large number of randomly generated comparison matrices.

It should be added that few literature sources provide *RI* values for larger comparison matrices (n>15). Such a need may arise when comparing more alternatives using equations (1)–(4). A valuable proposal in this respect is presented in the paper (Alonso, Lamata, 2006). Using the randomly generated values λ_{max}, the following function was determined as a result of the least-squares estimation:

$$\bar{\lambda}_{max}(n) = 2{,}7699n - 4{,}3513, \tag{7}$$

which allows *RI* index circumscribing as:

$$RI = \frac{\bar{\lambda}_{max}(n)-n}{n-1}. \tag{8}$$

Analysis of the urgency of consolidations in the area of the Moniecki county with the use of the AHP method

In the first place, global preferences were defined. The weight of accepted criteria, reflecting their mutual validity. The starting point for calculations was the comparison matrix in pairs of criteria, the elements of which were determined using the relative Saaty rating scale:

$$\mathbf{P} = \begin{bmatrix} 1{,}0000 & 0{,}2500 & 2{,}0000 & 0{,}2000 & 0{,}3333 & 0{,}5000 \\ 4{,}0000 & 1{,}0000 & 5{,}0000 & 0{,}5000 & 2{,}0000 & 3{,}0000 \\ 0{,}5000 & 0{,}2000 & 1{,}0000 & 0{,}1667 & 0{,}2500 & 0{,}3333 \\ 5{,}0000 & 2{,}0000 & 6{,}0000 & 1{,}0000 & 3{,}0000 & 4{,}0000 \\ 3{,}0000 & 0{,}5000 & 4{,}0000 & 0{,}3333 & 1{,}0000 & 2{,}0000 \\ 2{,}000 & 0{,}3333 & 3{,}0000 & 0{,}2500 & 0{,}5000 & 1{,}0000 \end{bmatrix}$$

Based on the above matrix **P**, using the matrix column averaging method, the vector w was determined containing the weights w_j of the adopted criteria:

$$\mathbf{w} = [0{,}0655 \quad 0{,}2488 \quad 0{,}0434 \quad 0{,}3794 \quad 0{,}1604 \quad 0{,}1024].$$

An integral part of this phase of calculations was the control of matrix **P** consistency, which resulted in:

$$\lambda_{max} = 6{,}169,\ CI = 0{,}034,\ CR = 0{,}027.$$

As you can see, this control showed the consistency of the initial pairwise pairing matrix, as the *CR* does not exceed the permissible value 0.10.

As mentioned in the title and in the introduction to this study, the area covered by the analyses in the Moniecki county, located in the Podlaskie District. In this connection, it should be added that the Moniecki county includes seven communes, which are: Goniądz, Jasionówka, Jaświły, Knyszyn, Krypno, Mońki, and Trzcianne.

The entire area is divided into land and building records for a total of 204 precincts. Three of them are urban areas: Goniądz, Mońki, Knyszyn, which were excluded from the analyses presented in this study. Further analysis based on the AHP method covered the remaining registration precincts in the number of 201.

The purpose of these analyses was to determine the urgency of consolidation works in the analyzed precincts, and in other words – the alignment of these enclaves in accordance with the urgency of consolidation works in their area, resulting from AHP obtained synthetic assessments of individual areas. The starting point for the conducted analyses were the parameters of individual precincts in the light of the adopted decision criteria. Due to editorial restrictions regarding the preferred volume of the text, it was not possible to provide these parameters in the article (this would increase the volume of the article by a factor of 2). However, if you are interested in these source data, the authors of the article will be happy to share it.

On the basis of the above data, in relation to each of the criteria, the so-called local preferences that reflect the mutual positions of the analyzed precincts. Appropriate matrices of pairwise comparisons of these ranges in the light of subsequent criteria were created using formulas (1)–(4).

Each of the six pairwise comparison matrices created in this way was subjected to consistency assessment, where formulas (5) and (6) were used to determine the RI. The resulting value for $n = 201$ is $RI = 1{,}7570$. The appropriate values λ_{max}, *CI* and *CR* are shown in table 2. As it results from the performed control, for each of the criteria, the *CR* of the relevant pairwise comparison matrix turned out to be significantly lower than the permissible value.

Table 2. Evaluation of consistency matrix comparisons in pairs

	Criteria					
	K1	K2	K3	K4	K5	K6
λmax	201,1936	203,5657	203,7845	201,0248	206,2895	201,1054
CI	0,00097	0,01283	0,01392	0,00012	0,02645	0,00053
CR	0,00055	0,00730	0,00792	0,00007	0,01505	0,00030

Source: author's own work.

Then, on the basis of local preferences (which were defined in relation to subsequent criteria) and the weights of the criteria, synthetic estimates of individual precincts were calculated. Using synthetic assessments and organizing the analyzed ranges in order from highest to smallest value of the synthetic evaluation, it is possible to indicate the cadastral areas that most urgently require consolidation works. The list of prefabricated areas with the greatest urgency of consolidation works, together with the obtained synthetic assessments, is given in table 3.

Table 3. Listing of precincts with the greatest urgency of merging works

Precint	Synthetic evaluation
200801_5.2101.Wólka Piaseczna-Łąki Różnych Wsi	0,01533
200803_2.0021.Zabiele	0,00997
200805_2.0004.Długołęka	0,00965
200807_2.0006.Giełczyn	0,00947
200802_2.0007.Kalinówka Królewska	0,00886
200807_2.0013.Nowa Wieś	0,00886
200807_2.0131.Nowa Wieś-Bagno-Ław	0,00861
200807_2.0017.Szorce	0,00848
200803_2.0005.Dolistowo Stare	0,00837
200801_5.0006.Klewianka	0,00801
200802_2.0013.Krasne Stare	0,00796
200806_5.0026.Przytulanka	0,00769
200805_2.0005.Góra	0,00762
200806_5.0016.Kulesze	0,00760
200807_2.0418.Budy-Dz.Długołęka	0,00749
200801_5.0311.Olszowa Droga	0,00746
200807_2.0015.Bajki Stare	0,00745
200804_5.0003.Grądy, Poniklica, Wodziłówka	0,00743
200807_2.0019.Wilamówka	0,00724
200803_2.0020.Szpakowo	0,00708
200801_5.2108.Wólka Piaseczna-Kalinówka K.	0,00702

Source: author's own work.

The summary in table 3 shows that the precinct, which most urgently requires taking appropriate actions related to the consolidation and replacement of land, '200801_5.2101.Wólka Piaseczna-Łąki Różnych Wsi'. In the case of this area, the synthetic evaluation, obtained by the AHP method, by over 50% exceeds the assessment of the next three ranges, located at the top positions in the ranking ('200803_2.0021.Zabiele', '200805_2.0004. Długołęka' oraz '200807_2.0006.Giełczyn'). The importance of the problem in the case of the area '200801_5.2101.Wólka Piaseczna-Łąki Różnych Wsi' It also proves that its synthetic evaluation is more than twice as high as the assessment of the thirteenth division in this ranking, which is '200805_2.0005. Góra'.

For similar reasons, as in the case of parameters of individual registers in the light of accepted decision criteria, in this study it was not possible to cite synthetic assessments for all 201 registers of them, as well as their assessments in the light of subsequent criteria. However, as in the previous case, the authors of the article will be happy to share it in case of possible interest.

At this point, you can only pay attention to the synthetic assessment of the area '200801_5.2101.Wólka Piaseczna-Łąki Różnych Wsi'. It is more than five times higher than the estimates of four precincts, which are located at the end of the ranking ('200807_2.0420.Budy-Dz.Koleśniki', '200807_2.0421. Budy-Dz.Guzy', '200801_5.2107.Wólka Piaseczna-Bagno II' and the '200807_ 2.0711.Gugny-Dz.Dług.Roma.') and which obtained synthetic ratings not exceeding the value 0,00300.

Conclusions

One of the reasons that prompted the authors to undertake analyses aimed at implementing the AHP method to determine the urgency of consolidation works in the area of the Moniecki county was the fact that this method is one of the most popular methods of multi-criteria decision analysis. As the review of various applications of the AHP method presented in the study (Sipahi, Timor, 2010) shows, it found many of applications in solving various decision problems. In the opinion of the authors of this study, the AHP method can be also useful in solving problems related to determining the urgency of merging works. The experience of the authors of this work has shown that a very useful tool proves to be an Excel spreadsheet.

The approach adopted by the authors, according to which all reference sections in the area of the Moniecki county were subjected to simultaneous analysis, does not exclude the possibility of performing similar analyses in a smaller area, as for example in any municipality. In this case, the analysis

algorithm used would be analogous. In the case study, presented in this research the sensitivity analysis of the final ranking to the change in the weightings of criteria, which is an integral part of the multi-criteria analysis, was omitted. However, this was not the main goal of the research, because the authors focused on the implementation of the AHP method to solve the decision problem.

Issues that would require additional research are the possible establishment of a universal set of decision criteria so that it can be applied regardless of the location of the analyzed area. There is no doubt that the key issue, which is of crucial importance from the point of view of a possible extension of the set of criteria, should be the availability of data, enabling the comparison of precincts in the light of all criteria.

According to the authors of this study, the subject of further research with regard to determining the urgency of merging works can and should be other methods of multi-criteria analysis, especially the PROMETHEE and TOPSIS methods, which – as mentioned in the introduction – can be considered as popular as the AHP method.

The contribution of the authors

Andrzej Kobryń – 50% (concept and objectives, literature review).
Tomasz Tekień – 50% (concept and objectives, research).

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