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Fuzzy expert system for land valuation in land consolidation processes

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Abstract. Land fragmentation is one of the main obstacles to sustainable agricultural and rural development. The main goal of sustainable agriculture development is the production of food by the synergy of economic, social and ecological requirements. The ineffective and defective legislation and even its complete absence have led to land degradation globally. The most adaptable and globally recognized method that has the effect to solve the existing land fragmentation and to prevent the trend of even more intensive land fragmentation is the method of land consolidation. Land consolidation is carried out in a way that each participant in the process of land consolidation gets new land of equal value, with land value reduction for general and common needs of settlements and participants of consolidation. The value of the land included in consolidation process is determined and shown in land consolidation assessment which is conducted by land classification in the defined classes, and the value in the land consolidation evaluation is shown in the estimation units. The estimation unit is the relative relation between the exemplar cadastral parcel and the cadastral parcel which need to be valued, taking into account all the relevant factors that can affect the land valuation. This paper proposes a model of land classification in the evaluation classes based on the Fuzzy Logic Method. The paper aims to develop an expert system that would improve and optimize the process of relative valuation of agricultural land as one of the critical steps in the implementation of the land consolidation. The proposed expert system would provide effective support in conducting the negotiation procedures and planning of land consolidation implementation with the involvement of different stakeholder groups with different requirements and wishes. The model will be validated for agricultural land on the island of Hvar in the Split-Dalmatia County.

Keywords: fuzzy expert system, land consolidation, land fragmentation, land valuation

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1. Introduction

Rural areas that represent the integration of environmental, ecological, living and cultivated elements are usually considered as being less productive areas both in developed and underdeveloped countries [7, 12, 18]. One of the main obstacles to sustainable agricultural and rural development is land fragmentation. Land fragmentation is characterized by small, very often irregular cadastral parcels that are disadvantageous to agricultural production, farmers' limitations to modernize and rationalize production by introducing new agricultural techniques such as irrigation machinery and irrigation systems and also unfavorable economic effects affecting the realization of agricultural projects. The lack of access roads, spatially-spaced crops (cadastral parcels dispersion) and the non-economical activities of agricultural machinery on small cadastral parcels have a particularly negative impact on the growth of transport and production

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costs, resulting in lower incomes [8]. Apart from economic influences, fragmentation also has a negative impact in the social aspect as it does not create equal conditions for agricultural production for all farmers. Likewise, the problems of social tension cause property disputes that often result in even greater fragmentation of land.

Although land fragmentation is a global problem, the causes of its emergence are related to various legislative, economic and social processes. Given the specificity of its emergence, fragmentation cannot be observed globally, but for its understanding as well as defining the techniques of resolution it is necessary to carry out detailed social and spatial analysis of a particular local area. The most viable and globally recognized method for preventing the trend of even more fragmentation of land cadastral parcels and addressing the solution of existing fragmented agricultural land is the land consolidation method [6]. With section 1, article 1, paragraph 2 of the Land Consolidation Act [14] consolidation is defined as a set of administrative and technical procedures for combining the small and fragmented areas of agricultural land into larger and more organized together with the planning of the road and canal network and by altering ownership and other relationships on the land.

Land valuation is the most crucial activity in the consolidation process. For quality evaluation, reliable spatial data should be available, and the procedure itself is prescribed by the Land Consolidation Act [14]. The process is carried out in a way that each participant of land consolidation gets new land of equal value, with land value reduction for general and common needs of settlements and participants of consolidation. The value of the land is determined in land consolidation assessment which is conducted by land classification in the defined classes, and shown in the estimation units. Each cadastral parcel is classified into the appropriate class and determines the relative relation between them. For each culture, the optimal number of classes should be determined, but not above 8, because too many classes require more technical works. Apart from the fact that the evaluation of land needs to be transparent and objective, it is equally essential that the process of relative cadastral parcels comparison is as accurate as possible taking into account the small differences in their attribute values. By classifying the cadastral parcels into appropriate class, the process accelerates on the one hand, but on the other hand, it is quite difficult to determine the optimal number of classes because of a large number of different cadastral parcels characteristics. The procedure of classifying the cadastral parcels and the definition of the class itself is a matter of expert assessment, but since the opinions and experiences of experts in solving the same tasks are never unequivocal, such issues cannot be defined by a simple mathematical statement. The sharp cadastral parcel affiliation into only one class (especially considering the comparison of the cadastral parcels attributes found on the lower and upper bounds of the class) loses precision in their relative comparison. By the recommended method for their estimation sometimes small changes in the cadastral parcel attribute values result in the classification into two class, while cadastral parcels with much greater attribute differences can belong to the same class. Likewise, monitoring the changes and the interaction of the cadastral parcels attributes exceeds the opportunities offered by simple systems for numerical evaluation of their values. Precisely for the reasons mentioned above, the need for applying a new approach to managing systems based on empirical assessments and characterized by complex descriptions of unclear interactions between input and output data has appeared. With fuzzy logic, the traditional definition of a class is replaced by fuzzy sets, binary affiliation to a particular set with a part of affiliation, and with experiential knowledge in the form of rules different interactions of the cadastral parcels attributes are expressed in order to provide a more precise, more objective and more consistent approach to their assessment.

Fuzzy logic is often used as a support in the process of land reallocation [2, 3, 4, 5, 10]. The use of fuzzy logic in the land classification process was found in the paper of Ertunç and Cay [9] where the method of determining the cadastral parcel index is based on the three input variables: soil index, productivity index and location index. Given that the process of consolidation is also carried out for smaller areas that often share similar valuation of soil and productivity characteristic, this methodology is based on a fuzzy logic to support the process of evaluating agricultural land taking into account the spatial characteristics of the initial cadastral parcels in order to establish a more equitable process of treating owners with future land cadastral parcels. Special attention is dedicated to the way of estimating input variables and to the way of aligning the whole process with the existing legislation in the Republic of Croatia. The proposed fuzzy system offers the possibility of adding or subtracting additional criteria for cadastral parcels evaluation depending on the needs of a particular task.

2. The fuzzy expert system for land valuation in land consolidation processes

Land reallocation is the most important component of land consolidation, which has the primary task of redistributing ownership rights by aligning the landowner's wishes with all the other relevant elements and conditions set in the individual consolidation project. Before the consolidation process, the most important is to affirm the criteria for assessing the cadastral parcel quality (cadastral parcel bonitet) in order to rightful cadastral parcel redistribution that will enable the landowner to obtain a new cadastral parcel of equal or greater agricultural productivity. The most important criterion is the soil index, but it is often of less importance if the project of consolidation is carried out for a smaller area where land cadastral parcels share similar attributes and thus equal the soil index.

Firstly, it is necessary to analyze the problem in details and to choose a method that will allow a more objective approach to its solution. Selection of criteria for cadastral parcels evaluation, determination of their mutual relations, and the way of determining bonitet values is important for experts' assessment. These experts have years of professional experience based on which they have the ability to deal with and solve given problematic. The involvement of experts in the decision-making process is conducive to decision-making in a professional and high-quality way, and the choice of a method that will enable the modelling of expert thinking in the form of certain rules seeks to provide an objective approach to solving the default problem. Therefore, the expert system, as an area of artificial intelligence that deals with the modelling of human thinking, has proven to be the most appropriate methodology of objectively evaluating of cadastral parcels bonitet.

It operates mainly in the form of a set of specific rules that allow the mathematical analysis of the problem and providing a feedback necessary to resolve it. Expert systems primarily have been developed from the need to assist in solving problems and making decisions to users who are not experts in a particular area that requires expert support. The well-known mathematical method of artificial intelligence is a fuzzy logic which is based on the structuring of human knowledge through the form of a series of rules in algorithms that simulate human knowledge. The implementation of fuzzy logic to define the model for cadastral parcel bonitet estimation is explained through the steps of the flow diagram shown in Figure 1.

The model starts with a definition of the problem, forming of the expert group and spatial analysis of the research area. With the spatial analysis set of cadastral parcels are defined for evaluation of their bonitet values. First, it is necessary to define what the bonitet value of the cadastral parcels is. Bonitet is a term that defines the ability of a particular entity to meet predefined conditions. By estimating the bonitet value, it is possible to describe the quality of a business entity, the creditworthiness of a company or a client, the quality of goods in a technological and economic terms, but also land can be estimated, whether it is agricultural or construction land, to determine its quality, taking into account the characteristics associated with its agricultural or construction utilization. Identification of the cadastral parcels attributes for their assessment depends on each task as well as on the availability of data for all alternative solutions (land cadastral parcels).

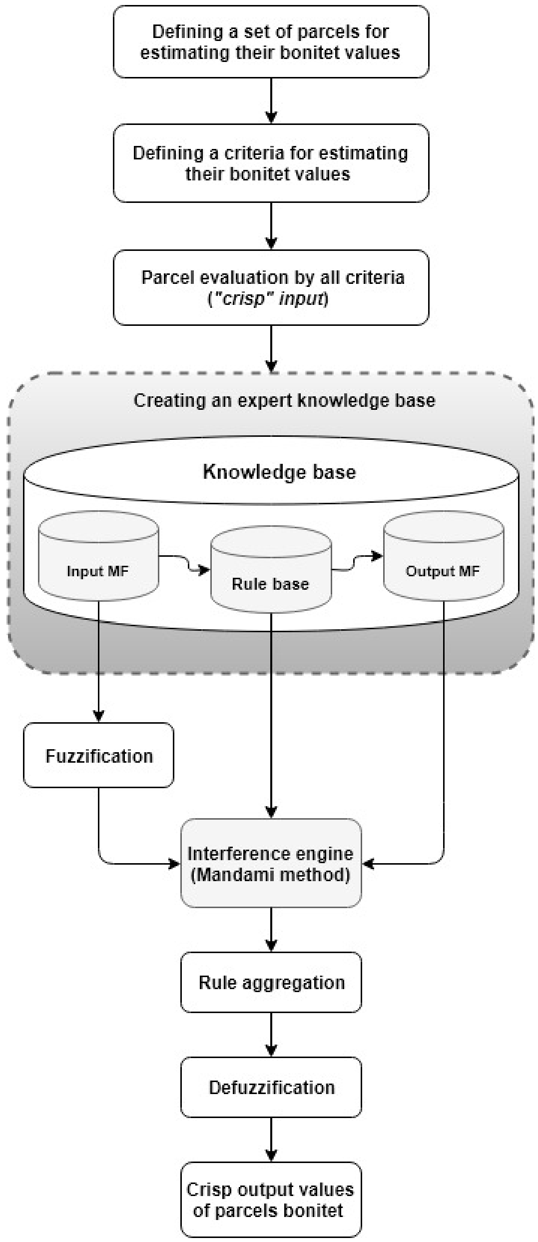


Figure 1: *The FES for land valuation in the process of land consolidation*

Estimating the bonitet of agricultural land cadastral parcels, their relationship which determines how much each cadastral parcel is better or worse than others is determined. Four variables for comparing land cadastral parcels have been identified: slope, shape, area and access to a registered road. Identified variables are shown in Figure 2. It depicts the general structure of the fuzzy logic model; the input data (variables) are shown to the left, and the output data, i.e. the estimation of the cadastral parcel bonitet values particle value, is shown to the right.

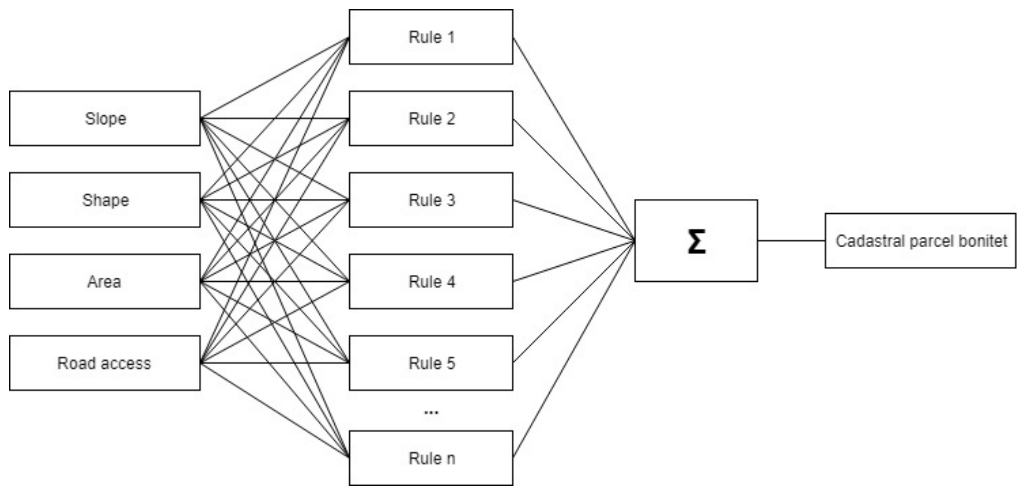


Figure 2: *A general structure of the fuzzy logic for estimation cadastral parcel bonitet value*

For normalization purposes as well as definition of the membership function (MF) of input variables the Ordinance of standards for the determination of particularly valuable land for cultivation (P1) and the valuable agricultural land (P2) [15] is used, which is the basis for the evaluation of state agricultural land in direct arrangement proceedings based on the values of soil, climate, relief and other natural conditions for agricultural production. The selected criteria in this paper directly affect the difficult use of agricultural mechanization, and thus the production costs as the basic measure of the economic viability of the agricultural process. The results need to be normalized for their comparison to determine one output value, i.e. the cadastral parcel bonitet.

The method of defining and evaluating each of the four input variables is shown below. All input variables are displayed in a range from 0 to 1 to enable their comparison in the process of fuzzy logic.

The criterion was determined by data for the slope of the terrain for each cadastral parcel of land. The value of the criterion is defined by the linear transformation of the cadastral parcels slope expressed in degrees. The slope is defined in the range from 0 to 1 as the criterion of a minimum. In accordance with the Ordinance of standards for the determination of particularly valuable land for cultivation (P1) and the valuable agricultural land (P2) [15] value 1 is assigned to those cadastral parcels having a slope from 0° to 2°, while value 0 is assigned to those cadastral parcels having a gradient of 33° and above. All the cadastral parcels with the slope value less than 2° are evaluated as parcels with extremely favorable slope, while all ones with slope value greater than 33° are evaluated as parcels with extremely unfavorable slope.

The normalized slope value of the cadastral parcel j is denoted as $V(Sl_j)$ or Sl_j^* and it is defined as a linear function [11]:

$$V(Sl_j) = Sl_j^* = \begin{cases} -0.0323Sl_j + 1.0645 & for \quad 2 < Sl_j < 33 \\ 1 & for \quad Sl_j \leq 2 \\ 0 & for \quad Sl_j \geq 33 \end{cases} \tag{1}$$

The shape of cadastral parcels also affects the use of modern mechanization, regular land treatment, and production costs. In accordance with the Ordinance of standards for the determination of particularly valuable land for cultivation (P1) and the valuable agricultural land (P2) the optimal representation of the cadastral parcel shape is calculated by the diversity coefficient according to the formula [15]:

$$Cd_j = \frac{P_j}{3.54\sqrt{A_j}}, \quad j = 1,\ 2, ..., k \tag{2}$$

where Cd is diversity coefficient, P is perimeter of the cadastral parcel and A is an area of the cadastral parcel j.

The value of the criterion is defined by the linear transformation of the cadastral parcels shape in the range from 0 to 1 as the criterion of a minimum. Value 1 is assigned to those cadastral parcels having the diversity coefficient from 0 to 1.5, while value 0 is assigned to those cadastral parcels having the diversity coefficient of 5 and more. According to the Ordinance [15], all the cadastral parcels with the diversity coefficient less than 1.5 are evaluated as parcels with regular shape, while all ones with diversity coefficients greater than 10 are evaluated as parcels with exceptional irregular shape.

The normalized shape value of the cadastral parcel j is denoted as $V(Sh_j)$ or Sh_j^* and it is defined as a linear function:

$$V(Sh_j) = Sh_j^* = \begin{cases} -0.2857Sh_j + 1.4286 & for \;\; 1.5 < Cd_j < 5 \\ 1 & for \;\; Cd_j \leq 1.5 \\ 0 & for \;\; Cd_j \geq 5 \end{cases} \tag{3}$$

Linear functions used for standardization, i.e. normalizaton of the slope (Sl), shape (Sh) and area values (A) are presented on a Figure 3.

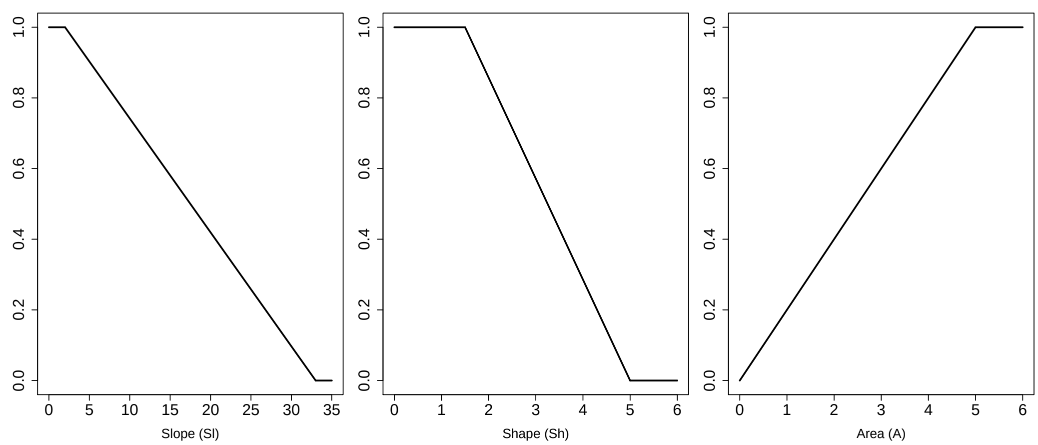


Figure 3: *A slope linear function (left), shape linear function (middle) and area linear function (right)*

The cadastral parcel area also has an impact on bonitet value due to the inability to use agricultural mechanization and the application of modern agro technical measures. The value of the criterion is also defined by the linear transformation of the cadastral parcels slope expressed in hectares. The area is set in the range from 0 to 1 as the criterion of maximum. In accordance with the Ordinance of standards for the determination of particularly valuable land for cultivation (P1) and the valuable agricultural land (P2) [14] value 0 is assigned to those cadastral parcels having an area less than 0.1 ha while value 1 is assigned to those cadastral parcels having an area 5 ha and more. All the cadastral parcels with the area less than 0.1

ha are evaluated as parcels with extremely unfavorable area, while all ones with slope value greater than 5 ha are evaluated as parcels with extremely favorable area.

The normalizedarea value of the cadastral parcel j is denoted as $V(A_j)$ or A_j^* and it is defined as a linear function:

$$V(A_j) = A_j^* = \begin{cases} 0.2003A_j - 0.0016 & for \;\; 0.1 < A_j < 5 \\ 1 & for \;\; A_j \geq 5 \\ 0 & for \;\; A_j \leq 0.1 \end{cases} \tag{4}$$

Furthermore, a binary criterion rating defines access to a registered road:

$$Ra_j = \begin{cases} 1 & for\ cadastral\ parcel\ having\ access\ to\ the\ registered\ road \\ 0 & for\ cadastral\ parcel\ that\ do\ not\ have\ access\ to\ the\ registered\ road \end{cases} \tag{5}$$

Since the criterion for land cadastral parcels estimation is defined with two crisp values (0 and 1), only two MFs are assigned, which is rarely applied when defining fuzzy logic MFs. The main reason is that in less than three functions it is not possible to achieve the differentiation of the set. However, since access to the road is one of the most important criteria for determining the cadastral parcel bonitet, its elimination would not give a true picture of cadastral parcel comparison for fairer and more objective estimation of cadastral parcel values.

Each criterion is given its crisp value. This is the part were procedures related to the steps of the algorithm definition of fuzzy logic is implemented. Since fuzzy logic is part of expert systems, the crucial step in implementing this model is to engage a group of experts who actively participate in the definition of all the key elements of the model. After the problem definition, spatial analysis provides an insight into the existing situation as well as the availability of data based on which expert evaluation is used to define the criteria for relative comparison of cadastral parcels. The result of comparison is estimation of the bonitet value of cadastral parcels. The bonitet value is in the range of 0 to 1, where the score 0 receives the cadastral parcel which is classified the worst according to all defined criteria, whereas the grade 1 receives the best rated cadastral parcel. This result is the relative comparison of the cadastral parcels according to input data, which can be displayed in its absolute form, depending on the needs of a particular task.

A fuzzy logic can be described through six important steps:

1. Creating an expert knowledge base. After the crisp values of criteria are given, each criterion gets its input membership functions with their belonging fuzzy set. The same is done for the cadastral parcels where each cadastral parcel gets its output membership function with fuzzy set. A membership function $\mu_F(x)$ of fuzzy set is continuum function that can determine membership degree of element x to set F. Fuzzy set F is defined as a set of pairs [19]:

$$F = \{(x, \mu_F(x)) | x \in X, \;\; 0 \leq \mu_F(x) \leq 1\} \tag{6}$$

where X is a universal set or set of observations, defining a set F, and $\mu_F(x)$ is the membership function of element x to F. Each fuzzy set is completely and uniquely determined by its membership function.

2. Defining of a knowledge base. Fuzzy rules are a tool for expressing expert knowledge. Along with the definition of the membership function of input and output data, they constitute a knowledge base. For the mathematical description of the process, the language rules of IF-THEN are commonly used. The total number of rules is obtained by the expression:

$$Z = \prod_{i=1}^{n} p_{\mu_F(F_i)} \tag{7}$$

where Z is total number of rules and $p_{\mu_F(F_i)}$ is the total number of membership functions for each input F_i.

3. Fuzzification process. Converting crisp values of input data to fuzzy values using defined membership functions. Each input value x_n joints the value of membership degree of fuzzy set [17]:

$$x_i = \mu(x_n) \quad 1 \leq i \leq N \tag{8}$$

where x_i is the degree of membership, μ_i is the ith function of the input, x_n is the crisp input and N is the number of basic membership functions.

4. A process of interference. By selecting the method of implication and by applying a fuzzy operator of the implication, transformation or implication of the conditional parts of the equation into their conclusion is defined. In this case Mamdani method is used. Mamdani's operator of minimum is $\mu_{F_A \cup F_B} = min(\mu_{F_A},\ \mu_{F_B}) = \mu_\alpha$ [13]. Comparing the membership degrees of all input variables defined by a single logical equation or rule, the minimum value is always chosen as the resultant μ_α. The output fuzzy set in the conclusion of each logical equation is cut off to the height of a certain degree of membership μ_α by using the cutoff method.

5. Aggregation process. Combination of results according to each rule. The aggregation of all output fuzzy set to the unique fuzzy set of each output variable is performed.

6. Defuzzification process. Deffuzification is the process of converting linguistic results (a resultant fuzzy set) obtained on the basis of a fuzzy inference mechanism into numerical values (a resultant crisp set). Converting output fuzzy data values to their crisp values z_o using centroid method [16]:

$$z_o = \frac{\int \mu_F(z) z dz}{\int \mu_F(z) dz} \tag{9}$$

where $\mu_F(z)$ is the degree of membership of the aggregate output z of fuzzy set F.

3. The fuzzy expert system validation

Determining the cadastral parcel bonitet their attribute values are analyzed to evaluate the deviation of each cadastral parcel from their ideal shape defined by the best grades (normalized values 1) according to the selected criteria for their evaluation. The deviation is determined by a resultant, crisp value called bonitet in the range of 0 (lowest bonitet value) to 1 (the highest bonitet value), and the result is rank list of bonitet values of all the cadastral parcels involved in validation of the fuzzy logic model.

Based on the spatial analysis of the research area which is island of Hvar in the Split-Dalmatia County, a set of 243 agricultural land cadastral parcels is defined. Figure 4 shows a map of the cadastral parcels along with their allocation identification. The agricultural cadastral parcels are light yellow colored while the registered roads for defining road access criteria are blue colored.

Given that the fuzzy logic is based on the modelling of expert knowledge, the involvement of experts in defining and implementing the model of cadastral parcel bonitet estimation is of crucial importance. The first step of the conversation with experts included defining criteria as well as determining how they were assessed. Their initial spatial analysis defines criteria for cadastral parcel comparison. For the analysis of the data the digital cadastral plan, the digital orthophoto map and Aster Digital Elevation Model [1] are used and processed in the GIS program (QGIS v.3.0.1). Since the land cadastral parcels are situated in a relatively small area, four criteria have been identified to compare the differences in their attributes in order to estimate cadastral parcel bonitet values. Table 1 shows the cadastral parcels evaluation according to defined criteria. The criteria values are normalized by the linear transformation shown in the previous section. The analysis is shown only for the first 30 cadastral parcels in the defined area.

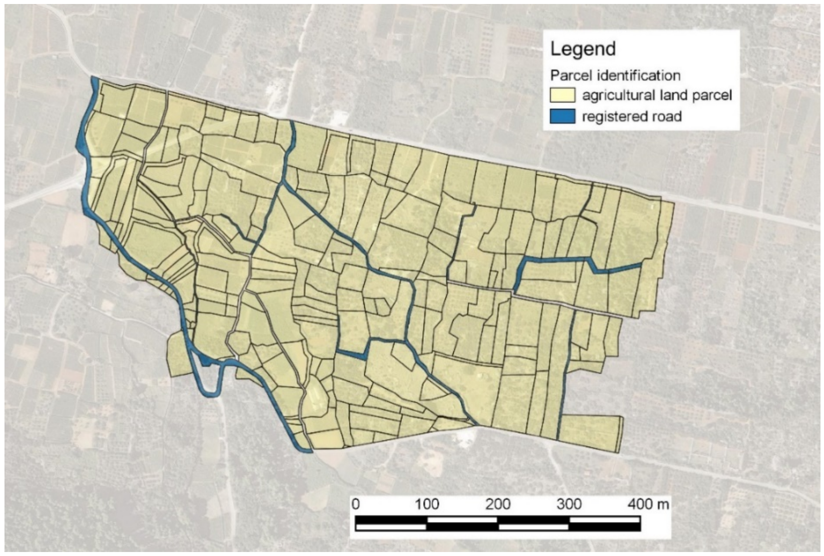


Figure 4: *Map of the cadastral parcels on the island of Hvar with their allocation identification*

cadastral	slope	shape	area	access	cadastral	slope	shape	area	access
9999/1	0.0504	0.0000	0.1021	0	2145	0.9731	1.0000	0.0591	0
2156/2	0.7016	1.0000	0.1185	1	3338	0.7662	0.1101	0.0000	0
1940	0.8282	0.9272	0.1144	1	1857	0.4786	1.0000	0.0571	1
2126/1	0.8374	1.0000	0.1100	1	3205/2	0.0000	0.0000	0.0000	0
1946/1	0.1238	0.9459	0.0142	0	1882	0.8803	1.0000	0.0428	0
2154/1	0.0000	0.8506	0.0000	1	2155/3	0.9702	0.952	0.0547	1
2150	0.7774	0.9958	0.0827	1	1906	0.6104	1.0000	0.0544	0
2116	0.1394	0.9052	0.0815	1	2141	0.5795	1.0000	0.054	1
2156/1	0.0000	0.7964	0.0000	0	1862	0.9832	1.0000	0.0408	1
2122/2	0.2571	1.0000	0.0742	0	1861/1	0.6901	1.0000	0.0129	1
3243	0.7945	0.2556	0.0000	0	2156/1	0.0000	0.7964	0.0000	0
3238	0.0000	0.6277	0.0000	1	1903	0.9829	1.0000	0.0147	0
3225/2	0.2148	0.6470	0.0000	0	2159	0.7958	0.9642	0.0490	1
1870/2	0.4842	1.0000	0.0670	1	1861/1	0.6901	1.0000	0.0129	1
2130	0.8212	0.9775	0.0605	0	2137/1	0.9884	1.0000	0.0480	1

Table 1: *Normalized results of cadastral parcel evaluation according to defined criteria*

The next step is a creation of an expert knowledge base that includes the definition of the MFs of input and output variables as well as the definition of a rule base. For a fuzzy logic model solution, MATLAB R2007b, Fuzzy Logic Toolbox was used. The triangular function has been selected for MFs determination. There is no optimal method to select the MFs, but its choice in most cases is the matter of the experts' subjective assessment involved in the decision-making process. The function itself does not play a significant role in shaping the way of the model functioning, instead, it is important to focus on selecting the number of MF of a particular variable. In that case, the best solution should be found between the minimum number of MFs that affect the system rate and the number that provides a sufficiently precise description of the input and output variables. Within this research, the distribution of MFs, as well as overlapping degrees, are defined by the evaluation classes described for each criterion individually. Table 2 shows fuzzy sets and value for linguistic variable slope.

fuzzy set	range of fuzzy set	value of linguistic variable slope
1	(0.0000, 0.0000, 0.2893)	abrupt slope (AS)
2	(0.0000, 0.2893, 0.5154)	extremely steep slope (ESS)
3	(0.2893, 0.5154, 0.6769)	very steep slope (VSS)
4	(0.5154, 0.6769, 0.7738)	steep slope (SS)
5	(0.6769, 0.7738, 0.8707)	moderately steep slope (MSS)
6	(0.7738, 0.8707, 1.0000)	moderately mild slope (MMS)
7	(0.8707, 1.0000, 1.0000)	very mild slope (VMS)

Table 2: *Fuzzy sets and value for linguistic variable slope*

Different MFs have been formed for slope (Sl), shape (Sh), area (A) and road access (RA). Fuzzy sets are given in the range of 0 to 1. Figure 5 shows the shape, number and range of MFs for the slope variable. The slope variable is defined by 7 MFs according to the defined evaluation classes by the Ordinance of standards for the determination of particularly valuable land for cultivation (P1) and the valuable agricultural land (P2).

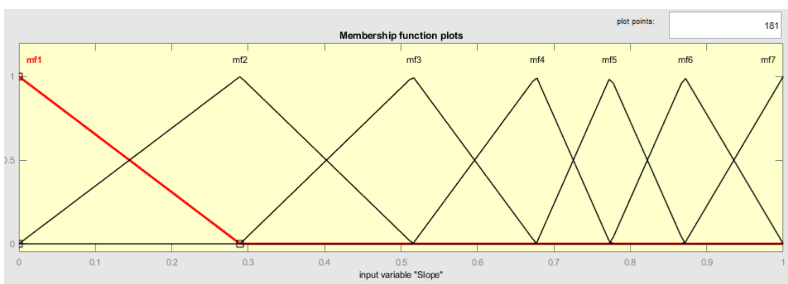


Figure 5: *Membership functions for the slope input variable*

The MFs for other input variables and output variable are shown on Figures 6-9. The defined classes also define the shape and the area variables according to the Ordinance mentioned above.

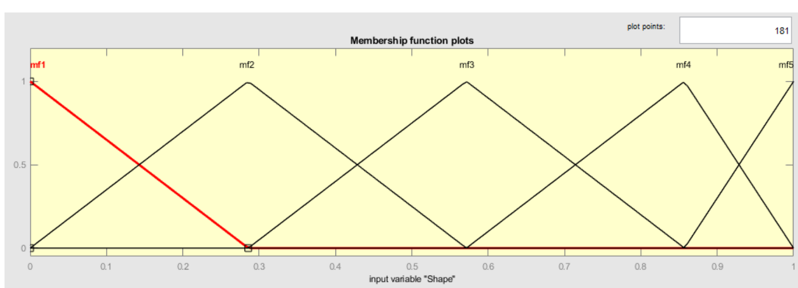


Figure 6: *Membership functions for the shape input variable*

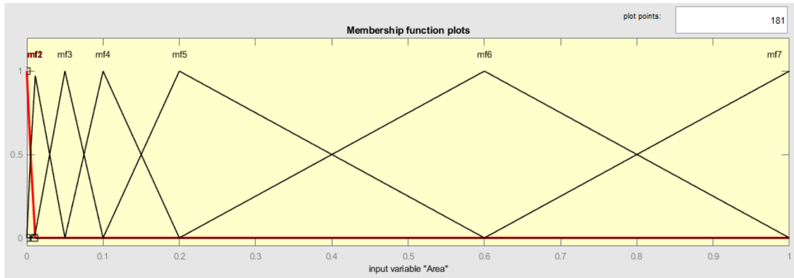


Figure 7: *Membership functions for the area input variable*

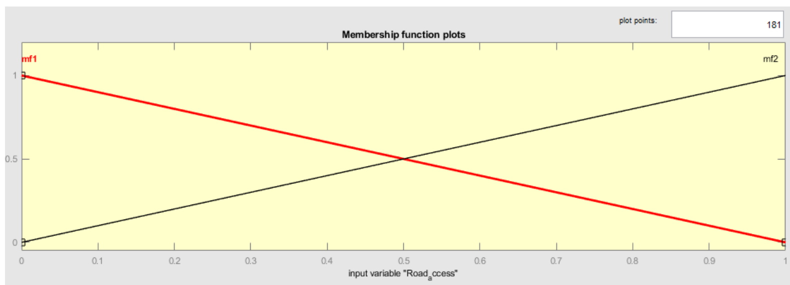


Figure 8: *Membership functions for the road access input variable*

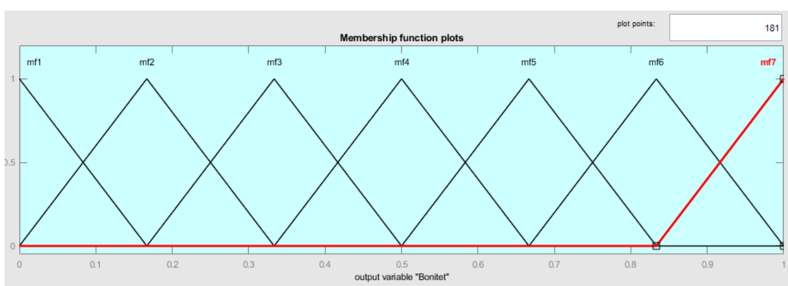


Figure 9: *Membership functions for the cadastral parcel bonitet output variable*

Forming of a rule base is a lengthy and complex process that needs to be carried out with constant communication with all the experts involved in the process of defining it. The total number of rules that are defined within eq.(7) is:

$$Z = \prod_{i=1}^{n} p_{\mu_F(F_i)} = 7 \times 5 \times 7 \times 2 = 490 \tag{10}$$

Part of the rule base is displayed in Table 3. Further, with the process of fuzzification the input numeric, crisp values are assigned to their fuzzy values. Since the fuzzy sets are described with the triangular membership function, each of crisp input value is assigned with two fuzzy values. The sum of membership degrees for each input variable is equal to the 1. Exceptions are the input values that are in the centre of the fuzzy set, i.e. their membership is defined only by one fuzzy set. This set is called a singleton set, and the degree of membership of the input value to one MF is 100%, $\mu_F(x) = 1$ respectively. For fuzzy decision-making operator, which involves implication and aggregation operators, Mamdani's operator, or max-min operator (a combination of minimum T-norm for implication and maximum T-conorm for aggregation) has been selected. It defines the resultant value of the fuzzy output set as a union of previously defined clips of all fuzzy sets of one output variable. The defuzzification is the final step in the process of running a fuzzy system for a given input. For this research method Center of Gravity (COG) was used to achieve a crisp, output values of cadastral parcel bonitet. The result of defuzzification for 30 cadastral parcels is shown in Table 4.

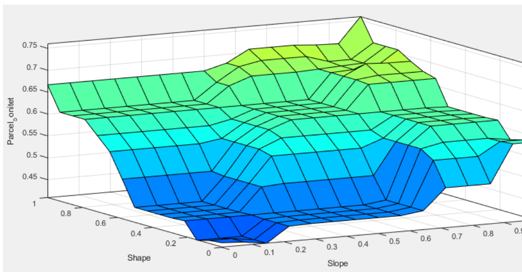
Rule	SL	SH	A	RA	PB
1	abrupt	very irregular	too small	has access	extremely worthless
2	extremely steep	very irregular	too small	has access	extremely worthless
3	very steep	very irregular	too small	has access	extremely worthless
⋮	⋮	⋮	⋮	⋮	⋮
161	very mild	medium regular	big	has access	medium valuable
162	abrupt	irregular	big	has access	worthless
163	extremely steep	irregular	big	has access	worthless
⋮	⋮	⋮	⋮	⋮	⋮
326	steep	irregular	small	no access	medium valuable
327	moderately steep	irregular	small	no access	medium valuable
328	moderately mild	irregular	small	no access	valuable
⋮	⋮	⋮	⋮	⋮	⋮
488	moderately steep	very regular	too big	no access	extremely valuable
489	moderately mild	very regular	too big	no access	extremely valuable
490	very mild	very regular	too big	no access	extremely valuable

Table 3: *Part of the fuzzy rules for cadastral parcel bonitet estimation*

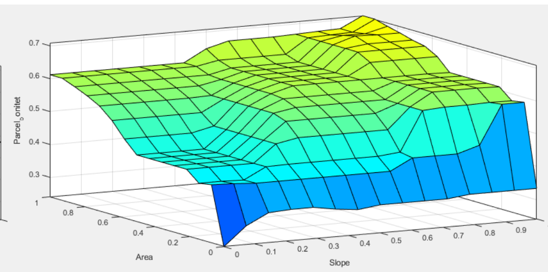
cadastral	bonitet value	cadastral	bonitet value
9999/1	0.167	2145	0.500
2156/2	0.833	3338	0.133
1940	0.836	1857	0.697
2126/1	0.835	3205/2	0.052
1946/1	0.240	1882	0.463
2154/1	0.167	2155/3	0.786
2150	0.825	1906	0.357
2116	0.667	2141	0.688
2156/1	0.162	1862	0.805
2122/2	0.333	1861/1	0.683
3243	0.165	2156/1	0.249
3238	0.373	1903	0.361
3225/2	0.117	2159	0.785
1870/2	0.728	1861/1	0.350
2130	0.459	2137/1	0.822

Table 4: *Bonitet values for cadastral parcels*

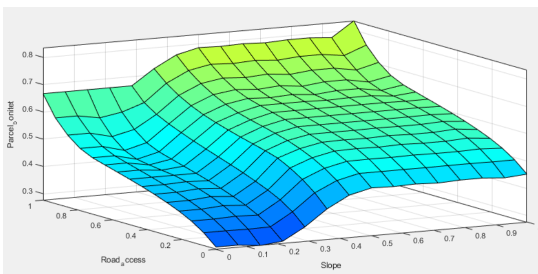
The cadastral parcel bonitet values in the research area of the island of Hvar range from $BV(3205/2) = 0.0523$ as the minimum value (cadastral parcel with the lowest estimation of bonitet values) to $BV(1940) = 0.836$ as the maximum value (cadastral parcel with highest estimation of bonitet values).



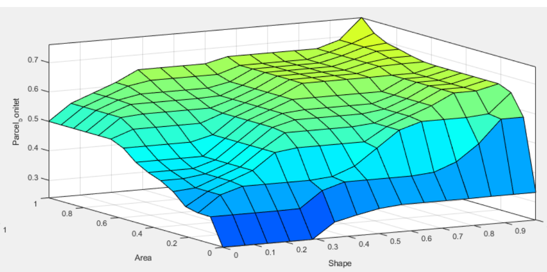
(a) slope *versus* shape



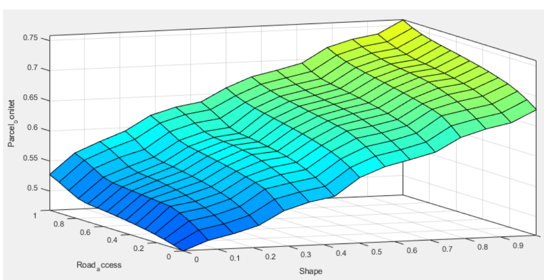
(b) area *versus* slope



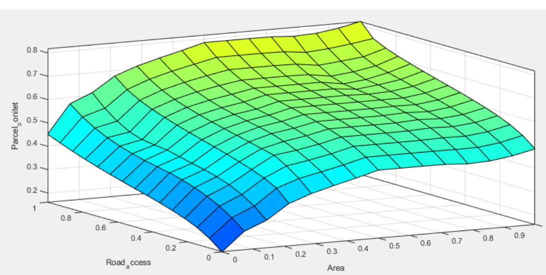
(c) road access *versus* slope



(d) area *versus* shape



(e) road access *versus* shape



(f) road access *versus* area

Figure 10: *Relation between input and output variables*

Figure 10 shows the 3D ratio for combinations of two input variables versus the output variable. This description was used to analyse the influence of the input variables on the value of the output variable. It can be noticed that the most significant influence on the output value has the criterion of the area which shows dominance concerning other criteria (the smallest dominance shows in relation to the road access). The least impact on the output value has a slope criterion which can be especially seen in the panels (b) and (c) where their relation with the area and road access is shown.

4. Conclusion

The need for a more objective, more efficient and more precise approach for solving complex tasks such as cadastral parcels valuation in the consolidation processes, has resulted in the application of a system based on artificial intelligence, a fuzzy logic system. Unlike a mathematical models whose accuracy and precision depends on the density and quality of the data set, the main advantages of fuzzy logic is that it does not need lots of data to train or even it can be model with no data at all as long as the domain is known and its behaviour rules can be created. Particularly challenging is the application of such a system in processes based on a traditional approach that is often characterized by subjectivity, inertia, inability to look at all relevant factors and lack of scientific approach. The sharp parcel membership to only one class loses precision in their relative comparison (especially considering the comparison of cadastral parcels attributes at the lower and upper bounds of the class). By recommended method of estimating their bonitet values sometimes small changes in cadastral parcels attribute values result in their classification into two-class, while cadastral parcels with much greater attribute differences can belong to the same class.

Applying a fuzzy logic, the traditional definition of a class is replaced by fuzzy sets, binary membership to an individual set by fuzzy membership, and by experiential knowledge in the form of rules the different interactions of the cadastral parcels attributes are expressed in order to provide a more precise, objective and consistent approach to their estimation. This research has aimed to develop a system based on the scientific approach and legal basis of the Republic of Croatia, which will support the process of land cadastral parcels valuation in sensitive processes of reorganization of the existing agricultural area. It can be concluded that the proposed approach has proven to be very successful in tackling above-mentioned disadvantages: modelling a system to support consolidation procedure accelerates the decision-making process, incorporating more experts into the decision-making process increases the objectivity of the process and the soft definition of the data sets boundaries for cadastral parcels classification achieves greater precision in a process of their valuation. The system is validated in the area of the island of Hvar but it can be applied to other areas with the possibility of adding or subtracting certain criteria depending on the attribute differences of the defined cadastral parcels set.

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