Application of Fuzzy Logic in Land Consolidation Activities

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Key words: Land consolidation, land reallocation, landholding, interview, fuzzy logic

SUMMARY

One of the most important steps of land consolidation projects is land reallocation studies. In Turkey, the reallocation studies of land consolidation projects are made according to farmer preferences (interviews). In addition to an interview-based land reallocation model, previous optimization studies have also used mathematical models for the reallocation procedure. Recently, the fuzzy logic method, which can model the human mindset and be used where it is impossible to create other forms of mathematical models, has also been applied to the field of geomatics engineering, as well as in other branches of engineering.
This study examined the applicability of a fuzzy logic method at the reallocation stage of land consolidation study where development of an accurate mathematical model was not possible. The results obtained from the fuzzy logic-based land reallocation model were compared with those obtained from the interview-based land reallocation model.

Arazi Düzenleme Çalışmalarında Bulanık Mantık Uygulaması

Anahtar Kelimeler: Arazi düzenleme, dağıtım, işletme, mülakat, bulanık mantık

ÖZET

Arazi düzenleme projelerinin en önemli adımlarından biri dağıtım çalışmalarıdır. Türkiye'de arazi toplulaştırma projelerinde dağıtım işlemleri çiftçi tercihlerine (mülakat) göre yapılmaktadır. Ayrıca, mülakata dayalı dağıtım modelinin yanında birçok bilimsel araştırmalarda dağıtım işlemi için matematik modellere dayalı optimizasyon çalışmaları da yapılmıştır. Ancak, dağıtım işlemi için kesin bir matematiksel model bulunmadığı için çok farklı çözümler önerilmiştir.

Bu çalışmada; bulanık mantık yönteminin, kesin bir matematiksel modeli bulunmayan arazi toplulaştırma çalışmasının dağıtım aşamasında uygulanabilirliği araştırılmıştır. Bulanık mantık esaslı dağıtım modelinden elde edilen sonuçlar mülakat esaslı dağıtım modelinden elde edilen sonuçlarla karşılaştırılmıştır.

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1. INTRODUCTION

Land consolidation (LC) is a tool for improving the effectiveness of land cultivation and for supporting rural development (Sklenicka, 2006). As an important approach to achieve the sustainable utilization of land resource, land consolidation not only need to regard the amount of the farm land for the sake of achieve thing homeostasis of farmland, but also need display the active effect in other aspects, such as improve the quality of farmland, reform the ecological condition and promote the adjustment of the economic formation etc.(Zou et.al., 2008).

In the whole countries, land consolidation is applied to improve the rural areas. Because rural areas comprise substantial parts of the regions and are subject to a range of pressures including water shortage, land degradation, failing commodity prices and depopulation. Land consolidation means to unite and reregister the lands, which were divided because of heritage, sales or irrigation canals (Cay and Iscan, 2004).

In Western Europe, for example in Germany and in the Netherlands, LC is often a part of a wider regional development programme for rural areas. In those regional development programmes LC is used for enhancing systematic land use in the rural areas and for readjusting the areas according to the assignment of the programme (Vitikainen, 2004). The contents of the LC process include similar main stages in all Europe. The process consists of the preparation, the inventory, planning, and the implementation stages, each varying in extent and duration.

Land reallocation is the most important and a time-consuming stage of land consolidation studies, as quite many criteria are evaluated at this stage. Conducting land reallocation studies in a way that meets the wishes of farmers and also the principles of equity and justice is crucial in terms of ensuring social peace.

The problem encountered in land consolidation studies can be defined as allocating “n” number of cadastral parcels to “m” number of blocks. To this end, optimization studies based on many mathematical models for the process of land reallocation have been conducted (Lemmen and Sonnenberg, 1986; Girgin and Kik, 1989; Kik and Sprik, 1990; Avci, 1999). However, many different solutions have been suggested, since no single accurate mathematical model for the land reallocation process exists. The success of the suggested mathematical models has been indicated to be low, as linguistic statements and human considerations that affect the reallocation could not be embedded in them.

Thus, the fuzzy logic (FL) method can be utilized at the reallocation stage of land consolidation projects, as this method is able to incorporate human experiences that can be expressed linguistic but which are difficult to express mathematically. In engineering and other disciplines, events and systems are defined by using accurate mathematical models. By using these created models, an attempt is made to predict the status or course of action that will be taken by the event or system. However, such mathematical approaches are not well suited to accurately representing variations or expressions inherent in the majority of problems or situations encountered in daily life. The FL approach can be utilized in analyzing and solving such problems.

The origin of the FL approach dates back to 1965 since Lotfi Zadeh's introduction of the fuzzy set theory and its applications. Since then the FL concept has found a very wide range of applications in various domains like estimation, prediction, control, approximate reasoning, pattern recognition, medical computing, robotics, optimization and industrial engineering, etc (Sen, 2004).

Zadeh (1965) published his famous paper "Fuzzy sets" in Information and Control providing a new mathematical tool, which enables us to describe and handle vague or ambiguous notions such as "a set of all real numbers, which are much greater than 1", " a set of beautiful women", or "a set of tall men". Since then, fuzzy set theory has been rapidly developed by Zadeh himself and numerous researches, and an increasing number of successful real applications of this theory in a wide variety of unexpected fields have been appearing in open literature. The main idea of fuzzy set theory is quite intuitive and natural. Instead of determining the exact boundaries as in an ordinary set, a fuzzy set allows no sharply defined boundaries because of generalization of a characteristic function to a membership function (Sakawa, 1993).

The framework of fuzzy logic is unique in its ability to represent subjective or linguistic knowledge in terms of a mathematical model. For this reason, FL provides a natural method for constructing systems that emulate human decision making processes. Literature on the subject of FL systems is extensive and applications, particularly in the field of fuzzy control and fuzzy expert systems, are prevalent. Mendel (1995) and Klir and Yuan (1995) provide good introductory texts on FLSs, while some examples of applications of FLSs may be found in Sugeno and Park(1993), Maiers and Sherif (1985) and Kandel (1991) and Ramot, et.al. (2003).

FL is a recognized instrument for modeling in many scientific and technical fields. There are also a lot of problems where fuzzy methods can be used to reach better solutions than classical models can do. It concerns on the one hand questions, where uncertain parameters occur, which cannot be handled by classical methods in adequate way. On the other hand, there are problems where linguistic fuzzy rules can describe relations better than it can be done by crisp mathematical formulas.

In the present study, FL was applied at the reallocation stage of a land consolidation study, for which an accurate mathematical model has not been found. The Konya Ilgın-Agalar district in Turkey was chosen as the project site. Local residents were interviewed to establish their views on land allocation. The results of the interview-based land reallocation model and fuzzy logic-based land reallocation models were compared. Comparison criteria were chosen as: The number of parcels and shares; average size of parcels; average number of parcels per landholding; production times of new parceling plans; the cost of the project; the status of landholdings with their close relatives (partner, father, mother, siblings and other landholdings whose land it uses), and; to what extent do the results comply with the wishes stated in interviews. In addition, a questionnaire was developed to establish farmers' preferred land reallocation model.

2. MATERIAL AND METHOD

2.1 Material

The main material of the research comprised of land consolidation project data of Agalar village in Ilgin country of Konya city of the study used MATLAB R2007b, Fuzzy Logic Toolbox, Simulink Toolbox and Netcad software. Land consolidation studies in the project field were carried out in accordance with the Land Consolidation Regulation (LCR) of 1979, which was abolished by Special Provincial Directorate of Administration. The new Land Consolidation Regulation took effect on 24 July 2009. Agalar village land consolidation project was developed upon request between the years 2000-2003 (Iscan, 2009).

2.1.1 Introduction of the Study Area

Agalar village in Ilgin county of Konya city was chosen as the research site. Agalar village is 88 km on Konya - Afyon highway and 7 km from Ilgın county center. 3 km of the total road length is stabilized, while the rest is asphalt. The study area is bordered by the Bulcuk Village registration frontier to the south, Orhaniye Village to the west and north, and Olukpınar Village to the east. The study area is dissected by the Ilgın – Agalar road (Figure 1).

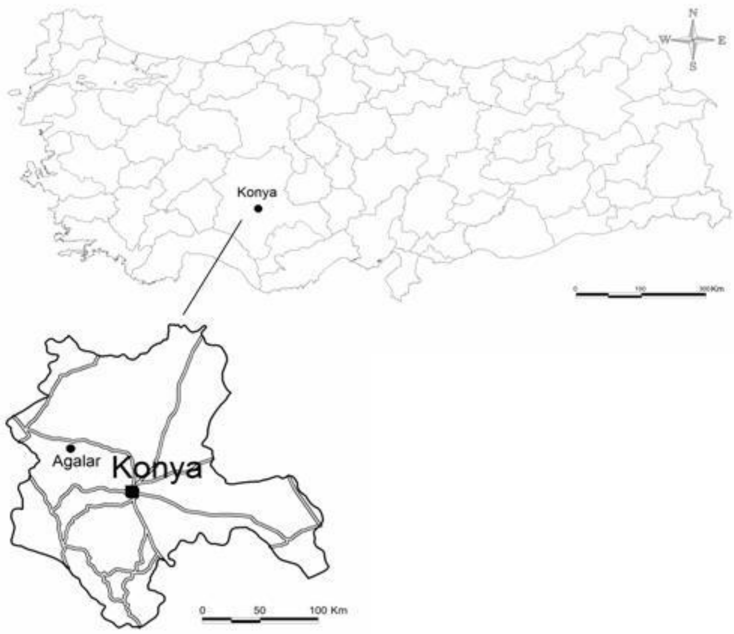


Figure 1. Study Area

The area of the Agalar Village land consolidation project is 1403 hectares. 1388 hectares of it is under arrangement. 989,4 hectares of this area is agricultural land, 288,7 hectares of it is pasture and 109.9 hectares is an expropriation area created previously by the Directorate General of State Water Affairs. There are 715 farmers (landholdings) present in the consolidation field and 1536 cadastral parcels available (Figure 2). 383 of these cadastral parcels are shared parcels. The average size of cadastral parcels is 0,6441 hectares.

Figure 2. Cadastral Status of Agalar Village and conditions of the cadastral parcels belonging to the 24th landholding

2.1.2 Preparatory Works

Provisional documents of cadastral parcels, grading map and interview forms were supplied by the Special Provincial Directorate of Administration. The original map sections at 1:5000 scales were taken from Directorate of Cadastre of Ilgın. Cadastral parcels included in the project, and were identified and listed. Areas, owners and other rights of the parcels were obtained from the Land Registry Office of Ilgın.

The obtained cadastral map sections were digitized and the areas were calculated. The calculated areas were compared with the areas obtained from the land registry. Parcels where a disparity in area was identified were amended in accordance with the cadastral legislation. Irrigation plans made by the Regional Directorate of State Water Affairs were supplied. Using these plans as a basis, block plans showing the road network of irrigation were processed on the cadastral plots. 76 agricultural blocks were formed in block plans.

There are three parcel indexes (PI) in the study area, being 64, 70 and 73. The parcel index of each cadastral parcel is calculated by making use of grading maps. Owners, areas, types, parcel indexes and block areas were computerized. The rate of contribution to common facilities was calculated as 0,017637 %. This calculated rate is relatively low, since the irrigation channels were expropriated before.

2.2 Method

According to the Land Consolidation Regulation, the process of land reallocation is conducted in line with an interview-based land reallocation model. In this part, the interview-based land reallocation model and fuzzy logic-based land reallocation method are explained.

2.2.1 Interview-based land reallocation model

The method through which the land reallocation is carried out in accordance with the farmers' preferences during the LC is called an "interview-based land reallocation model". First, parcels are placed in the blocks according to the first preferences of the landholdings by looking at the interview forms. The surpluses and the shortages in the blocks are corrected regarding the second and/or third choices of the landholdings. Finally, the parcelling procedure is carried out according to the location of the landholdings in the block (Cay et al., 2006).

Land reallocation work is completed with this method, which can be deemed traditional for land consolidation projects, after two or three repeats. The preferences of the responsible project engineer have a direct impact on the new parcelling plan. Daily attitudes, experience, skills, and the responsibility he/she bears for the job are effective in the formation of the new parcels.

2.2.2 Fuzzy Logic-based Land Reallocation Model

Fuzzy logic Model Variables:

Within the process of land reallocation, it is of utmost importance that the farmers do not suffer any injustice and are granted equivalent parcels. The satisfaction of the farmers directly affects the success of the land consolidation studies. Therefore, it is important to know which factors farmers pay attention to in land reallocation. In this case, the criteria of farmers and the persons applying the land consolidation will form the input variables of the FL model. Below are the factors that farmers and applicators pay attention to in land reallocation, as indicated by research:

- The location where the farmer has the largest parcel,
- The location where the farmer's parcel density is,
- The location of the farmer's fixed facility (house, stable, hayloft, well, cluster of trees etc.)
- The location where the farmer has the second largest parcel

These criteria constitute the input variables of the FL system. However, since these criteria express location information, the reference system should be in angle and distance according to beginning point. Therefore, each criterion must be expressed as two different input variables. For this reason, there must be 8 input variables (4 factors ×2 location input variables). In the same way, since the output of the model also expresses location information, two output variables are required. However, in a system with 8 inputs and 2 outputs, thousands of rules may be produced, depending on the number of membership functions. Therefore, it is possible to reduce the number of inputs in order to more easily establish the system. Thus, the location of the largest parcel is taken as the first input variable and the other 3 criteria are taken together as the second input variable. Due to this structure, the locations of the fixed facility, parcel density and second largest parcel of a farmer might not be available at the same time. Whichever is present, that criterion has been taken as the second input. An input variable is required to determine from which block and according to which criteria they will receive. For this reason, parcel areas' being larger or smaller than others has also been taken into consideration. The FL system therefore comprises 5 inputs and 2 outputs. A starting point has to be specified, as the input and output variables will be entered as polar coordinate values. A location that will define the study area and will not produce an excessive data stack within the FL system was chosen.

The general structure of FL model is shown in Figure 3. The MATLAB – Fuzzy Logic Toolbox Program was used for the fuzzy model solution. This program provides users with ease-of-use. For instance, users can select the numbers of input and output variables, the type and number of membership and methods of inference and defuzzification.

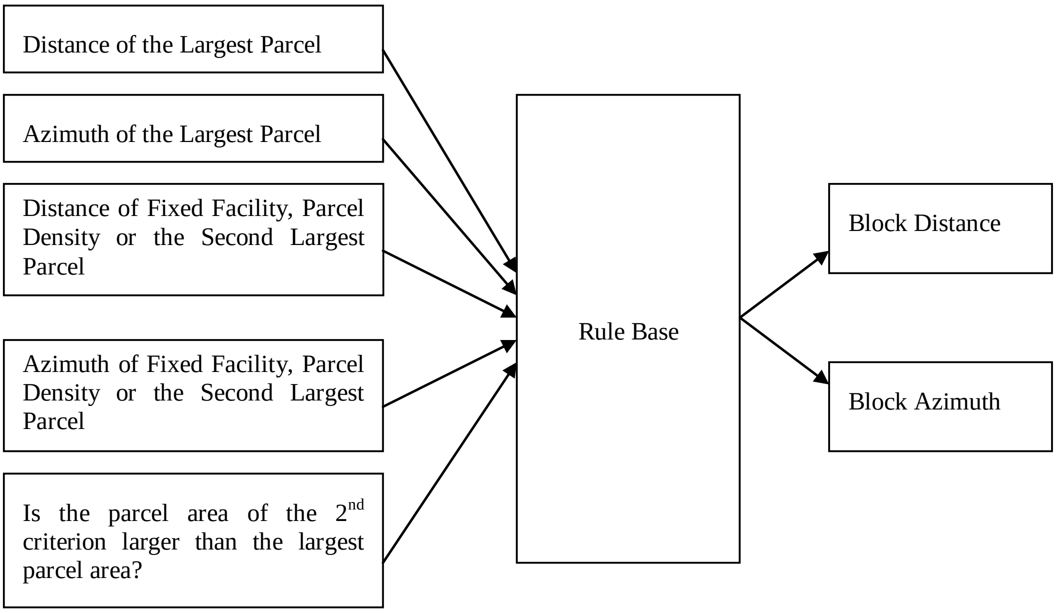


Figure 3. General Structure of FL Model

Determination of Membership Functions:

Membership functions of input and output variables were determined by benefiting from the knowledge and experience of experts and farmers, land consolidation law. The membership functions and pillar widths must be the same, except for the 5th input because the distance and azimuth will be the same for the study area. Pillar width for the distance inputs should not be less than the distance from the starting point to the farthest parcel. For the azimuth, it should not exceed 100 grades.

For the distance inputs in input and output variables, trapezoidal membership functions were used, while triangular and trapezoidal membership functions were used for azimuth inputs. For the distance input variables, 3 membership functions were selected for close, distant and far-off linguistic variables and for azimuth input variables, 4 membership functions were chosen for narrow, medium, wide and very wide linguistic variables. Since the input of "Is the parcel area of the 2nd criterion larger than the largest parcel area?" is an inquiry, it takes a value of either "0" or "1".
Membership function values for distance input variables are given in Table 1.

Table 1. Membership Function Values for Distance Input Variables

Fuzzy Set	**Membership Function**	**Values**
Close	Trapezoidal	[-766, 1500, 2187, 5350]
Distant	Trapezoidal	[3500, 5070, 5860, 7359]
Far-off	Trapezoidal	[5730, 6909, 9130, 11400]

Membership function values for azimuth input variables are given in Table 2.

Table 2. Membership Function Values for Azimuth Input Variables

Fuzzy Set	**Membership Function**	**Values**
Narrow	Trapezoidal	[-36, -4, 5, 30]
Medium	Triangular	[10, 43, 60]
Wide	Triangular	[38, 65, 85]
Very Wide	Trapezoidal	[65, 80, 113, 152]

Figure 4 shows a schema of membership degrees of input variables. Figure 5 shows a schema of membership degrees of output variables.

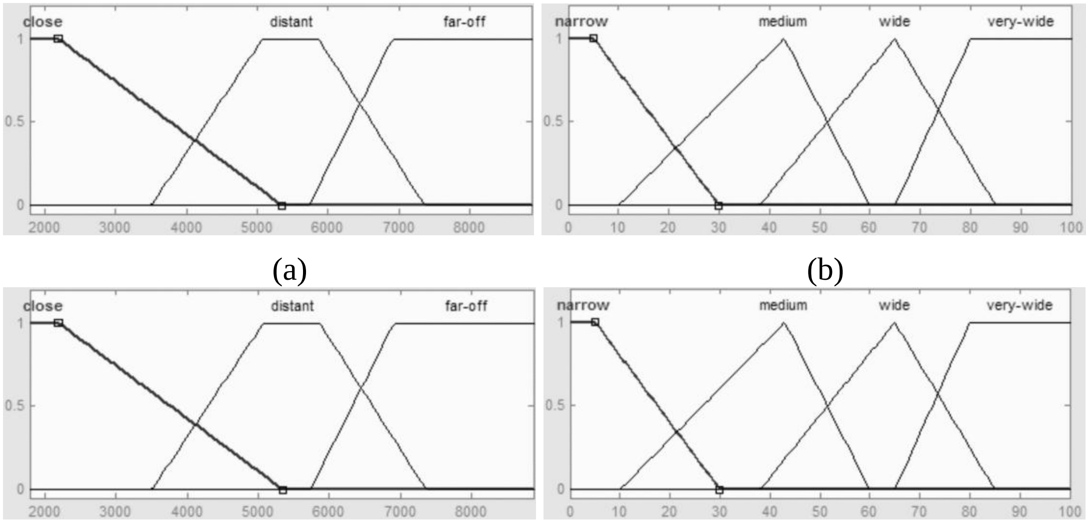
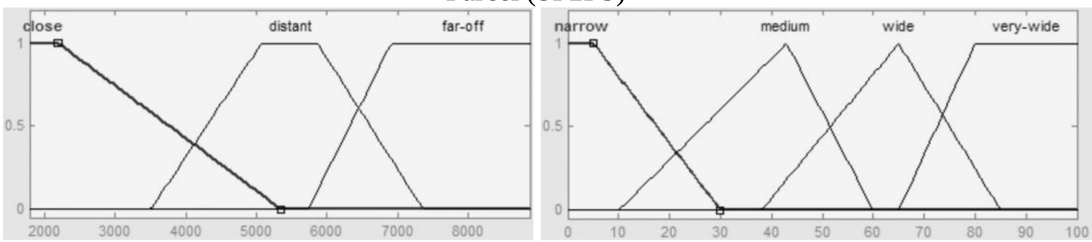


Figure 4. Schema of membership degrees of input variables **a)** Distance of the Largest Parcel (EPM) **b)** Azimuth of the Largest Parcel (EPS) **c)** Distance of Fixed Facility, Parcel Density or the Second Largest Parcel (SP2PM) **d)** Azimuth of Fixed Facility, Parcel Density or the Second Largest Parcel (SP2PS)



(a) (b)

Figure 5. Schema of membership degrees of output variables **a)** Block Distance (BM) **b)** Block Azimuth (BS)

Creating the Fuzzy Logic Rule Base :

Following the determination of membership functions, comes the stage of formulating the FL rule base. The FL rule base is composed of two parts divided with a logical operator: [IF-THEN]. The pioneer part [IF], is composed of input variables and within the inference part [THEN], there is linguistic information to receive the output value. In this study, there are 3 membership functions for "the distance of the largest parcel", 4 for the "azimuth" and 2 membership functions for the variable of "Is the parcel area of 2nd criterion larger than the largest parcel area?" In addition, there are 2 output variables. A set of 288 rules (3×4×3×4×2=288) were created, considering the numbers of membership function. The 288 rules created in order to receive the results of the fuzzy system are connected with the conjunction [AND]. At this point, the Mamdani inference mechanism is utilized. These created rules were entered in the relevant part of the MATLAB Program Fuzzy Logic Toolbox to create the fuzzy rule base.

Defuzzification:

The center of gravity method (centroid), which is the most common method for defuzzification, is used in order to defuzzy fuzzy output. While the centroid method is among the alternatives of MATLAB program, it is principally made with the mathematical formula below.

$$z^* = \frac{\int u_c(z).zdz}{\int u_c(z)dz} \quad (1)$$

A graphical demonstration of the defuzzification process in the FL model is given in Figure 6.

2.2.3 Obtaining the Results

In the fuzzy logic toolbox of the MATLAB program, data are entered individually. This process takes too long for a large set of data entries. Accordingly, the Simulink program is used to evaluate the data effectively and quickly.

In order to find which landholding is placed in which block, data are entered in Simulink block. Some of the data are given in Table 3.

Table 3. Fuzzy System Data

No	**Landholding No**	**EPM**	**EPS**	**SP2PM**	**SP2PS**	**1/0**
1	3	3069.55	59.47	1784.00	0.00	0
2	4	3069.55	59.47	1784.00	0.00	0
3	7	3069.55	59.47	1784.00	0.00	0
4	8	7239.98	47.36	1784.00	0.00	0
5	9	7239.98	47.36	1784.00	0.00	0
6	17	4341.35	64.71	5973.70	69.47	1
7	18	3771.33	66.45	1784.00	0.00	0
8	19	7960.02	60.01	7392.43	57.44	1
9	20	6728.11	81.04	5960.31	51.91	0
10	21	6232.55	53.71	6232.55	53.71	1
…	…	…	…	…	…	…
…	…	…	…	…	…	…

Output values obtained via the Simulink block are polar coordinate values. In a sense, they are obtained as distance and azimuth. In order to convert these values into the national coordinate system, the formulae below are used.

$$X = X_0 + S*Cos(AB) \quad (2)$$

$$Y = Y_0 + S*Sin(AB) \quad (3)$$

X_0 and Y_0 express beginning coordinates, S distance, AB as for azimuth. X_0= 4234244.879, Y_0=407491.047 are taken as beginning coordinates for this study. Output values are converted into the national coordinate system via these formulae. These converted coordinates are added to the project field.

To determine the blocks in which the landholdings are reallocated, a grid system is organized in the project field (Figure 6). The grid system is organized by a 20×21 grid network in X and Y direction at 250 meters distances.

As seen in Figure 6, values derived from the FL system are in a convenient range. However; it can be seen that, in some regions, landholdings are intense, in some they are rare.

In order to follow an automated analysis, parts including from grinding the project field to the first reallocation of landholdings to blocks are written in the MATLAB program by writing an M-file folder.

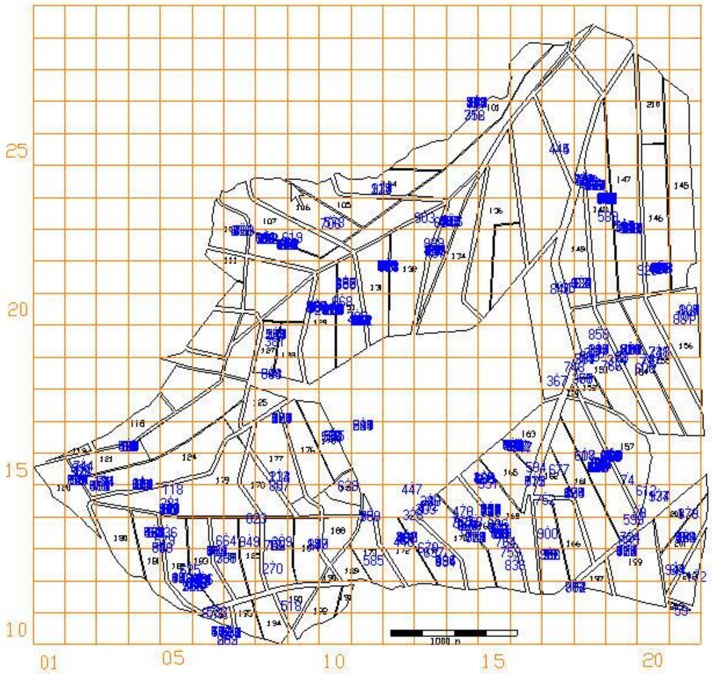


Figure 6. Grid System

It is necessary to determine which block represents which grid to achieve the reallocation of landholdings to blocks. Here; some blocks are represented by one grid while some are represented by more than one.

Following these procedures, the first reallocation is done by the FL method. After the first reallocation, it was ascertained which landholding went to which block. When the results were analyzed, it was seen that some blocks were completely full, some were not and some were extremely full. Comparisons are made in accordance with the Parcel Value Numbers (PVN) of the blocks and landholdings.

Blocks numbered 130, 147, 152, 154, 160, 162, 163, 183 and 184 are extremely full. This is a result of the sizes of landholdings reallocated to blocks. The landholdings that are not completely filled are certainly placed in the same blocks after the first fuzzy land reallocation. The number of landholdings which are certainly placed is 390. However, some of the landholdings in full blocks need to be certainly reallocated. Landholdings with a single parcel and fixed facility can be given as examples. The number of this kind of landholding is 120. Therefore, the number of the certainly reallocated landholdings is 510. According to this, 71.33% (510/715) of the landholdings are successfully placed after the first land reallocation.

The land reallocation of the rest of landholdings is made via block balancing. In other words, landholdings in full blocks are placed in empty ones. To achieve this, 4 criteria below are taken into account in landholdings that can not be reallocated:

- Block with largest parcel,
- Block with fixed facility, parcel density or the second largest parcel,
- Block with the third largest parcel,
- Block with same parcel classification.

Land reallocation is completed using these criteria and parceling of landholdings in blocks is done.

3. DISCUSSION
3.1. Number of Parcels

The current and previous situations of the parcels belong to the landholdings in terms of the number of parcels in the study area are shown in Table 4.

Table 4. Examination of Models in Terms of Number of Parcel

Parcel size (da)	**Cadastral situation**	**Interview-based model**	**Fuzzy logic-based model**
	Number of Parcels	**Number of Parcels**	**Number of Parcels**
0-5	831	140	264
5-10	436	244	168
10-20	194	240	133
20-30	45	79	66
30+	30	51	81
Toplam	**1536**	**754**	**712**

Land consolidation field in Agalar village, parcel number with regard to the interview-based land reallocation model decreased to 754, while there are 1536 old cadastral parcels. The number of parcels in terms of fuzzy logic based land reallocation became 712. 347 shared parcels were formed in interview based land reallocation. 16 shared parcels were formed in the fuzzy logic based model. The decrease rate in the interview-based model is 51%, compared to 54% in the fuzzy logic based model. This result indicates that, in terms of the decrease in parcel numbers, the fuzzy logic based model is the preferred model.

The number of parcels per landholding before land consolidation was 2.1. This number decreased to 1.05 in the interview-based model, and decreased to below 1 in fuzzy logic based model.

3.2. Average Parcel Size

One of the primary objectives of the land consolidation project is the reclamation of the lands which belong to landholdings. The average size of landholdings in Turkey is 54 decare.

Average parcel size of the landholdings regarding fuzzy logic based land reallocation model is 13.66 decare. This area is far below the national average for Turkey, due to the limited number of landholdings with large areas in the land consolidation site. Average parcel sizes of the study area are seen in Table 5.

Table 5. The examination of the models in terms of average parcel sizes.

Parcel Size	**Square**	**Increase Rate (%)**
Previous parcel size	0.6441 ha	-
Parcel size based on the interview-based model	1.2895 ha	100
Parcel size based on the fuzzy logic-based model	1.3656 ha	103

When the models are evaluated in terms of average parcel size, parcel size increased 100% in accordance with the interview-based land reallocation model, and increased 103% in accordance with the fuzzy logic based land reallocation model.

3.3. Duration and Cost of the Land Reallocation

In interview-based land reallocation model, holding interviews with farmers, and recording their preferences about land reallocation is one of the most difficult steps of the land consolidation. First of all, a place for interviews that everyone can attend should be chosen. During interview hours, everyone should be present, irrespective of their shifts. In order to hold interviews with the landholdings in Agalar village, 65 days were spent in total, 35 of which are in the consolidation field. An additional 45 days were spent determining the land reallocation and the new parceling plan. This situation affects both the project group and increases the cost of project. Moreover; since it extended the time, the project has ended late. Also, due to the delay in planting crops, no contribution could be made towards the national economy. The cost of interview studies for Agalar village consolidation field was $26500, based on the commercial rates of the Chamber of Cadastral Map Engineers. Since the fuzzy logic based land reallocation model would not require an interview study, the project cost would be $26500less. While 45 days were previously required for the preparation of the necessary data for land reallocation, in the fuzzy logic based land reallocation model, it was completed in a 25-day-period, thereby saving 20 days. The economic value of this saving is around $7650. In total, a 3-month-time saving could obtained for the Agalar village consolidation project.

3.4. Examination of interview-based and fuzzy logic-based models on the basis of landholdings

The proportion of landholdings with one parcel is 37.76%. This rate is 75.10 % in the interview-based model after land consolidation, compared to 94.94% in the fuzzy logic based model. As far as possible, landholdings are combined in one parcel after land consolidation. The fuzzy logic based land reallocation model is more successful in terms of combining landholdings within one parcel than the interview-based land reallocation model.

Five landholdings were chosen that serve as an example in the application site. Parcel numbers derived from cadastre, interview and fuzzy logic based land reallocation results are given in Table 6.

Table 6. Evaluations on the basis of landholdings

Landholding No	Surname, name	Number of cadastral parcels	New parcel numbers after the interview-based model	New parcel numbers after the fuzzy logic -based model
24	Akgöl Mevlüt	4	2	1
70	Arı Ethem	3	2	1
74	Arık Mustafa	5	3	1
80	Arslan Güler	2	2	1
95	Aşık Mustafa	8	4	1

The conditions of the cadastral parcels belonging to the 24th landholding are shown in Figure 2, the new parcels formed after applying the interview-based model are shown in Figure 7, and the parcels formed after applying the fuzzy logic based model are shown in Figure 8.
At the end of the fuzzy logic based land reallocation, 433 of 715 landholdings are placed into the same blocks with the interview-based land reallocation. In means; 60.6% of the landholdings match with the interview based land reallocation. This result shows that the fuzzy logic based land reallocation model is successful.

In land consolidation projects, it is not always possible to comply with the requests made by landholdings during interviews. In the interview-based land reallocation model, the requests made by 586 (90.1%) of the 650 interviewees were fulfilled; the requests of 64 (9.9%) could not be fulfilled. When the fuzzy logic based land reallocation is compared with the requests made during interviews, 477 landholdings are fulfilled, while the requests of 173 could not be fulfilled. This result shows that the fuzzy logic based land reallocation model fulfilled 73.4 % of landholding requests. From this perspective, it can be said that the fuzzy logic based land reallocation model is successful at fulfilling the requests of the farmers.

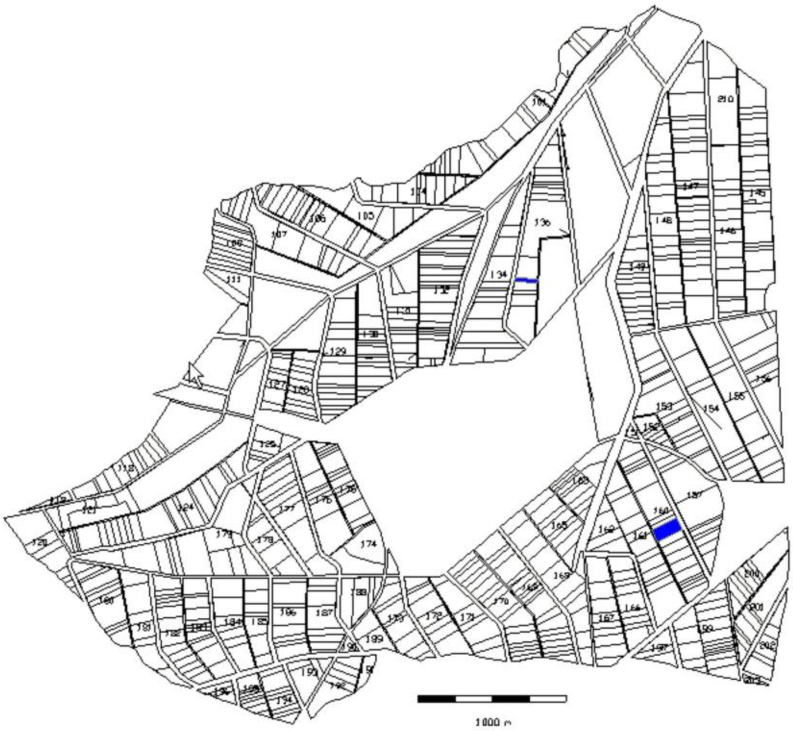


Figure 7. New Parcels of the 24th Landholding after the interview-based model

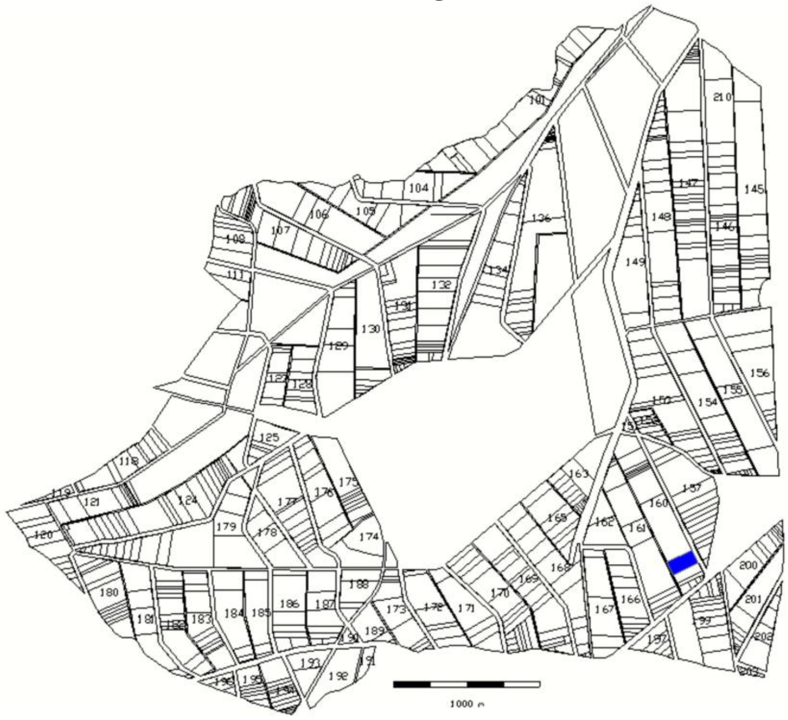


Figure 8. New parcels of the 24th landholding after the Fuzzy Logic Based Land Reallocation

4. CONCLUSION

Land reallocation works on the basis of the interview-based and fuzzy logic-based models have been compared in terms of the number of parcels, average parcel size, duration of the land reallocation process, project cost, and the conditions of the landholdings with respect to those of the owners' relatives. As a result of these comparisons, it has been concluded that the fuzzy logic based model was more successful in terms of number of parcels, average parcel size, average number of parcels per landholding, duration of land reallocation process, project cost and farmer satisfaction, whereas the interview-based land reallocation model proved to be more applicable in meeting the conditions set by the landholdings concerning their relatives and other landholdings.

In the fuzzy logic based land reallocation model developed in the present study, more than half of the landholdings are given from the blocks with new parcels based on the interview-based reallocation model. When the interviews conducted with farmers to perform the interview-based land reallocation are analyzed, the fuzzy logic based land reallocation method gave quite successful results in fulfilling the requests of the landholdings. This is important, since farmer satisfaction is among the objectives of land consolidation.

According to the results of the interviews conducted with the farmers, it appeared that they are much happier with the outcome of the fuzzy logic based land reallocation model than that of the interview-based land reallocation model. Considering the fact that farmer satisfaction is important in land consolidation projects, the fuzzy logic based land reallocation model is judged to have been successful.

As a result of this study, a fuzzy logic based method can be recommend for the land reallocation procedure in land consolidation projects, since FL has suitable characteristics to model human processes of thinking and behavior. Due to this characteristic, it can incorporate and represent more variable parameters than classical forma of logic, and can be used to incorporate linguistic expressions and opinions. One of the most important characteristics of this method is that, since it is better able to model human behaviors, it can provide solutions to situations even when it is not possible to derive a standard mathematical model. The application of FL to an increasing range of issues suggests that the FL method, which is currently used in areas such as engineering applications, will soon be used more widely.

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