Optimization in Land Consolidation

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Key words: Land consolidation, land reallocation, optimization, linear programming.

SUMMARY

In the whole countries, land consolidation is applied to improve the rural areas. Land consolidation refers to the process in which fragmented or scattered lands of a farm family or farm are incorporated. Land reallocation is the most important activity in the process of land consolidation. In land consolidation, land planning and implementing is conducted by land reallocation step. For this purpose, firstly the land is divided into blocks by planning an optimal network for road and channel. Secondly the problem of how much land from which block is given to a farm is solved. Some countries where land consolidation is extensively applied investigated the application possibilities of operations research techniques. Klemper, Kropff, Riemer and Sonnenberg studied how to use different algorithms of the mathematical programming methods in reallocation of farm lands.

In this study, a method which obtains optimum formation for the land reallocation in land consolidation; which can easily be programmed for computers is described. The manner of solution in this method, which can also be accepted as optimization in land consolidation, is based on principles of linear programming. An example illustrating the way the method works is also provided in the solution.

Arazi Toplulaştirmasinda Optimizasyon

ÖZET

Arazi toplulaştırması tüm ülkelerde kırsal alanları iyileştirmek için uygulanır. Arazi toplulaştırması bir çiftçi ailesinin parçalanmış veya dağınık arazilerinin birleştirilmesi süreciyle ilgilidir. Arazi dağıtımı arazi toplulaştırmasının en önemli aşamasıdır. Arazi toplulaştırmasında, arazi planlaması ve uygulaması dağıtım aşamasında yürütülür. Bu amaçla, öncelikle araziler en uygun sulama ve yol ağı planlaması ile bloklara bölünür. Daha sonra, bir çiftçiye hangi bloktan ne kadar arazi verileceği belirlenir. Arazi toplulaştırmasını kapsamlı bir şekilde uygulayan bazı ülkeler yöneylem araştırması tekniklerini uygulama olanaklarını araştırmışlardır. Klember, Kropff, Riemer ve Sonnenberg arazi dağıtımında matematiksel programlama yöntemlerinin farklı algoritmalarının nasıl kullanılacağını çalışmışlardır.
Bu çalışmada, arazi toplulaştırmasında parsellerin dağıtımında optimum düzenlemeyi sağlayacak, bilgisayarlarda çözüm açısından kolaylıkla programlanabilecek bir yöntem izah edilmektedir. Arazi toplulaştırmasında optimizasyon olarak kabul edilen bu yöntemin çözümü lineer programlama esaslarına dayanmaktadır. Ayrıca yöntemin çalışma prensibi bir örnekle açıklanmıştır.

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1. INTRODUCTION

Public tend to arrange the places they live and manage the relations between their living areas, according to the technical, economical, ecological and socio-cultural conditions of time. Shaping and managing the areas can be done only by planning. Planning aims at carrying the common interests and benefits among publics, to the highest level. To achieve this goal in a country, complimentary arrangement of rural and urban areas; at all 'land arrangement' is indispensable (Aclar, 2000; Cagdas, et.al., 2002).

Land Arrangement is a formative precaution, which provides the confirmation of ownership conditions to land usage plans, can be defined as a part of land policy and its continuous relations with law, economics, environment, sociology, political sciences, geodesy planning and construction sites which are assigned to social benefits, rather than both dynamic and static meanings (Seele, 1994).

Land Consolidation Projects are costly rural development actions that are often questioned. Integrated Land Consolidation Projects are geographically confined Land Rural Development Actions and their ex ante evaluation involves interdisciplinary research, in order to predict changes in farmers behavior, patterns of land use and in crops and technologies used (Coelho J.C., Pinto P.A., Silvo L.M., 2001).

The objective of Land Consolidation is creating the better conditions for farming and forestry management. Such a goal can be reached by improvement of spatial structure of farms, forests and forested areas. Land Consolidation Projects are aimed at rational management of the spread of Land plots and border adjustment to the water and road networks considering terrain relief (Wilkowski W. and Pulecka A., 2002).

The land reallocation task is the most complicated stage of an entire land consolidation process. It is a kind of land exchange between the individuals and the community, and also among individuals. Often several pieces of fragmented lands are consolidated into one. In this stage, landholders receive new parcels in a different size and location to their original parcel. Land consolidation, however, affects land tenure and changes the existing parcel structures in accordance with the planning details. Therefore, reallocation of the new parcels is the most sensitive stage of the whole process, which requires a highly refined solution to the land reallocation (Yomralioğlu, et.al.,1996).

In land reallocation, old cadastral parcels are reallocated to new development blocks. In both theoretical and practical applications, the principle of equivalence is left to the discretion of the applicator. Hence, the reallocation is performed in a totally subjective manner, and since the applications performed are not based on mathematical grounds, the solution to the reallocation problem can not be encoded onto the computer and therefore labour-intensive calculations are required.

2. OPTIMIZATION STUDIES IN LAND REALLOCATION

Optimization is the process of finding the best solution and can be applied to all problems that are quantifiable. The general optimization problem consist of finding minimum or maximum values of a quantified parameter, objective function, by varying design variables under given design constraints. Optimization can be considered as minimizing a quantified parameter since maximization can always be translated into minimization by changing the sign of the objective function.

During the years many different optimization methods have been developed and in the last decades optimization has been a growing field due to improvement in computer speed. The existing optimization methods range from very general to problem specific formulations and from the strict mathematical to more intuitive formulations (Nielsen, 2002).

Linear Programming, a specific class of mathematical problems, in which a linear function is maximized (or minimized) subject to given linear constraints. This problem class is broad enough to encompass many interesting and important applications, yet specific enough to be tractable even if the number of variables is large (Overton, 1997).

The Simplex Method is an algebraic method for solving linear programming problems. The Simplex method is based on a direct comparison of function values without using derivatives. The algorithm superimposes a simplex in the solution space with n+1 points. The value of the objective function is evaluated in each point of the simplex. In each iteration step, the point with the highest value of the objective function is replaced by another point. The algorithm consists of three main operations: reflection, contraction and expansion of the simplex. These operations are used to replace points in the simplex by moving around in the solution set. If the search is successful the points in the simplex moves towards a minimum of the objective function (Nielsen, 2002).

A method was developed by Kik (1980) to investigate the reallotment in the preparatory phase of a land consolidation project. The method depends on the improvement of economical characteristics of farms by means of shortening farm-plot distances and decreasing number of plots. Girgin (1982), Büker and etc. (1990), Girgin and Kik (1989) comparatively examined some of the consolidation projects applied in Turkey through this method and the manual method from the standpoint of farm economics. Avcı (1989) compared the results from a model that minimizes both exchanges between classes and plot distances with the results from parcellation plan of the classical method.

A new model, which is used in determining of reallotment plan in land consolidation, have been presented and this model have been applied to Turkey-Salihli-Yılmaz Village. Then, the results of this model have been compared with results of the conventional method. This method takes account the maximization of the amount of land non-exchanged and is based on linear programming. According to the results from this study, the average number of plots per farm decreases to 1 in plan obtained from this model, while the amount of the non-exchanged land were obtained as high as conventional methods(Avci, 1999).

Essadiki et. al. has been done a study in 2003. The main objective of this study is the optimization of technical steps of a land consolidation project using a Geographic Information System (GIS). A new approach for "Temporary Land Reallocation" was developed to determine the landowner list for reallocation inside a block by giving a weight to each land consolidation qualitative and quantitative parameters. The developed interface using the SML language based on PC Arc/Info (ESRI, CA), allows the acquisition, process, query, analysis, and archiving of the data base(Essadiki, et.al., 2003).

In general, criteria in mathematical models are given as follows:
- Landowner wishes
- Constant foundations
- Reducing of parcel number
- Minimization of parcel distances

Main objective of using optimization methods in rural land arrangement is to improve organization and activity of agriculture holdings and is to use productive present agricultural sources. In addition to that, consolidation proportion is very high in reallocation studies by using optimization methods.

In this paper, a method will be proposed that will be able to best maintain the principle of equivalence in reallocation that will be implemented while forming new blocks in land consolidation and that will be easily encoded onto computers. The manner of solution in this method, which can also be accepted as optimization in land consolidation, is based on principles of linear programming. An example illustrating the way the method works is also provided in the solution.

3. MATHEMATICAL PRINCIPLES

The problem encountered in land consolidation can be defined as the reallocation of n number of cadastral parcels subject to the application to m number of blocks. Generally, the total area of n number of parcels subject to the application is greater than the total area of m number of blocks. The reason for this is that the total area of roads, green spaces etc. that will be set aside for public use is greater than their previous area. In the newly developed optimization method, on the other hand, it is required that the total area of the parcels subject to arrangements be equal to the total area of the blocks on which reallocation will be conducted. Therefore, the areas of old cadastral parcels need to be arranged, in accordance with the method, in proportion to their sharing ratio of common area before they are put to arrangement. So, let units in Figure 1 indicated with S be cadastral parcels whose areas were arranged in proportion to their sharing ratio of common area and which will be subjected to reallocation and units indicated with S' be blocks on which reallocation will be implemented. Again in Figure 1, i parcel no being ($0 \leq i \leq n$), j block no being ($0 \leq j \leq m$), let b_{ij} terms indicate the proportions of amounts of old cadastral parcels that will correspond to new blocks after reallocation to the full. In this case, in order to demonstrate the situation of cadastral parcels after reallocation, it is possible to form matrix *B* that can be defined reallocation matrix composed of *i* lines and *j* columns.

$$\underset{n,m}{B} = \begin{bmatrix} b11 & b12 & .... & b1m \\ b21 & b22 & .... & b2m \\ \multicolumn{4}{l}{...} \\ bn1 & bn2 & .... & bnm \end{bmatrix} ....(1)$$

Since negative area/zone values can not be considered in reallocation, it should be $bij \leq 0$. After this stage, in order to establish the principles of equivalence in reallocation a new matrix like *A* has to be formed.

$$\underset{m,n}{A} = \begin{bmatrix} a11 & a12 & .... & a1n \\ a21 & a22 & .... & a2n \\ \multicolumn{4}{l}{.......................................} \\ am1 & am2 & .... & amn \end{bmatrix} ....(2)$$

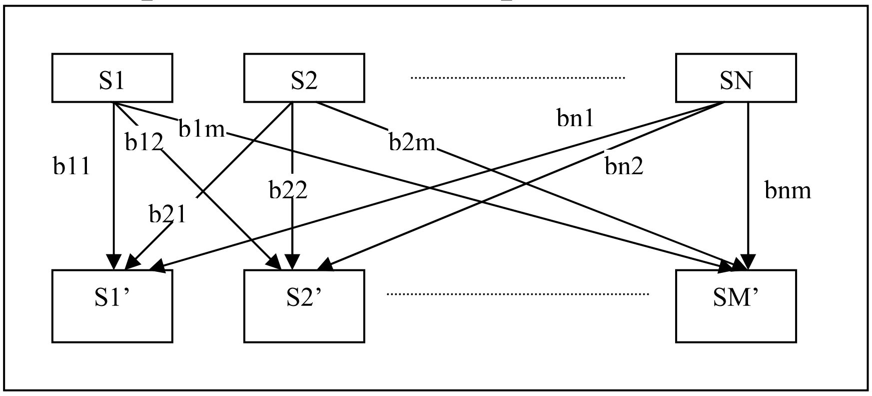

Figure 1. Condition of cadastral parcel and block

The members of matrix *A* should be so determined that if parcel no *i* is near block no *j*, it should assume that big a value, and the further it is, a smaller value it should assume. The distance of parcels to blocks can be determined as distances of parcels to geometrical midpoints. Furthermore, in respect of the application of the method, the values that matrix *A* may take should be determined as $0 \leq aji \leq 1$.

By the way, it is also possible to determine the area values of cadastral parcels that will be subjected to arrangement as members of a vector like *S*, and the area values of blocks on which reallocation will take place as members of a vector like *S'*.

$S^T = [s1, s2, ..., sn]$ $S'^T = [s'1, s'2, ..., s'm]$...........(3)

Subsequent to these definitions, it is possible to explain the method under the rubric of optimization problem as presented below.

3.1 Optimization Problem

In land consolidation and reallocation, it may be required that a cadastral parcel be reallocated to different blocks. In that case, the total of percentage values of reallocated values to the whole of the parcel value has to be 1. This is called the principle of maintaining the parcel value in the method. The statement of this principle in matrixes is as follows:

$$\underset{n,m}{B} * \underset{m,1}{e} = \underset{n,1}{e'} \qquad \text{....................(4)}$$

Here, *e* and *e'* are vectors, all of whose members are 1.
On the other hand, the total of parcel values to be reallocated to any block has to be equal to the value of the block. This is called the principle of maintaining the block value. It is possible to express this principle *i* representing the parcel number and *j* representing the block number as follows:

$$S'_j = \sum_{i=1}^{n} S_i * b_{ij} \qquad \text{....................(5)}$$

by generalizing this statement to include all plots that will be subject to reallocation and blocks to which reallocation will be performed;

$$\underset{1,n}{S^T} * \underset{n,m}{B} = \underset{1,m}{S'^T} \qquad \text{..................(6)}$$

The principle of maintaining the block value is written in matrix form.
One of the things that have to be considered during reallocation is reallocation of parcels to the nearest block possible. This is called the principle of equivalence in the method. In order to satisfy this principle, a matrix *C* as stated below is formed.

$$\underset{m,m}{C} = \underset{m,n}{A} * \underset{n,m}{B} \qquad \text{....................(7)}$$

By writing matrixes *A* and *B* in the form of line and column vectors;

$$A = \begin{bmatrix} \underline{a1} \\ \underline{a2} \\ .... \\ \underline{am} \end{bmatrix} \text{ ve } \quad B = [\, \underline{b1}^T \quad \underline{b2}^T \quad \text{...............} \quad \underline{bm}^T \,] \text{...................................(8)}$$

is obtained. From here, the equation:

$$IZ\,(\,C\,) = M = \underline{a1}\ \underline{b1}^T + \underline{a2}\ \underline{b2}^T + \text{..........} + \underline{am}\ \underline{bm}^T \qquad \text{..........(9)}$$

has to be formed in order to bring optimum solution to the reallocation problem. By making the IZ (C) value as maximum, the principle of equivalence in reallocation of parcels is satisfied.

Members of matrix *B* are tried to be found by complying with the limitations in equations (4) and (6) so that the *M* value given in (9) is rendered maximum. Thus, the reallocation of parcels to blocks is properly implemented. The solution to the members of matrix *B* is a special problem of linear programming, and is performed via an algorithm called SIMPLEX (Noble and Daniel, 1977; Nowacki, 1980).

4. APPLICATION OF THE MODEL

In application is used number of parcel value (**P**arsel **D**eğer **S**ayısı - **PDS**) for reallocation. For compute number of parcel value is used Land Index (PE) and area (PDS = PE * (Area) / 100). In this study, Land Index (PE) of cadastral parcels and blocks is 80.

Let's take as an example the operation in which two cadastral parcels of 4000 PDS and 5000 PDS were put to arrangement and reallocated to two blocks of 3000 PDS and 6000 PDS (Figure 2).

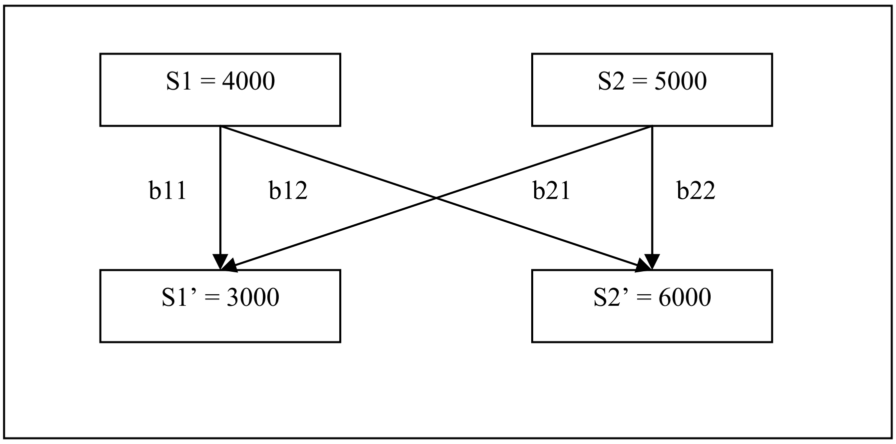

Figure 2. An example the reallocation

In this example, it is possible to write *A* and *B* matrixes and *S* and *S'* vectors of parcel no 1 to block no 1, and parcel no 2 to block no 2 as follows considering one closer or intersecting compared with the other.

$$A = \begin{bmatrix} 1 & 0.5 \\ 0.5 & 1 \end{bmatrix} \quad B = \begin{bmatrix} b11 & b12 \\ b21 & b22 \end{bmatrix} \quad S = \begin{bmatrix} 4000 \\ 5000 \end{bmatrix} \quad S' = \begin{bmatrix} 3000 \\ 6000 \end{bmatrix} \qquad \text{...............(10)}$$

Here, by opening equation (4) ;

b11 + b12 = 1
b21 + b22 = 1 ....(11)
and by opening equation (6) ;
4000*b11 + 5000*b12 = 3000
4000*b21 + 5000*b22 = 6000 ....(12)
is obtained.

When equations (11) and (12) are considered, one of the equations seems to be in a linear link to the others. Therefore, one of these equations can be left out of evaluation. This adds up to the following theoretically: if reallocation to all other blocks barring the last block is known, reallocation to the last block will be self-evident.

According to this, by not considering the last equation in (12);

$$b11 + b12 = 1$$
$$b21 + b22 = 1$$
$$4000*b11 + 5000*b21 = 3000 \quad ....(13)$$

Equation cluster is obtained. On the other hand, in order to maintain the principle of equivalence, the equation is maximized by putting the given in place in (9);

$$M = b11 + 0.5\ b21 + 0.5\ b12 + b22 \quad ....(14)$$

There are three equations and four unknowns in the equation cluster given in (13). It is possible to solve this equation by assigning a random value to one of the unknowns, but the solution can be reached by following different methods. In each step, by making one of the unknown coefficients zero, the other unknowns are attempted to be solved. The unknowns whose coefficients are different from zero are called basic unknowns and solutions to them are called basic solution. If any basic solution satisfies condition (13), this is called probable solution. Also, if the basic solution satisfies the conditions in (13) and makes value M in (14) maximum, this is called probable optimum solution. According to the Simplex method, if there is a probable optimum solution as regards the unknowns of an equation cluster, there is certainly a basic solution to the unknowns ((Noble and Daniel, 1977 ; Nowacki, 1980; Dreyfus and Law, 1977; Cross 1981).

When equation (14) is examined, which of the b variables representing unknowns will maximize value M can be seen. According to this, it is seen that unknowns' $b11$ and $b22$ are the most appropriate for this purpose. When $b11$ and $b22$ values are increased a unit, they affect M a unit whereas when $b12$ and $b21$ are increased a unit, they affect M half a unit.

Therefore, one of $b11$ or $b22$ is chosen for a solution to the problem (let's consider $b11$ has been chosen). In order to see what maximum value the chosen unknown may take, by taking those containing $b11$ from equations no (13), the unknowns in these equations are so arranged as to be calculated in value $b11$.

$$b12 = 1 – b11$$
$$b21 = 0.6 – 0.8\ b11 \quad ....(15)$$

On condition that $b12 \geq 0$ and $b21 \geq 0$, the maximum value that can be assigned to $b11$ is investigated. From an examination of the equations in (15), it is seen that value $b11$ can take the maximum value of 0, 75. By putting this value in (13):

$$b11 = 0.75$$
$$b12 = 0.25$$
$$b21 = 0$$
$$b22 = 1 \quad ....(16)$$

are obtained. In this case, $b11$, $b12$, and $b22$ are basic unknowns. By putting the values in (16) in place in (14);

$$M= 185 / 100 \quad ....(17)$$

is found. After this stage, the unknowns $b11$ are removed from equation (14) and ;

$$M = 0.5\ b21 – 0.5\ b12 + b22 + 1 \quad ....(18)$$

is obtained. In order to maximize value *M* and provide a solution to the problem, this time unknown *b22* is chosen. The equation containing *b22* in (13) is taken and

b21 = 1 – b22 ....(19)

is obtained. When this equation is examined, it is seen that, for $b21 \geq 0$, *b22* can be *1* at the most. These values are put in place in (13) and

b11 = 0.75
b12 = 0.25
b21 = 0
b22 = 1 ....(20)

is obtained. These values are put in place in (14) and

m = 185 / 100 ....(21)

is obtained. When the obtained maximum value is compared with the maximum value obtained at the end of the previous solution, no improvement is observed in maximum value.

We mentioned previously that when equation (14) is examined, the values that unknowns' *b11* and *b12* can take will not be able to affect *M* to a maximum as much as unknowns' *b11* and *b22*. All the same, in order to bring the solution to a controlled conclusion, to what extent unknowns' *b12* and *b21* can affect *M* is investigated. To this end, at this stage of the solution, unknown *b22* is removed from equation (18) and

M = -0.5 b21 – 0.5 b12 + 2 ....(22)

is obtained. As will be seen, when positive values are assigned to unknowns' *b12* and *b21*, value *M* seems to end in a negative value.

When resulting values obtained in (17) and (21) are examined, if one of the values *M* were greater than the other, then the stage at which unknowns yielding maximum *M* value are solved would be the solution sought. However, since values *M* here are equal, the results given in (16) and (20) are accepted as optimum solutions.

According to these results, it is required that 0.75 of parcel *S1* given in Figure 2 (4000* 0.75= 3000 PDS = 3750 m^2) be given to block *S1'*, again 0.25 of the same parcel (4000* 0.25= 1000 PDS = 1250 m^2) be given to block *S2'*, and the whole of parcel *S2* (5000 PDS = 6250 m^2) be given to block *S2'*.

5. CONCLUSION

In the method developed, all issues desired in reallocation, by establishing a kind of condition equations, how reallocation procedure should take place can be described or determined.
In application of the method, the optimum solution possible after reallocation can be found for all parcels subject to reallocation while maintaining their equivalence.
The mathematical principles and their solution algorithms can easily be programmed on computers. Therefore, in applications, arrangement procedures can be finalized in a short time and there remains no need for labour-intensive calculations.

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