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OPTIMIZATION OF THE PARCEL LAYOUT IN RELATION TO THEIR AVERAGE DISTANCE FROM FARMING SETTLEMENTS IN THE EXAMPLE OF MŚCIWOJÓW VILLAGE, POLAND

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Summary

In this study, an optimization process of the spatial layout of a village from the viewpoint of minimization of distances between parcels and farming settlements is presented. It is illustrated by the data coming from the village Mściwojów, which is situated in the south-western Poland. The proposed calculation process uses linear programming methods, and the input data are the result of the processing of the ground and building registration data bases. The results indicate a wide range of application possibilities of the optimization process of the parcel layouts, at different stages of operations connected with the restructuring of spatial distributions of rural areas. In particular, it refers to the realization of conceptions of the land consolidation results which are viable in a given area.

Keywords

village layout • land consolidation

1. Introduction

The observed spatial layout of the village and the parameters which describe them are characteristic for the spatial structure of layout of parcels in rural areas. These are the results of long-lasting transformations of social, economic and historical character. Essentially the developments of the existing parcels layout can only be the result of complex land consolidation-cultivation work. The generations-long influence of the new parcel layouts on a given area necessitates development of its most optimum conception. To obtain it, the methods of land layout optimization can be used for particular land owners in a given area.

The main criterion for this problem is the minimization of the distance of parcels from farm settlements. This has been the subject of discussion both in Poland [Harasimowicz 1986, Janus 2011] and in the world [Kik 1980, Cay and Ayten 2006,

Cay and Iscan 2006, 2008, Ayranci 2007, 2009]. The optimization task of land allocation to farms is closely related to the basic aim of the conducted land consolidation work which is the improvement of performance of agricultural farms. The factors influencing the expense are largely the size and shape of farming fields, and their distance from a given farm settlement.

2. Methodology

If we assume that the transportation network system in a given area is an element which does not undergo changes in the process of optimization, the shape of parcels is influenced only by changes in crop belt widths. These belt widths are related to the parcel area, and the increase of the parcel area, as well as the width, result in the decrease in the unitary costs connected with cultivation.

One of the most important indispensable and accountable elements in the process of optimization is the distance between the farm settlement and the grounds of a given farm. The measurement of distance for the needs of the optimization procedure should take advantage of the shape of the real road network and it should take into account the scaling distances. This refers to the quality and inclination of a given road section [Harasimowicz 2002].

In the optimization process the necessity of considering the distance between the farm settlements and the parcels belonging to the farm requires division of the land into complexes which afterwards will be divided into individual farms. These complexes are usually divided as a result of the analysis based on the transportation network, location of constant elements, natural obstacles and external boundaries of a given area. The allocated group of complexes should have the specified following features:

- total value of the complex or its area,
- calculated distances between the complexes and the farm settlements,
- optionally, individual requests of the land consolidation participants.

For such a defined group of complexes, the number of shares of a farm of the index "j" in the complex of the index "i" (variable x_{ij}), makes a set of deciding variables of the processed model with a function of objective. This is the minimization of the distance from the settlements to the parcels belonging to the farms. In this case, the function of objective constitutes the sum of the farms' shares (x_{ij}) in the complexes and their distances from the settlements.

A series of conditions should be considered for the linear model resolution which can be defined. The most important of them is: the necessity of preserving values (of the area) of individual farm lands before and after consolidation. Another important condition specifying that the sum of values of all farm lands is equal to the value of the whole object, as it is the sum of the values of particular complexes.

The presented process of optimization of the parcel layout used the data from the ground and building register data. This data has been presented in the example of the

village Mściwojów (Mściwojów municipality, Jawor district, Lower Silesia), situated in the south-western part of Poland (Figure 1). One of the more important stages of the preliminary data processing is the identification of the agricultural farms in the area of the potential consolidation. An assumption was made that farm land should constitute parcels under their owners' one common address.

Source: The Land Register Data

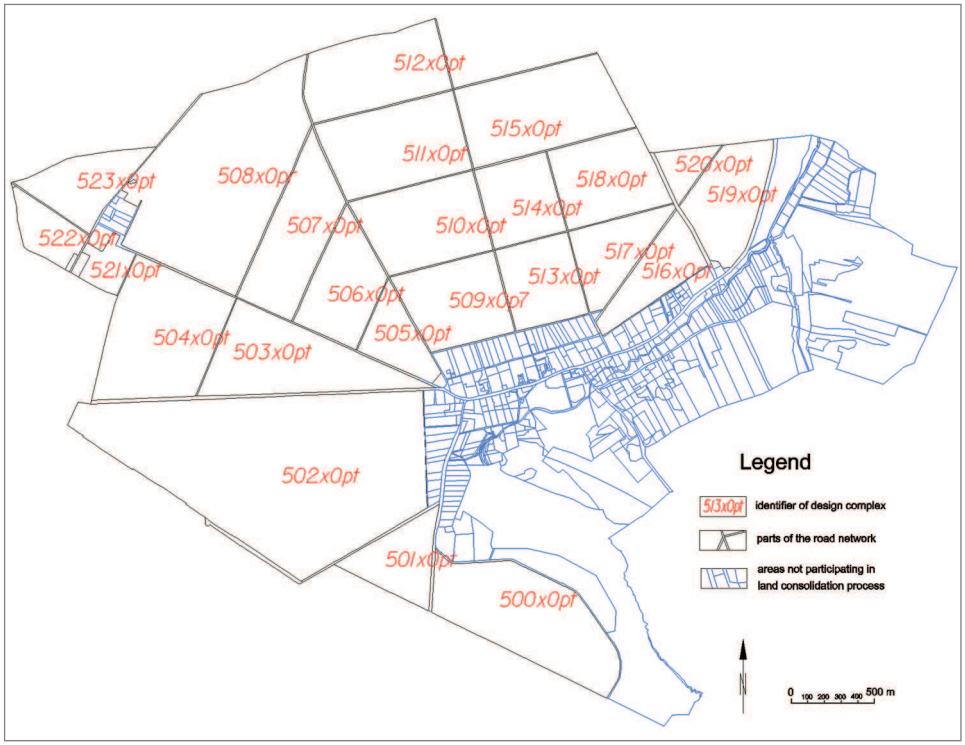
Fig. 1. The existing layout of parcels in the village Mściwojów

The next stage of calculation is the creation of a map of the village, with the division into constant elements as well as design complexes. Constant elements will be the areas where the existing layout of parcels will be preserved in the consolidation process (this most often refers to the invested-in areas and forests).

Another element affecting the quantity and the final shape of design complexes is the agricultural transportation network in the area under discussion. The analysis of density and the course of the existing elements of the road network is indispensable for the determination of needs in the scope of design of new road sections, removal of unnecessary roads, as well as adjusting the course of some of them. These adjustments aim at providing access to all the newly designed parcels in the optimized

complexes, and designing parcels of appropriate shapes. The interference in the existing transportation network is analyzed on the preparatory stage of the optimization process of the object. It is also approximated to the interference carried out in real consolidation processes.

Another element to account for in the set of consolidation complexes under development are the directions of the design of parcels in the complexes. The directions must make it possible that the designed parcels have access to the transportation network. On the other hand, they should take into account the existing surface structure of the area. The final layout of the optimized complexes in the area of the village Mściwojów is shown in Figure 2.



Source: authors' study

Fig. 2. The area division of the village Mściwojów into design complexes, participating in the optimization process of the layout of parcels

Another important element of the calculation process is to establish distances between the selected elements of the village model. The methods of using elements of the graph theory were applied when the distances were calculated by the algorithm by Dijkstra. The first set of the obtained data contains information on the average

distance between the grounds of individual farm lands. This data set is indispensable in the optimization process as comparative element by the evaluation of the current value of the function of objective. This is the average distance of the grounds from the farm settlements in the optimized village. The second data set is the matrix of distances between all farm settlements and the set of points which constitute the entry points from these settlements to the group of the selected design complexes.

Having the data defining both the set of the farm lands participating in the optimization process, as well as the distances between the settlements of these farms and the complexes, one can formulate the optimization problem of a new allocation of shares of these farms in the separated consolidation complexes. These allocation of shares will be in relation to the distance minimization in the area of the discussed village. In the presented case, a linear programming methods have been proposed and the calculation process has been realized by means of the GLPK (GNU Linear Programming Kit) package. This is intended for solving large-scale linear problems.

3. Presentation of results

The final result text file from the calculation process includes areas of individual farm lands which should be separated as parcels in subsequent consolidation complexes. Moreover, such an assignment allows for the reduction of the average distance of parcels belonging to the farms in the whole village (assuming the division of the village into complexes and the distance measurement to the entry points of the complexes from individual farms). In the case of the village, as a result of the optimization by the method of linear programming, a considerable decrease of the average distance from parcels to settlements (from 966.37 m to 505.28 m) was observed. A significant improvement has been noticed in other parameters of the parcels layout which are presented in Table 1. The total number of farm shares decreased from 177 to 101 in the optimized consolidation complexes. In particular, for the smallest area groups these values changed respectively: for shares of up to 1 ha from 51 to 17 shares, for shares of up to 0.5 ha from 39 to 9, for the smallest shares of an area under 0.2 ha the reduction is the greatest, from 19 to 2 shares. As a result of the essential optimization, no farm with a rise of the average distance between parcels and settlement were noticed. The average surface area of a parcel in the area of the village discussed increased from 3.15 to 5.53 ha, whereas the average number of parcels in a farm land decreased from 3.4 to 1.8. The general improvement of the layout of farms resulting from the optimization process is essential for all the discussed aspects. However, the developed system still has some drawbacks which should be removed even at the cost of a slight increase of the average distance value in the village discussed. The most important drawbacks are:

- Small shares of farm lands in complexes make it difficult to separate appropriate farm fields of shapes and areas minimizing the cultivation expenditure. It is advantageous to decrease the number of shares in all groups under 1 ha, especially the shares of small areas.

- Big differential of advantages benefited by individual farms from the viewpoint of the decrease of the average distance of the parcels from the settlements. In particular cases, despite the distance reduction in the whole village, for some farms it means the increment of the distance to the owned grounds in the new state.
- The occurrence of shares in complexes on the basis the shape of the complex. Consequently the cultivation length, the extension of the parcels is excessive and unfavourably affects the cultivation expenditure due to the shape.

For the removal of the above mentioned disadvantages of the ground system, several adjustments of the optimum solution have been suggested. The first of these improvements is the *correction of shares' grouping in complexes* which is denoted in Table 1, as correction with "A" symbol. The application of this correction allows for further reduction of the total number of shares from 101 to 96; simultaneously this reduction allowed for the whole elimination of the smallest shares (up to 0.2 ha), as well as considerable reduction of the last two land groups. In the case of shares of an area from 0.2 to 0.5 ha the reduction is from 9 to 4 shares, whereas in the case of shares in the range from 0.5 to 1 ha the number of shares decreased from 17 to 6.

As a result of a field questionnaire, two other parameters of the parcels layout underwent deterioration. They were: the average distance between parcels and settlements in the village Mściwojów which increased from 505.28 to 507 metres. There also emerged a group of six land farms in which there was a slight growth noted of the average distance of their parcels from the farm settlements.

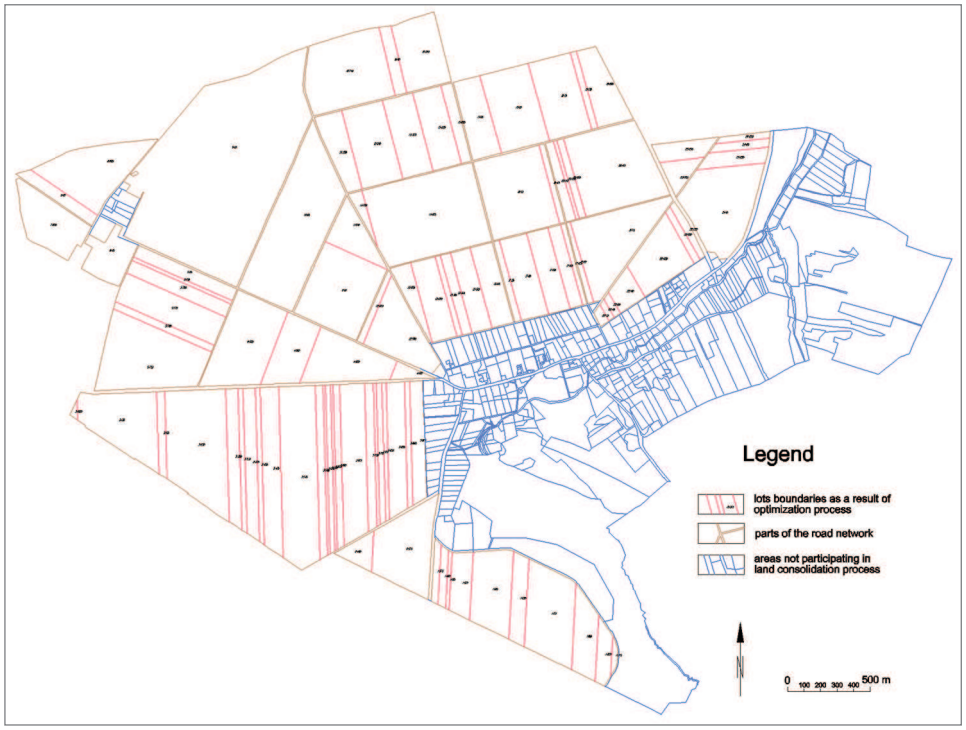
Limitation of the dimensions of this phenomenon can be adjusted, by the application of the *correction which restricts distance increments in land farms* and is denoted by symbol "B". The essence of its influence lies in the division of larger farm shares of considerable reduction, of the average distance from grounds and their exchange with farms. The unfavourable phenomenon of the average distance increase was noticed. This correction leads to a slight increase of the total number of shares in the area of the optimized village. In the case of the village of Mściwojów, this correction made it possible to reduce the number of farms with a distance increment from 6 to 1 at the cost of the increase of the share number. In the range from 0.5 to 1 ha from 6 to 8, as well as the increase of the total number of shares from 96 to 101. The average distance between parcels and settlements in the village slightly decreased and after corrections, it is equal to 506.47 m. However, the final values of the average surface of a parcel in a land farm and the number of such parcels are respectively 5.53 ha and 1.8 of a parcel.

The parcel layout which is the result of optimization with allowance for the removal of occurring distance increments in the selected land farms is shown in Figure 3. Blue color has been used there to denote the areas of constant character, whereas the red color has been used for a new set of parcels which will be further described in a separate chapter, on correction of small parcels. The data which are characteristic for optimization effects are presented in figures in the Table 1.

Table 1. The effects of the development of the ground system by the method of linear programming with allowance for the removal of excessive distance increments in land farms

Stages of the ground system development	Distance [m]	Number of surface area elements in complexes				Number of land farms with distance increments	Average parcel area	Number of parcels in a land farm
		all shares	up to 1 ha	up to 0.5 ha	up to 0.2 ha			
Initial state	966.37	177	51	39	19	0	3.15	3.4
Distance optimization	505.28	101	17	9	2	0	5.53	1.8
Correction of share grouping (A)	507	96	6	4	0	6	5.82	1.7
Correction limiting distance increments (B)	506.47	101	8	4	0	1	5.53	1.8

Source: authors' study



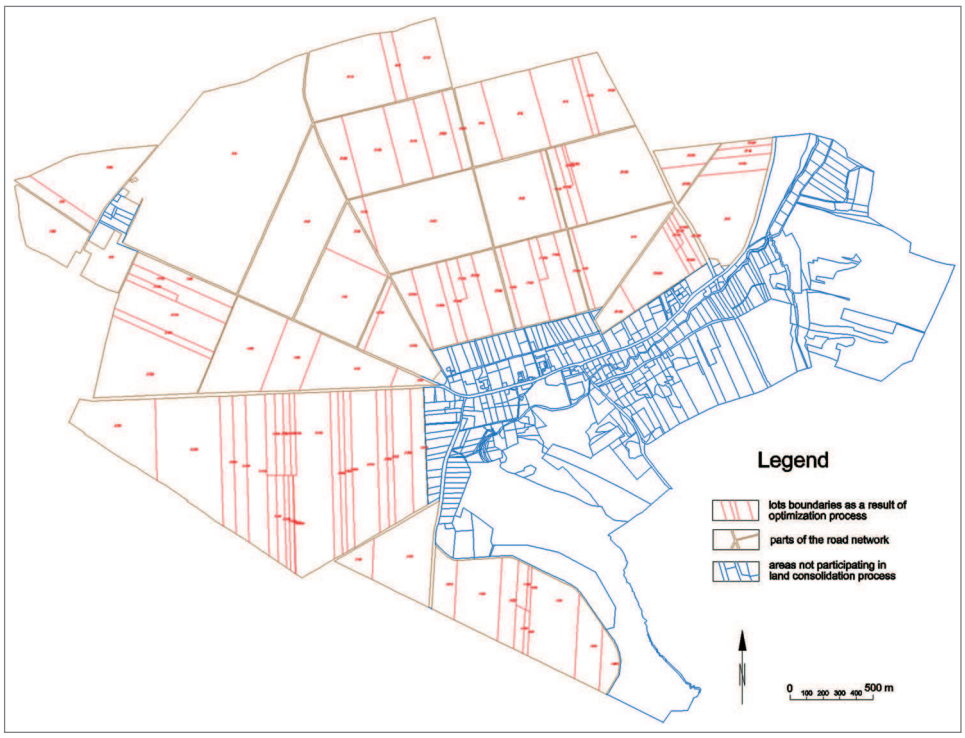
Source: authors' study

Fig. 3. The effects of the development of the ground system by the method of linear programming with allowance for the removal of excessive distance increments in land farms presented as a new system of parcels

As a result of the stages of optimization, a group of parcels of small areas and excessive length has been created. The improvement of their shape can be obtained either by densification of the road network (usually uneconomical), or by the introduction of the one-side access of these parcels to roads in the selected parts of the design complexes. This makes it possible to decrease the length of small parcels and at the same time reduce cultivation losses.

The correction for small parcels eliminated parcels of excessive length which is connected to their accessibility from roads. The realization of this correction leads to further improvement of spatial structure of the optimized area.

An essential problem, is the appropriate separation of a group of parcels which should undergo the correction, so that the resulting benefits obtained from the length decrease should be larger than the expenses connected with the change of accessibility of the fields to the roads.



Source: authors' study

Fig. 4. The result of the optimization of the ground system after the correction of small parcels. The boundaries of new parcels were marked red

The calculation process connected with the determination of the appropriate set of parcels, involves determining limiting parameters of the runner which indicate

the legitimacy of the change of accessibility from roads. It refers to such parameters as surface area, parcel length and the distance between the neighbouring roads. This is possible on the basis of the analysis of changeability of the cultivation expenditure dependent on the change of the parcel shape [Janus 2011]. It proved that for every land area it is possible to determine such a distance between roads which changes the accessibility to roads from the one-sided to two sided accessibility.

Among parcels of an area of up to 2 ha, the limiting length indicates the need of transition into two-side access. The changes in the range is from 1 : 14 to 1 : 18. The distances between adequate roads to this length are from 85 to 500 m. Ignoring elements related to transportation to the parcel in the calculation process showed that the discussed length is constant and is equal to 1 : 17.

The application of the correction for the area of the village Mściwojów under discussion led to the identification of several parcels for which the way of road access has been changed from two-side to one-side access way. The result of this correction is the final proposed system of new boundaries of parcels, which is presented in Figure 4. The red color is used to show new parcel boundaries, whereas blue color denotes groups of parcels which did not participate in the optimization process. This system represents the optimum solution because of the minimization of the average distance of parcels from the settlements in the village of Mściwojów with the allowance for elimination of the cases of the increase of this distance for individual farms. This constitutes the final solution of the whole presented calculation process.

4. Conclusions

The submitted optimization process of the parcels layout in the village of Mściwojów has made it possible to propose the appropriate layout of parcels belonging to individual land farms. This has taken into account both the minimization of their average distance from the settlements in the whole village as well as the necessity of the relatively uniform distribution of advantages resulting from the new parcel layout for individual land owners. The proposed transportation system has taken advantage of the existing system which has been corrected and improved according to the information obtained from the contractors of the cultivation-consolidation operations in the area of the village of Mściwojów.

The applied calculation procedures which used methods of linear programming along with the corrections from the initial optimum solution turned out to be effective. Only, in the case of one land farm, a slight increase of the average distance of its parcels from the settlement has been observed. It has been possible, however, to reduce the average distance from farm settlements to its parcels of about 50% (from 966 to 506 meters) in the sample village, by a similar scale of reduction of the parcel number which decreased from 3.4 to 1.8. The last correction of small parcels allowed for an effective reduction of a group of parcels of an excessive length by changing their shape along with the introduction of one-side connection with the neighboring road of rural transportation.

It should be noted that the achieved results are notably dependent on the accepted assumptions related to the development of the village model, as well as the formulated optimization conditions in the process. A dissimilar solutions could be obtained in the case of the application of an optimization model which would consider a simulation of requests submitted by the participants of the consolidation process. Also the same might occur if we use the separation of grounds with the assumption of their equipoise in relation to their value and not the area. Regardless of the conditions, for the village area, in each of these cases a relatively large number of options of the layout of parcels (of the average value of the parcels), the distance from farm settlements close to the proposed one can be suggested. The reason for this is a relatively big uncertainty of the optimum solution in the areas of concentrated building development (in a point wise or linear way). It is a phenomenon which favorably affects the possibility of the application of procedures. This optimizes the system of ground cultivation-consolidation operations because it allows for considerable flexibility of the parcel layout modification. These depend on local conditions as well as further changes in the submitted requests. These are without a significant increase of the average distance of the separated cultivation fields from the farm settlements.

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