Survey Review

ISSN: 0039-6265 (Print) 1752-2706 (Online) Journal homepage: http://www.tandfonline.com/loi/ysre20

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**To cite this article:** Zlatica Muchová (2017): Assessment of land ownership fragmentation by multiple criteria, Survey Review, DOI: 10.1080/00396265.2017.1415663

**To link to this article:** https://doi.org/10.1080/00396265.2017.1415663

Published online: 20 Dec 2017.

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# Assessment of land ownership fragmentation by multiple criteria

**Zlatica Muchová** *

In this contribution, a simple way of assessing land ownership fragmentation by evaluating land consolidation projects on the basis of multiple criteria is proposed. Obviously, for the criteria that describe fragmentation directly (number of plots, co-owners per plot and plots per owner), minimum values are regarded as favourable. Average size of the plot in a low-fragmentation situation is, of course, higher and is an expected benefit. Distances in spider/radar plots (star coordinates) or the Euclidean distance from an 'ideal point' are used as well to measure the (de)fragmentation. Post- and pre-consolidation ratios reflect the changes. Rankings based on the calculated values help to identify problematic cases. Thus proposed system takes into account not only the ownership fragmentation, number and size of plots, but also the co-ownership shares. Its application is demonstrated using the data on 50 finished projects of land consolidation in Slovakia.

**Keywords:** Land fragmentation, Land ownership, Land consolidation, Evaluation of projects, Multi-criteria methods, Exclusive ownership, Ownership in shares, Plot scattering

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## Introduction

Bentley (1987) defines land fragmentation (scattering, parcelling) as a situation where a single owner owns several discontiguous parcels, often scattered over the entire cadastral area. Several experts (King and Burton 1982, van Dijk 2003) regard excessive land fragmentation as a serious obstacle to agricultural development since it results in a reduction of net income from agriculture, prevents efficient mechanisation and leads to non-efficient production with the need of high costs to mitigate these effects. Fragmentation impacts land use in several ways. According to Kadigi *et al*. (2017), plot scattering increases transportation costs, and results in difficulties for producers of certain agricultural crops, thus preventing farmers from increasing their yields. According to King and Burton (1982), the land fragmentation is closely connected to six basic factors: size of land holding, number of plots in a farm, size of plots; shape of plots, spatial arrangement of plots and distribution of plot sizes. E.g. van Dijk (2003) distinguishes between four types of land fragmentation: fragmentation of plots, fragmentation of ownership (related to the number of owners), fragmentation of land use (related to the number of land tenants) and separation of ownership and use. The works of Hartvigsen (2016) contain overviews of 25 Central and Eastern European countries that point to the current level of ownership and land-use fragmentation. Slovakia, together with the Czech Republic, Hungary and former eastern Germany belongs to the category with high level of ownership fragmentation but low level of land-use fragmentation. High levels of both types of fragmentation are mentioned for Poland, Albania, Romania, Bulgaria, Slovenia, Croatia, Serbia, Bosnia and Herzegovina, Montenegro and Moldavia.

There are several possibilities to characterise/describe the degree of land fragmentation resulting in a number of fragmentation indices. The first category of indices is based on the principle of calculation of the relation of the plot area to the plot perimeter, the so-called shape metrics indices. Shape and edge length of a parcel are among significant criteria in utilising agricultural land effectiveness, e.g. shape index of McGarigal and Marks (1994). Shape indices are also formulated by Rutledge (2003). Krummel *et al*. (1987), O'Neill *et al*. (1988), Janus *et al*. (2016) and Milne (1991) describe the use of fractal dimension as a degree of shape complexity. The fragmentation index defined as the percentage of land owned by the owner within a single cadastral area was mentioned by Edwards (1961). The fragmentation index according to Simmons (1964), takes into account the number of plots in relation to the relative size of each plot. The degree of fragmentation increasing proportionally with the number of plots and the share of small parcels was defined by Januszewski (1968). Theoretically, the maximum consolidation is achieved when each owner will have just one plot calculated as the number of plots per owner. Reduction index or land consolidation (LC) coefficient according to Crecente *et al*. (2002) is calculated as the ratio of number of parcels before and after the consolidation project with relation to the number of LC owners. The same reduction index, the so-called consolidation coefficient, is also used in Slovakia in order to evaluate the proportion of original and new parcels. It is

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© 2017 Survey Review Ltd
Received 14 June 2017; accepted 6 December 2017
DOI 10.1080/00396265.2017.1415663

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accompanied by the determination of the consolidation coefficient of ownership calculated as the ratio of original and new ownership relationships. Indices that take into account certain relations (e.g. dispersion of productivity, cultivation benefit, planning costs, etc.) have been described by Schmook (1976), Gonzalez *et al.* (2004), Igbozurike (1974), Boyce and Clark (1964).

Another category consists of procedures based on the distribution/dispersion of plots in space and is associated with the assessment of the consolidation typical for farms or farm households. Spatial dispersion of land is closely related to accessibility of individual plots. Dispersion means the distance of individual plots from the centre of the municipality, i.e. the distance that the owner has to cross from there to the nearest point on the plot border and back using the available road network. In the Slovak Republic, the distribution of plots is based on project blocks that are described by soil quality, average distance from municipality and price. Project blocks are defined within an LC project and are agreed in advance by the owners that accept the distribution of the plots within a project block provided that these new plots are equivalent in quality and value to their original ones.

However, the above-mentioned coefficients for determination of the level of fragmentation are focused on measuring the so-called outer fragmentation. The problem is that they do not consider the so-called inner fragmentation, i.e. the shared ownership of a single plot, which is typical in Slovakia (Muchová and Jusková 2017). It can be clearly stated that the internal fragmentation is a wide-spread problem (Munton 2009). Differences between countries are manifested mainly in the numbers of ownership relations per one owner. Glowacka *et al.* (2016) describe the fragmentation in Poland. They state that in their model territories up to 86.59% of the parcels are in majority ownership, 7.53% are owned by 2, 3.96% by 2–5, 1.55% by 5–10 owners and only 0.38% are in co-ownership of 10 or more people. Vranken *et al.* (2004) report that 50% of land in Bulgaria is co-owned, with one-fifth of the parcels being owned by two households, another 14% having three co-owners, and around 16% of the parcels are owned by at least four co-owners. They also mention that the descriptive statistics show that the land fragmentation is quite strong. Households own on average 5.6 plots, while the average plot size is about 7000 $m^2$. The average number of plots per owner in Slovakia is 11.11, with the average area of 5600 $m^2$. Average parcel size in the Czech Republic is 3400 $m^2$ (1.59 plots per owner). This means (see, e.g. Muchová and Jusková 2017) that larger (by 65%) plots in Slovakia have seven times as many co-owners as the Czech ones.

Shared ownership means the ownership relationship of several persons (at least two) to the same item. Its basic notional feature is the share which expresses the degree to which the co-owners enjoy the rights and share obligations resulting from the co-ownership of their jointly owned item. The basis of shared ownership is the fact that each co-owner shares the rights and obligations resulting from the shared ownership to the extent that corresponds with the size of her/his share. The shared ownership is merely registered without being recorded in spatially explicit terms (Fig. 1). Co-owners often do not know the exact location of their share on a parcel. A specific case is the matrimonial property. Married couple counts as one owner (single ownership relation). This co-ownership cannot be divided by an LC project. The so-called unknown owners also make the situation difficult. These are the owners of approximately 5500 $km^2$ of land in the Slovak Republic. Their existence is due to imperfections in the cadastral records. Changes of ownership and inheritance procedures were not registered with the cadastre, in particular in the 1950s. Moreover, the land registers only contained name and surname and no other identification data. The result is that nowadays many people have no idea that they, in fact, own a piece of land or forest. Towards the end of the 1990s, the state started settling the land ownership relations and implemented a Registry of Renewed Land Inventory. Its purpose is to determine all land owners, but due to missing data, in many cases their determination is impossible.

LC project designers seek information on parcels that are registered for unknown owners. If this effort fails, the Slovak Land Fund becomes the administrator of the plots. This institution decides on these parcels (strictly in favour of an unknown owner) until the person can be identified. Those decisions are binding for the owner. The Fund may not sell the plots of unknown owners, but it is authorised to rent them (for their maintenance). No other management is allowed. Plots of unknown owners have no impact on the duration or quality of an LC project.

The purpose of this contribution is to present a simple system for evaluation of outer and inner (with focus on co-ownership shares) ownership fragmentation by multiple criteria. The result consists of a set of attributes and measures for unbiased comparison of ownership fragmentation and subsequent evaluation of the real situation, proposals or finished LC projects.

## Material and methods

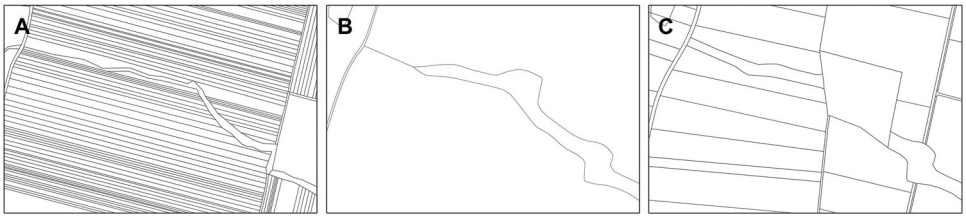
The evaluation in the proposed system for determination of the level of ownership and land fragmentation using multiple criteria is (also) based on the distance (in spider/radar plot, star coordinates or Euclidean distance) from the defined optimal point. Exact formulas, calculations, visualisation and interpretation, are given in the Results and discussion.

The following attributes have been selected for evaluation of ownership consolidation:

- A number of (land) owners (*noo*), defined as the sum of all types of owners, i.e. known and unknown.
- A number of plots (*nop*), which determines the number of parcels, i.e. the assets with registered owner or a group of several owners.
- Average number of co-owners per plot ($cpp = nor/nop$), defined as the ratio of the number of co-ownership relations (*nor*) and the number of parcels (*nop*).
- Average number of plots per owner ($ppo = nop/noo$) defined as the ratio of the number of plots (*nop*) and the number of landowners (*noo*).
- Average plot size ($aps = size/nop$) defined as the ratio of area (*size*) and number of plots (*nop*)

Expectations associated with optimum fragmentation/defragmentation of land ownership can be expressed as follows:

- Each owner has just one plot in exclusive/sole ownership ($ppo = 1$, $cpp = 1$).
- Average value of parcel area is as large as possible ($aps_{after} > aps_{before}$, $aps_{after} = \max = size/noo$).




**1 Fragmentation of ownership before LC; plots are mostly co-owned (*a*), of land use; unaffected by LC (*b*), of ownership after LC; plots are mostly in exclusive ownership (*c*)**

The total area of a zone before and after LC must always be the same. If for some reason, in exceptional cases, the size would change during the process; all indicators have to be normalised.

The evaluation of the proposed method for assessment of land ownership fragmentation involved the use of summary data of LC projects that were finished (registered in the land registry). As of 30 June 2016, there are 384 projects registered in Slovakia. LC projects in Slovakia are carried out on the basis of Act No. 330 of 1991 and are ordered in the territory if after an initially written survey majority of owners (no response means implicit agreement) agrees to LC. Owners can also initiate LC, if they demonstrate support of their majority. The state can also launch an LC, in particular, to solve environmental problems or to address enormous fragmentation of land ownership. LC projects are fully funded by the state and the European funds. Average duration of a project is 7 years, but there are continuing activities aimed at streamlining, time and financial cuts. The whole process is based on strict consolidation rules (criteria of proportionality), and the designer is required to discuss obligatory parts of the project with each owner separately until agreement. There are 3542 cadastral areas; this means that the LC projects only cover 12% of the area of the state. Fifty randomly selected LC projects are used for presentation. Data on selected attributes have been obtained from available registration cards of individual projects, which are published mandatorily (e.g. on www.pozemkovyurad.sk).

LC project in the cadastral area of Veľké Vozokany (identified as cadastral area 1) has been selected as an example. There are 4.01 co-ownership shares per single parcel on average. Considering the average value in the Slovak Republic (11 co-owners per single parcel), this area is less complicated. Table 1 contains ownership characteristics which served as the basis for proposed criteria.

Fig. 2 shows an example of spatial fragmentation of plots before and after the LC project. Fig. 3 shows the ownership status of an owner with shares in 100 plots scattered over the entire cadastral area and in shared co-ownership before the project. After the project, the owner's shares were consolidated into three plots in exclusive ownership.

Table 2 contains data for each evaluated attribute (*nop*, *cpp*, *ppo*, *asp*) and the status before and after the LC project for 50 randomly selected cases. Percentage changes for each pair of indicators are also included.

**Table 1 Basic data on ownership before and after the LC**

| | Before LC | After LC |
|---|---|---|
| Number of ownership relations (*nor*) | 16 581.00 | 3000.00 |
| Number of owners (*noo*) | 1201.00 | 1201.00 |
| Number of parcels (*nop*) | 4140.00 | 2340.00 |
| Average plot size (*aps*) ($m^2$) | 2164.00 | 3829.00 |
| Average number of co-owners pre plot (*cpp*) | 4.01 | 1.28 |
| Average number of ownership relations per owner | 13.81 | 2.50 |
| Average number of plots per owner (*ppo*) | 3.45 | 1.95 |

## Results and discussion

The evaluation of projects by multiple criteria (Hušek and Maňas 1989, Pitel 1990, Konc 2012) classifies them based on 'quality' (the situation that differs least from the ideal, target or in any suitable way defined status that is of interest is considered the best). It allows for exclusion of subjective opinion in the decision-making process, except, of course, for basic definitions where the subjective nature cannot be entirely excluded but may be reduced (by requirements of the method). A more sophisticated approach (especially with a large number of attributes or a finer granularity of the description of the situation) based on the 'ideal state' is possible using goal programming (Jones and Tamiz 2010) or other optimisation methods (Pitel 1990).

Area 11 (see also Table 3) represents maximum recorded defragmentation (*nop*, *cpp*, *ppo* decreased significantly) with the expected benefit of increased size of plots (*aps*). It also has the lowest overall level of fragmentation after the LC in the data set used. In a case of a comparative study, it would be an example of a successful project.

Area 21 (see also Table 3) is an example of a situation which might escape attention without the use of coefficients and factors presented below. Although the attributes *nop*, *cpp* and *ppo* decreased and *aps* increased, the overall level of fragmentation dropped minimally (fourth lowest reduction) and remained high even after the LC (12th highest). Area 34 (see also Table 3) could be overlooked as well. The overall level of fragmentation after the LC is low but the reduction vs. previous state is also low.

Areas 45 and 46 (see also Table 3) are cases of high (to very high) fragmentation even after the LC and contain adverse/unexpected changes of attributes. An increase in *nop*, *ppo* and reduction of *aps* was observed in area 45 and a significant increase of *cpp* in area 46. Such changes should be subject of increased interest when assessing LC projects, and it is likely that they should not/did not have to occur at all. It may be that they were not spotted when inspecting the materials (maps).

For simple evaluation of land ownership fragmentation, the authors propose to combine attributes co-owners per plot (*cpp*) and plots per owner (*ppo*), which already

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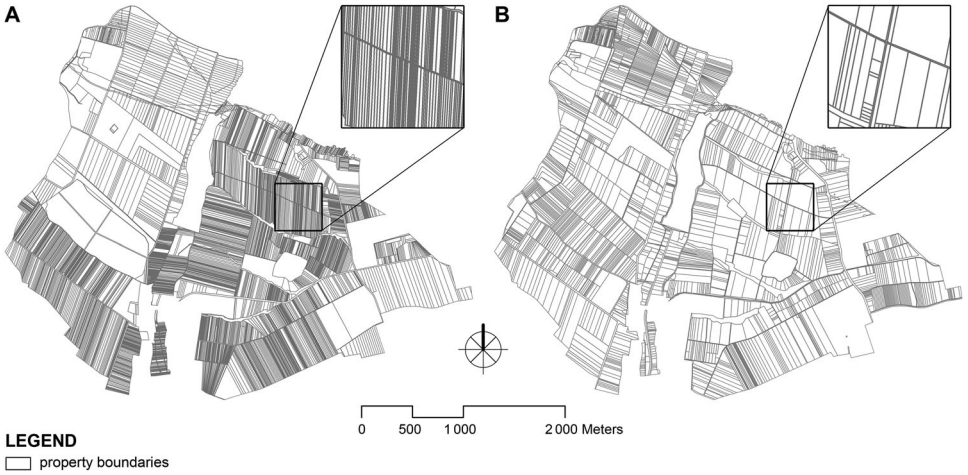



**2 Land fragmentation: before LC project (*a*), after LC project (*b*)**

include the number of plots (*nop*), number of owners (*noo*) and number of ownership relations (*nor*) into new indicators.

Radar plot fragmentation coefficient (*rpfc*) is the Manhattan distance from the ideal status of complete defragmentation:

$$rpfc = abs\left(\frac{cpp - cpp_{\text{optimal}}}{cpp_{\text{optimal}}}\right) + abs\left(\frac{ppo - ppo_{\text{optimal}}}{ppo_{\text{optimal}}}\right) \quad (1)$$

where $rpfc \geq 0$ and in our case $cpp_{\text{optimal}} = 1$ ($cpp \geq 1$ should apply), $ppo_{\text{optimal}} = 1$. Distance from optimum (*dfo*) is the Euclidean distance from the ideal condition of complete defragmentation:

$$dfo = \sqrt{\left(\frac{cpp - cpp_{\text{optimal}}}{cpp_{\text{optimal}}}\right)^2 + \left(\frac{ppo - ppo_{\text{optimal}}}{ppo_{\text{optimal}}}\right)^2} \quad (2)$$

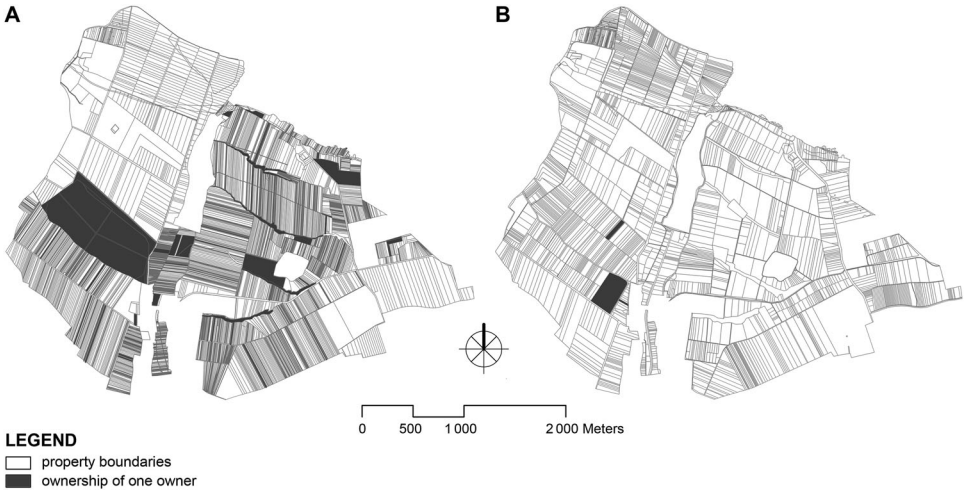
where $dfo \geq 0$, and in our case $cpp_{\text{optimal}} = 1$ ($cpp \geq 1$) should apply, $ppo_{\text{optimal}} = 1$.

Factors of variables show fragmentation change when moving from the condition b(before) to a(after), where a *variable* may be (*rpfc*, *dfo*, *aps*, *nop*, *cpp*, *ppo*):

$$variablef = \frac{variable_a}{variable_b} \quad (3)$$

where $variablef \geq 0$, $variable_b > 0$, $variable_a \geq 0$.

The radar plot fragmentation factor (*rpff*) or the distance from optimum (*dfof*) is the main (primary) measure of change in the condition, and its minimisation is expected. The average plot size factor (*apsf*) is a supplementary (primary) measure of change in fragmentation when moving from the condition *b* to *a*, and its maximisation is expected. However, it may also decrease, e.g. when the co-ownership in forest and pasture communities is cancelled (i.e. 2/3 majority of owners decides in the course of the project that they do not wish to continue to operate in a common property, which automatically leads to division). In case of other (secondary) factors, a decrease is expected (*nopf*, *cppf*, *ppof* < *1*) under normal circumstances. A change in other direction might indicate non-standard conditions or an error in records or project processing.




**3 Land ownership fragmentation of one owner: before the LC project, usually in co-ownership shares (*a*), exclusive ownership after the LC project (*b*)**

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**Table 2 Data describing fragmentation of 50 project areas, before and after the consolidation**

| # | $nop_{before}$ | $nop_{after}$ | $nop_{change}$ (%) | $cpp_{before}$ | $cpp_{after}$ | $cpp_{change}$ (%) | $ppo_{before}$ | $ppo_{after}$ | $ppo_{change}$ (%) | $aps_{before}$ | $aps_{after}$ | $aps_{change}$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4140 | 2340 | −43.48 | 4.01 | 1.28 | −68.08 | 3.45 | 1.95 | −43.48 | 2164 | 3829 | 76.94 |
| 2 | 364 | 401 | 10.16 | 11.64 | 6.93 | −40.46 | 0.77 | 0.87 | 12.99 | 14038 | 12743 | −9.22 |
| 3 | 683 | 697 | 2.05 | 13.33 | 3.93 | −70.52 | 0.85 | 1.01 | 18.82 | 6633 | 6499 | −2.02 |
| 4 | 4216 | 2374 | −43.69 | 4.07 | 1.37 | −66.34 | 1.56 | 1.40 | −10.26 | 2778 | 4933 | 77.57 |
| 5 | 733 | 877 | 19.65 | 11.12 | 1.34 | −87.95 | 1.47 | 1.75 | 19.05 | 4243 | 3546 | −16.43 |
| 6 | 2420 | 1775 | −26.65 | 3.44 | 1.15 | −66.57 | 1.58 | 1.58 | 0.00 | 3438 | 4687 | 36.33 |
| 7 | 1395 | 1153 | −17.35 | 3.12 | 1.38 | −55.77 | 1.49 | 1.26 | −15.44 | 3355 | 4059 | 20.98 |
| 8 | 2194 | 2237 | 1.96 | 3.91 | 1.10 | −71.87 | 0.89 | 1.53 | 71.91 | 4704 | 4613 | −1.93 |
| 9 | 547 | 830 | 51.74 | 7.93 | 1.12 | −85.88 | 1.38 | 2.06 | 49.28 | 6124 | 4036 | −34.10 |
| 10 | 2005 | 1049 | −47.68 | 3.86 | 1.12 | −70.98 | 2.28 | 1.58 | −30.70 | 2733 | 5224 | 91.15 |
| **11** | 1891 | 1426 | −24.59 | 4.50 | 1.11 | −75.33 | 1.25 | 1.07 | −14.40 | 6171 | 8184 | 32.62 |
| 12 | 499 | 275 | −44.89 | 1.18 | 1.09 | −7.63 | 2.34 | 1.39 | −40.60 | 7194 | 13055 | 81.47 |
| 13 | 1629 | 681 | −58.20 | 6.21 | 1.22 | −80.35 | 3.11 | 1.39 | −55.31 | 3917 | 9369 | 139.19 |
| 14 | 1181 | 994 | −15.83 | 5.17 | 1.61 | −68.86 | 1.46 | 1.41 | −3.42 | 8171 | 9708 | 18.81 |
| 15 | 1385 | 641 | −53.72 | 5.52 | 1.79 | −67.57 | 3.12 | 1.47 | −52.88 | 1913 | 4134 | 116.10 |
| 16 | 1227 | 601 | −51.02 | 2.89 | 1.34 | −53.63 | 2.89 | 1.47 | −49.13 | 3977 | 8120 | 104.17 |
| 17 | 5259 | 1749 | −66.74 | 36.80 | 11.45 | −68.89 | 2.28 | 1.66 | −27.19 | 2466 | 7416 | 200.73 |
| 18 | 991 | 657 | −33.70 | 20.42 | 4.64 | −77.28 | 2.78 | 1.86 | −33.09 | 4178 | 6301 | 50.81 |
| 19 | 1103 | 1178 | 6.80 | 10.51 | 2.08 | −80.21 | 4.36 | 5.35 | 22.71 | 2593 | 2428 | −6.36 |
| 20 | 1377 | 1418 | 2.98 | 90.04 | 11.00 | −87.78 | 1.36 | 3.02 | 122.06 | 5178 | 5028 | −2.90 |
| **21** | 480 | 375 | −21.88 | 6.04 | 4.61 | −23.68 | 2.70 | 2.42 | −10.37 | 4000 | 5120 | 28.00 |
| 22 | 1293 | 1730 | 33.80 | 14.21 | 2.98 | −79.03 | 1.57 | 2.33 | 48.41 | 3998 | 2988 | −25.26 |
| 23 | 3417 | 3174 | −7.11 | 7.45 | 1.02 | −86.31 | 3.03 | 3.66 | 20.79 | 2499 | 2691 | 7.68 |
| 24 | 4090 | 822 | −79.90 | 3.66 | 3.58 | −2.19 | 10.65 | 2.35 | −77.93 | 1689 | 8406 | 397.69 |
| 25 | 1561 | 983 | −37.03 | 11.65 | 2.44 | −79.06 | 2.12 | 1.54 | −27.36 | 5291 | 8403 | 58.82 |
| 26 | 1465 | 877 | −40.14 | 2.78 | 1.35 | −51.44 | 2.63 | 1.57 | −40.30 | 3078 | 5143 | 67.09 |
| 27 | 1098 | 1425 | 29.78 | 11.02 | 8.29 | −24.77 | 1.04 | 1.89 | 81.73 | 8743 | 6737 | −22.94 |
| 28 | 1725 | 1426 | −17.33 | 4.58 | 2.08 | −54.59 | 1.82 | 1.50 | −17.58 | 5096 | 6164 | 20.96 |
| 29 | 3757 | 2426 | −35.43 | 4.71 | 1.24 | −73.67 | 3.75 | 2.48 | −33.87 | 4575 | 7086 | 54.89 |
| 30 | 5650 | 2369 | −58.07 | 4.94 | 1.25 | −74.70 | 4.81 | 2.03 | −57.80 | 3306 | 7885 | 138.51 |
| 31 | 5494 | 1842 | −66.47 | 3.36 | 1.47 | −56.25 | 5.20 | 2.06 | −60.38 | 4445 | 13257 | 198.25 |
| 32 | 715 | 553 | −22.66 | 4.77 | 1.29 | −72.96 | 1.49 | 1.20 | −19.46 | 4126 | 5335 | 29.30 |
| 33 | 990 | 1035 | 4.55 | 4.41 | 1.10 | −75.06 | 1.25 | 1.52 | 21.60 | 5586 | 5343 | −4.35 |
| **34** | 909 | 812 | −10.67 | 1.50 | 1.03 | −31.33 | 1.58 | 1.44 | −8.86 | 8108 | 9076 | 11.94 |
| 35 | 3116 | 1676 | −46.21 | 5.67 | 1.20 | −78.84 | 1.93 | 1.28 | −33.68 | 3270 | 6080 | 85.93 |
| 36 | 1744 | 1361 | −21.96 | 9.09 | 10.26 | 12.87 | 3.82 | 2.91 | −23.82 | 4226 | 5415 | 28.14 |
| 37 | 1273 | 1191 | −6.44 | 6.48 | 3.36 | −48.15 | 2.54 | 2.38 | −6.30 | 2600 | 2779 | 6.88 |
| 38 | 1300 | 629 | −51.62 | 2.85 | 1.16 | −59.30 | 2.55 | 1.24 | −51.37 | 5708 | 11797 | 106.67 |
| 39 | 1496 | 453 | −69.72 | 10.56 | 6.83 | −35.32 | 5.52 | 1.66 | −69.93 | 1945 | 6424 | 230.28 |
| 40 | 739 | 973 | 31.66 | 63.88 | 9.14 | −85.69 | 1.50 | 2.26 | 50.67 | 7510 | 5704 | −24.05 |
| 41 | 1480 | 788 | −46.76 | 3.20 | 2.23 | −30.31 | 2.69 | 1.52 | −43.49 | 5473 | 10279 | 87.81 |
| 42 | 1907 | 802 | −57.94 | 11.31 | 1.08 | −90.45 | 4.50 | 2.37 | −47.33 | 3644 | 8666 | 137.82 |
| 43 | 4027 | 5416 | 34.49 | 9.03 | 2.04 | −77.41 | 0.90 | 1.52 | 68.89 | 3293 | 2448 | −25.66 |
| 44 | 479 | 147 | −69.31 | 18.35 | 9.86 | −46.27 | 3.26 | 1.00 | −69.33 | 2463 | 8027 | 225.90 |

(*Continued*)

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**Table 2** Continued.

| # | $nop_{before}$ | $nop_{after}$ | $nop_{change}$ (%) | $cpp_{before}$ | $cpp_{after}$ | $cpp_{change}$ (%) | $ppo_{before}$ | $ppo_{after}$ | $ppo_{change}$ (%) | $aps_{before}$ | $aps_{after}$ | $aps_{change}$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **45** | 391 | 734 | 87.72 | 16.13 | 6.43 | −60.14 | 0.83 | 1.55 | 86.75 | 10307 | 5490 | −46.74 |
| **46** | 1206 | 453 | −62.44 | 2.89 | 10.14 | 250.87 | 7.35 | 2.7 | −63.27 | 2811 | 7483 | 166.20 |
| 47 | 1343 | 549 | −59.12 | 5.27 | 1.11 | −78.94 | 11.58 | 4.73 | −59.15 | 1914 | 4681 | 144.57 |
| 48 | 1687 | 1056 | −37.40 | 3.04 | 1.57 | −48.36 | 3.02 | 1.86 | −38.41 | 7030 | 11231 | 59.76 |
| 49 | 1306 | 800 | −38.74 | 2.76 | 1.21 | −56.16 | 1.88 | 1.17 | −37.77 | 5658 | 9238 | 63.27 |
| 50 | 1540 | 810 | −47.40 | 12.54 | 2.60 | −79.27 | 4.30 | 2.40 | −44.19 | 2396 | 4556 | 90.15 |

Note: Percentage changes for each pair of indicators are also provided. Discussed projects are highlighted. Markings and units are the same as in Table 1.

Table 3 contains values for the radar plot fragmentation coefficient after the LC (*rpfca*), rankings of areas based on it (*rpfca* #), radar plot fragmentation factor (*rpff*) as the main primary one and the rankings of areas based on it (*rpff* #), distance from optimum factor (*dfof*), average plot size factor (*apsf*) as a supplementary primary and secondary factors (*nopf*, *cppf* and *ppof*).

According to Gonzalez *et al*. (2004), the measurement of either spatial or ownership fragmentation is interesting in particular due to the study of increase or control of productivity of the LC proposals. The evaluation of a sample of 50 LC projects using primary factors (*rpff*, *apsf*) indicates that as many as 25 areas show low defragmentation or an unexpected condition, and of that 17 have unexpected/adverse change observed by some of the secondary factors (*nopf*, *cppf*, *ppof*), with each of them being detected using primary factors as well.

The proposed fragmentation evaluation procedure has identified 'suspicious' changes in the designs based on primary factors (*rpff*, *apsf*). Their manifestations may be narrowed using overall final fragmentation measured by the deviation from ideal status (*rpfca*) and secondary factors (*nopf*, *cppf*, *ppof*). Outputs can be easily visualised either by means of tables, determination of rankings (Table 3), or graphically. We can see that very close to well defragmented status are the areas 11 (best 50th defragmentation according to *rpff*, the lowest 50th final fragmentation according to *rpfca*, no unexpected changes in attributes) and 34 (although only a 10th change in fragmentation, but also a low 47th final fragmentation without unexpected changes in attributes). Areas 21 (low, only 12th change in fragmentation and high, 4th final fragmentation, although with no unexpected changes in attributes), 45 (low, only 12th change in fragmentation and high, 10th final fragmentation with unexpected increase in *nop* and *ppo*) and 46 (1st worst change, increase in fragmentation and high, 4th final fragmentation accompanied by unexpected increase in *cpp*) are more to much too distant.

With the methodological procedure presented, 'problematic' projects can be pointed out. This should be followed by an analysis of causes that have led to the status and subsequent evaluation of effectiveness of the entire LC project. In case of mistake on the part of the designer (i.e. if it was not caused by a non-standard situation in the area, as maybe in the case of #45, Table 3), such as shoddy consolidation works, there is a tool available which would clearly show in which indicator/indicators it was manifested.

The re-allotment process is an important part of the LC project, designing several (as few as possible, while keeping area, price and quality appropriate) new plots instead of a number of original plots, usually in shares.

There are approaches that address optimisation and quality of new proposals using other indices that take into account the combination of size and shape of plots and the quality of plots distribution. Latest results (Harasimowicz *et al*. 2017) on optimisation of the layout of plots according to the shape and size of parcels and transport costs formulated as a mixed integer programming problem indicate a progress towards the needs of LC.

The entire situation in the conditions of Slovakia is also complicated by a large number of very small and scattered plots over the entire cadastral area. Presented procedure for evaluation of LC success at land ownership

**Table 3. Results describing change in fragmentation in selected areas before and after an LC project using a coefficient (*rpfca*) and factors (*rpff*, *dfof*, *apsf*, *nopf*, *cppf*, *ppof*)**

| # | *rpfca* | *rpfca #* | *rpff << 1* | *rpff #* | *dfof << 1* | *apsf > 1* | *nopf < 1* | *cppf < 1* | *ppof < 1* |
|---|---|---|---|---|---|---|---|---|---|
| 11 | 0.182 | 50 | 0.048 | 50 | 0.038 | 1.326 | 0.754 | 0.247 | 0.853 |
| **21 | 5.030 | 12 | 0.747 | 4 | 0.730 | 1.280 | 0.781 | 0.763 | 0.897 |
| **34 | 0.468 | 47 | 0.430 | 10 | 0.571 | 1.119 | 0.893 | 0.684 | 0.909 |
| *45 | 5.986 | 10 | 0.391 | 12 | 0.361 | 0.533 | 1.877 | 0.399 | 1.877 |
| *46 | 10.840 | 4 | 1.315 | 1 | 1.403 | 2.662 | 0.376 | 3.511 | 0.367 |

Note: Primary factors are highlighted. Percentiles for primary factors are 70% (0.317) for *rpff* and 30% (1.107) for *apsf*, which include the 'worst' defragmentation cases. Low defragmentation cases detected using both primary and secondary factors (*nopf*, *cppf*, *ppof*) are marked with an asterisk. Two asterisks mean primary detection only.

defragmentation is more complex and more suitable than a simplified recalculation per owner.

## Conclusion

The aim was to propose a new system for evaluation of the degree of (de)fragmentation of land ownership, which would take into account not only ownership fragmentation and number and size of plots, but also co-ownership shares within a single parcel. The evaluation is based on such attributes as the number of all (land) owners (*noo*), number of plots (*nop*), average number of co-owners per plot (*cpp* = *nor*/*nop*), i.e. ratio of the number of co-ownership relations (*nor*) and number of plots (*nop*), average number of plots per owner (*ppo* = *nop*/*noo*), i.e. ratio of the number of plots (*nop*) and the number of landowners (*noo*), average plot size (*aps* = *size*/*nop*) defined as the ratio of area (*size*) and number of plots (*nop*). The optimum status of (de)fragmentation of plot ownership is defined as follows: each owner has just one plot in exclusive/sole ownership (*ppo* = 1, *cpp* = 1) and the average size of parcel area is as high as possible ($aps_{after} > aps_{before}$, $aps_{after} = \max = size/noo$). The attributes co-owners per plot (*cpp*) and plots per owner (*ppo*) are used in order to define the distance from ideal status of complete defragmentation (radar plot fragmentation coefficient, *rpfc*, or Euclidian distance from optimum, *dfo*). The evaluation framework is based on factors (ratios of attributes after and before the proposal). The primary ones are radar plot fragmentation factor (*rpff*) and the average plot size factor (*apsf*). These are supplemented with the coefficient of fragmentation *rpfc* in the design proposal and secondary factors for *nop* (*nopf*), *cpp* (*cppf*), *ppo* (*ppof*). With critical values determined strictly enough, the critical percentiles used are 70% (0.317) for *rpff* and 30% (1.107) for *apsf*, the primary factors can successfully detect low defragmentation and unexpected/adverse changes, the manifestations of which may be narrowed by the coefficient of fragmentation and secondary factors. Changes in internal fragmentation (co-ownership) have to be included in the assessment of LC projects. Even a small adverse change in external attributes might not be as important as overall reduction of ownership fragmentation.

## Funding

This work was supported by the Ministry of Education of the Slovak Republic and of Slovak Academy of Science [grants number VEGA 1/0673/2016 and KEGA 008SPU-4/2017].

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