UNCERTAINTY OF LPIS DATA OR HOW TO INTERPRET ETS RESULTS

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ABSTRACT

During the last few months there was a lot of activity focused towards assessing the quality of LPIS data. However, do we actually know which quality we are measuring? When we get good or bad results, are we aware what is the reason for those? Is it a non-accurate control layer? Or is it the interpretation? Thresholds?

We will try to analyze all steps of the LPIS data production – starting with the aerial photography acquiring, processing, digitization and field measurement. For each of these, error margin will be estimated. In that way we should be able to calculate a technical/random error margin of a specific LPIS polygon. By comparing this value to the ETS results the systematic effects should remain. These are the errors the administration can reduce by improving their processes; the technical errors are pre-defined by a selection of e.g. reference parcel or a reference layer.

With the result of this exercise we will, hopefully, be able to get a general idea about what the ETS results tell about the LPIS quality. We will also describe some ideas about improving it.

1. INTRODUCTION

In the past year the LPIS community is trying to assess the state of quality of LPIS data by performing Executable Test Suite (ETS, [3]). We believe that this is very good idea in general as it is most important to be aware of the data quality. By understanding the quality, one is able to proceed with steps to improve the system, which results not only in better quality but also improves efficiency and reduces problems.

However, in order to understand the quality of the LPIS data we have to analyze all the processes which influence it, starting with gathering the base data (aerial photography, digital elevation model…), digitization, interpretation etc. Only proper analysis of these processes will allow us to understand the theoretical limits of the data quality. Then we will be able to line up some useful decisions.

Mr. Brian Klinkenberg from the Department of Geography at the University of British Columbia states in one of his lectures: "Often little is known of the input data quality, and far too much is assumed about the output quality." We decided to try to assess the quality of input data, which should result in understanding the output quality. We focused on those parameters, which influence the accuracy of LPIS area, as the area is the basis for most of agriculture-related EU payments. The side result of this exercise is a comparison between theoretical estimates of achievable data quality and the demands from ETS testing and other legislation.

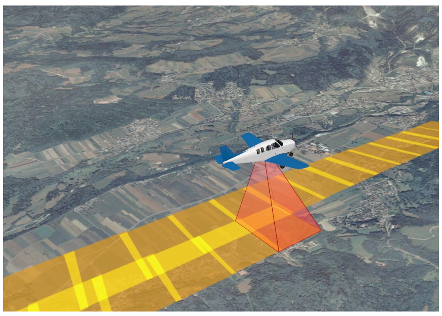
2. THEORETICAL BACKGROUND

During preparation of this article we have spent several months working on theoretical background, mostly analyzing different statistical models and preparing theoretical simulations about area uncertainty. However, we wanted to focus this article on the results of the analysis more than on the theory itself. For those who are interested in mathematical models on this topic, we have prepared quite extensive Supplementary material ([1]), which is available on Sinergise's web-site for download. The document also includes the results of our test cases, simulations and some other topics.

3. AERIAL PHOTOGRAPHY

LPIS acquisition usually begins with aerial photography (combined with digital elevation model). This is the basic dataset and there are some legislation-based rules, which should ensure proper administrative control of the gathered data. The two most important ones are: the rule from 1782/03 that the level of details should be at least 1:10.000 and the MARS Wiki advice that the dataset should not be older than 5 years. Member states usually also define the absolute position error specification - RMSE 1m. However, none of these specifications ensures the accuracy of the area. Trying to assess the current estimate of the area-related error of the ortho-photo we mostly came to an answer that "the relative position error is important for the area, not absolute and that relative position error is 0 due to correlation of data on the parcel-level". We were not really satisfied with this answer. It might be true that the relative position error is very small but it cannot be 0.

To better understand the errors of aerial photography (and satellite images) we have to understand the process of gathering the data.



The aerial imagery is usually taken by airplane flying at low altitudes, taking several images in a row. These images are later post-processed, ortho-rectified and overlaid on top of a digital elevation model of the area. The procedure is complex and even though there are several processes in place to ensure the quality of the data, it is not possible to avoid the errors completely, even those which affect the area accuracy:

- errors in digital elevation model,
- image transformation errors,
- deformation of optical lenses, and
- other human-performed errors.

It is correct that most of these errors are correlated on the small-scale but we were not able to get any exact information about this correlation. Therefore we tried to analyze the data which are collected during assessment of absolute position error. The image below shows the vectors of absolute position errors on two neighboring sheets of aerial imagery. The scale is larger than parcel-level (the nearest two measurement points were 300 m apart) but one still notices that the correlation is not that obvious.

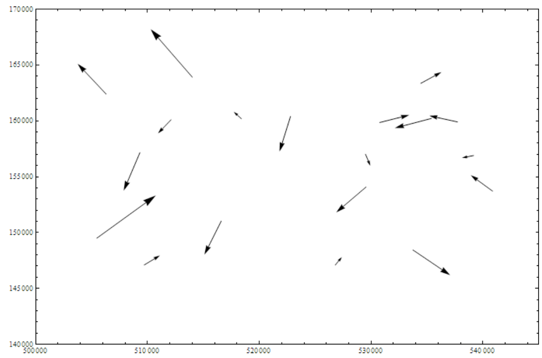


Figure 1: absolute position error vectors after orto-rectification

To analyze the correlation we charted a difference of all error vector pairs.

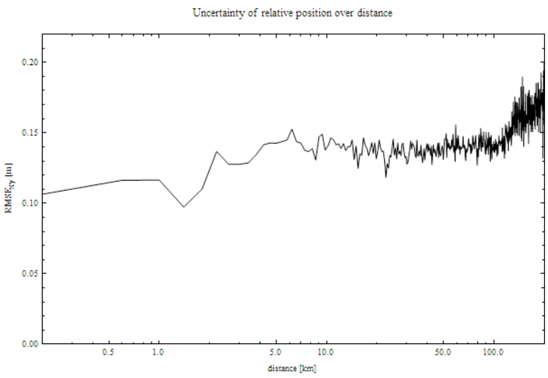


Figure 2: difference between error vector pairs in correlation with their distance

There is one thing not clear from this chart – that the correlation is strongly dependent on the distance between two error vectors. Therefore we cannot simply dismiss relative position error on the parcel-level (e.g. distance of 100 m).

As mentioned, we were not able to find any proper research about relative position error but we came with some estimation:

- the relative position error is probably in the range of one pixel size (e.g. 0.25 – 0.5 meters with recent ortho-photos),
- the error is strongly related to the terrain structure – it will be much bigger in the hilly areas, where the terrain is very dynamic, than on the flat areas,
- the error is especially significant at the borders of flat and steep areas, where the steepness of the terrain changes,
- the effect on area is highest with very long narrow parcels,
- the angle of the photography.

How does relative position error affect the polygon area? It is easiest to show this by assuming that every point (e.g. vertex) of the polygon can be shifted away by some random amount in random direction. Therefore a perfect rectangle (black) can be in reality significantly different (red, pink, blue variations):

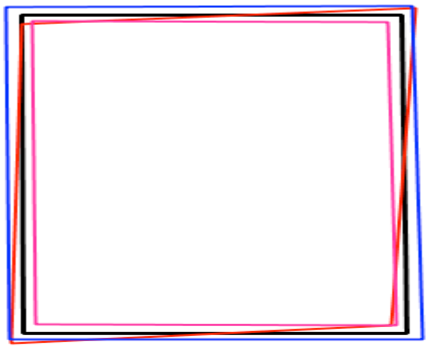


Figure 3: different representations of a black rectangle due to relative position error

To estimate the area uncertainty as a result of relative position error we have simulated thousands of possibilities of such random small movements of rectangle border points for three representative shapes – a square (the most perfect rectangle), long polygon (ratio between width and height 1:10) and very long polygon (ratio 1:30). Such long polygons are quite common in some member states such as Slovenia.

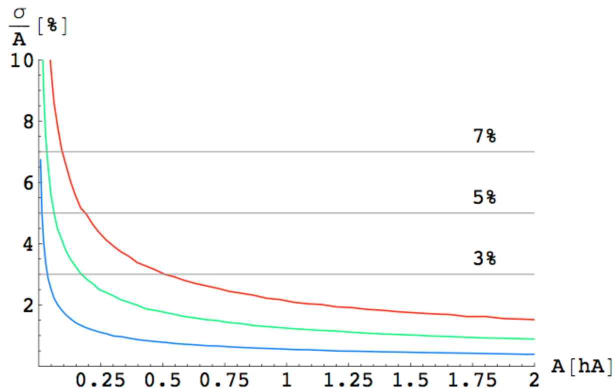


Figure 4: Relative area uncertainty due to relative position error (0.2 m) for three shapes - square (blue), long rectangle (green), very long rectangle (red)

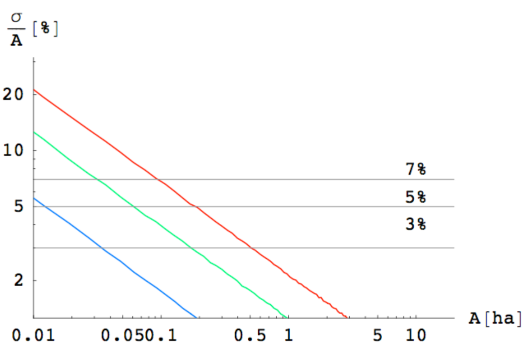


Figure 5: Relative area uncertainty due to relative position error (logarithmic scales)

We notice that the relative area uncertainty is very significant for small and long polygons.
Note that the area uncertainty will be larger when using satellite images instead of aerial photography due to their lower resolution.

4. DIGITIZATION

LPIS related procedures recommend digitization of the polygons between scales 1:1.000 and 1:2.000 (also dependent on the aerial images resolution). However, the images below show that this might not be accurate on some occasions:

Figure 6: LPIS parcel in the scale 1:1500

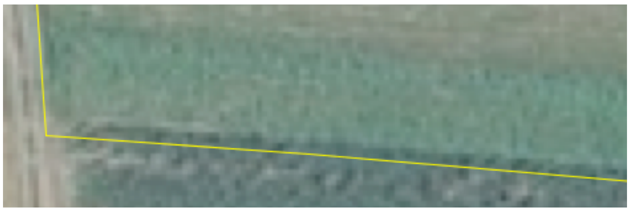


Figure 7: LPIS parcel in scale 1:350

We notice that the parcel is not digitized accurately but this is not clear when observing at the scale of 1:1.500. From this example we can assume that digitization cannot be perfect following up-to-date guidelines.
To analyze this effect we did a simple test. We generated a set of polygons and asked several users to draw their borders on two scales (1:1.000 and 1:2.000). Afterwards we have joined all results in one image:

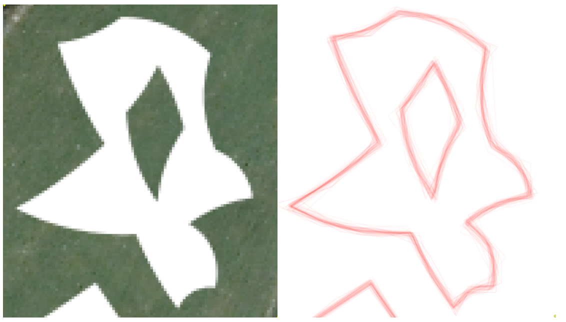


Figure 8: result of digitization of the same polygon

It is clear that the border is not exact even though the polygon is a white shape on the greenish background so the borders are as clear as possible.
What happens is that the users are not able to digitize accurately due to several reasons:

- the mouse pointer moves a bit while pushing the button,
- the screen resolution makes it difficult to exactly define even the "clear" borders (that was even more obvious when the shape was red which was perceived by some users as "radiating" and thus larger),
- people's sight is not able to see that accurately,
- some users are simply more precise than others.

From our experiment the digitized border was approximately 1 meter wide (non-accurate). In China there was a much larger experiment performed where the users were asked to digitize sharp angles [7]. Their results showed a RMSE of 1.58 pixels. Depending on the scale of digitization this can range between 0.45 (1:1.000) to 0.9 meters (1:2.000).

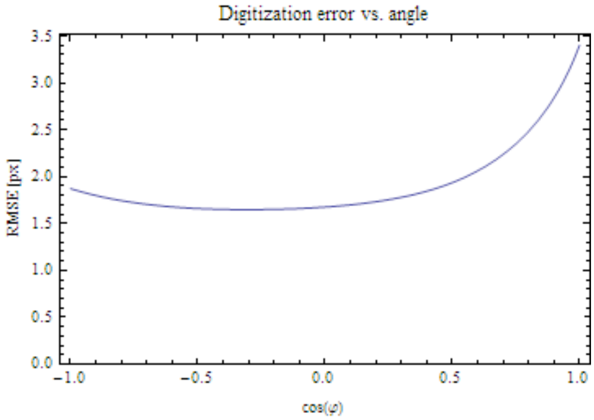


Figure 9: error in pixel positions depending of the angle which was digitized

Using the result of this exercise we have repeated simulation of the area uncertainty of different shapes and sizes of polygon. We have treated digitization error as random/non-correlated – this means that the users would in some occasions click left of the border and on other occasions right of the border. Random errors result in smaller overall error.

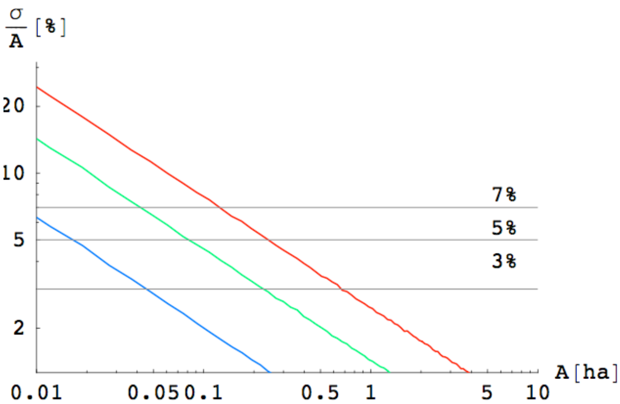


Figure 10: Relative area uncertainty based on combined error - 0.2 m for aerial imagery and 0.4 m for digitization

Comparing this chart to the previous simulation we notice that the uncertainty lines are shifting right, which means that the error is growing for all shapes of polygons.

5. INTERPRETATION

The third set of errors users are doing is due to uncertain interpretation of polygon borders. Note that there are two types of interpretation errors – wrongly understanding the rules, methodology or image and thus wrongly attributing, for example, an illegible land as legible. The other type is wrong interpretation due to unclear borders. This can happen due to non-sharp image, patch of trees on the border, steep areas, etc. We will be focusing only on the latter as it is not easy to solve it by education and training.

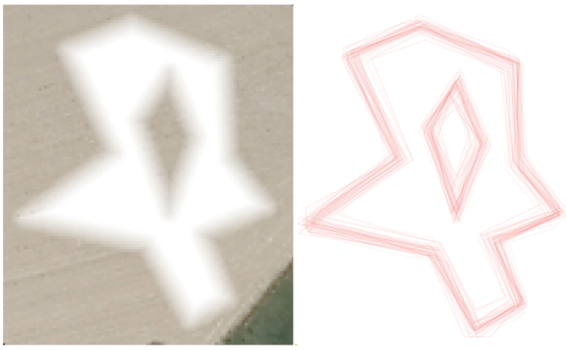


Figure 11: Result of digitization of a polygon with blurry border

We notice two things. The joined border is much wider than before (4 m). What is even more important is that the interpretation error is correlated. The users were, based on their character, digitizing only the “inner” perceived border or the “outer” one or somewhere in between. This correlated mistake significantly increases the area uncertainty.

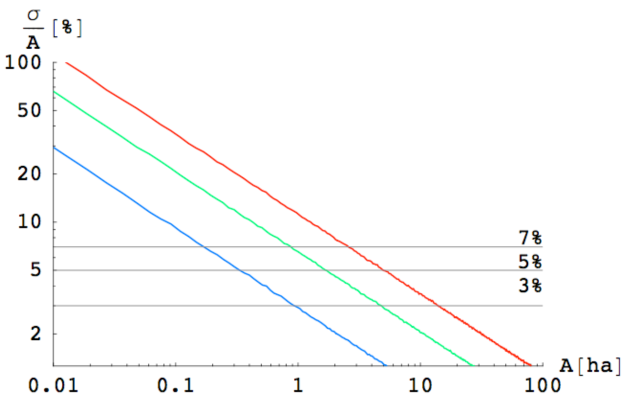


Figure 12: Area uncertainty of the combined error - random aerial imagery and digitization ones (0.2 and 0.4 m) and correlated interpretation error (1m)

We notice that the uncertainty is larger than 3% even for 1 ha large square parcels and 17 ha for very long parcels.

6. PERFORMING ETS (OR CWRS)

The ETS procedure requires blind digitization of a set of polygons and comparison of their areas to those from LPIS. The procedure is very similar to the procedures performed during Control with Remote Sensing (CwRS). However, when performing this task, the users are producing the same set of errors as described earlier. They cannot avoid them. Actually, by using the satellite imagery with lower resolution the errors are even bigger.

When they are comparing the area from initial digitization to those from ETS they are comparing two erroneous results, in worst case scenario one result is smaller than the “proper” area and the other is bigger, thus making the difference of these two measurements even more significant. We performed a simulation of such cases and derived the uncertainty of the difference of two results. We have taken into account the same parameters as before for first measurement (0.2 m for aerial, 0.4 m for digitization and 1 m RMSE for interpretation) and a “best case” for the second measurement (0.4 for imagery as we would use satellite imagery with lower resolution, 0.4 for digitization, same as before, and 0 for interpretation, as these users would be perfect interpreters).

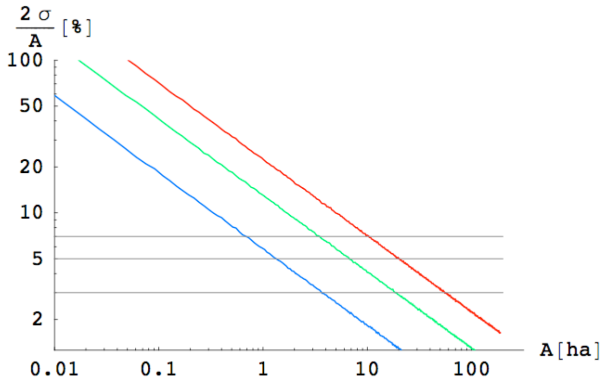


Figure 13: 95% confidence interval of uncertainty of difference of two area measurements, similar to performing ETS

Note that we have charted the “95% confidence interval” at this point, contrary to RMSE (root mean square error) in earlier charts. This is to have results comparable to those from ETS methodology where only 5% of measurements are allowed to be outside of the thresholds.

In order to have a better overview of the numbers, let us put some cases in the table (more examples are available in Supplementary material [1]).

		area uncertainty (%)			diff (%)
ha	**shape**	**DOP**	**DOP+ DIG**	**DOP+DIG +INT**	**ETS**
2	**Square**	0.4	0.9	3.9	4.0
	Middle	0.9	2.0	8.9	9.1
	Long	1.5	3.4	15	16
0.5	**Square**	0.8	1.7	8.0	8.1
	Middle	1.8	3.9	18	18
	Long	3.0	6.7	31	31

The uncertainty of measurement is pretty significant, especially compared to allowed thresholds for ETS testing (3% for parcels larger than 1 ha, 5% for those between 0.2 and 1 ha and 7% for those bellow 0.2 ha). We have to ask ourselves how relevant the overall ETS results are if the measurement itself produces much larger errors than they are allowed. Note that these uncertainties are related only to small “technical” errors and are not related to the “real” errors, such as cheating, methodological problems of LPIS maintenance process in some member states, outdated data, etc. – the errors which the ETS should really focus on.

7. POLYGON AREA UNCERTAINTY

All of the above mentioned results were calculated using simulations with large number of cases and trying to identify some specifics (using Monte-Carlo method).

However, we can calculate exact area uncertainty of any polygon (not only rectangles) using the following equations:

$$\sigma_A{}^2 = \frac{\sigma^2}{4}\sum_{i=1}^{N}(y_{i+1}-y_{i-1})^2 + (x_{i+1}-x_{i-1})^2 + 2\,\sigma^2.$$

Figure 14: Area error produced by independent point position error

$$\sigma_A = \sigma_s\sqrt{l^2 + 3\,(N_{\text{out}} - N_{\text{in}})^2\,\pi^2\,\sigma_s{}^2}$$

Figure 15: Area error produced by correlated offset from the true boundary

Using these two equations we have built a tool TopoCheck ([2]), which allowed us to compare the theoretical area uncertainty, based on the shape of the polygon and initial parameters (relative position error, etc.) with the results of ETS testing.

8. LESSONS LEARNED

a) Spatial imagery error

We are using spatial imagery (aerial and satellite) for many years already as a basis to measure the area of agriculture parcels. However, we do not have good information about the relative position error – the aspect of image data accuracy that affects area measurement. We should put more focus into analyzing the quality of these data.

b) Shape of the polygon

We are aware that small parcels (smaller than 1 ha) are problematic from the point of area uncertainty. However, we should include additional attribute of the parcel – how long they are. The calculations show that very long parcels are problematic even though they have large area.
Note that we should not focus only on rectangle-like parcels when determining their length. There are other shapes, which have a high perimeter/area ratio, mostly due to exclusions.

Figure 16: An example of a large (1 ha) parcel, which looks normal but is quite long based on perimeter area/ratio

c) Digitization guidelines

In our tests we have digitized polygons on two scales – 1:1.000 and 1:2.000 and the area accuracy has been significantly better on the scale of 1:1.000. Therefore we recommend digitizing at larger scales (1:1.000 - 1:750).
Another thing we have noticed is that the results are much better when there were a lot of points taken for a specific polygon. This might be counter-intuitive as the line looks nicer (more straight) if there are only two points taken for it. However, due to digitization errors, the area accuracy is much worse. We recommend recording a polygon point every 3-5 meters even for straight lines.
It might be useful to use image recognition tools to correct small digitization mistakes (e.g. “snapping” the line to raster imagery line).

d) Area uncertainty awareness

All the stakeholders of IACS system should be aware of the area uncertainty, which comes from small technical errors. It might be useful to use precision-based styling to represent the uncertainty of each point or line.

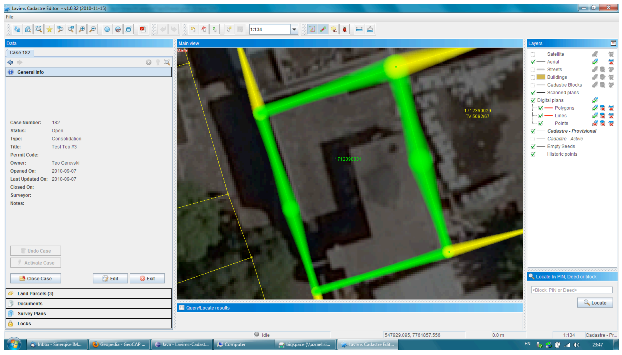


Figure 17: Precision based styling

e) Hard thresholds are problematic

IACS regulations are full of different thresholds – tolerances, penalty limits, ETS limits. Additionally, many of these eligibility tests are made on the level of individual parcel. However, we learned that the uncertainty itself could be bigger than the allowable thresholds in many cases, which causes many problems to the administration and farmers and brings additional work.
To demonstrate this problem we have calculated area uncertainty using TopoCheck ([2]) on all LPIS parcels in Slovenia. 19.7 % of all parcels had the area uncertainty larger than allowed by ETS limits (3/5/7 %, depending on the area size). This fact might look dramatic. However, when calculating the total area uncertainty of all parcels (not just mentioned 19.7%) it would affect only 0.002% of total area – a number which is not significant on IACS scale. The reason for this lies in the fact that Slovenia has a lot of small and long parcels and thus a large number of relatively significant over- and under-declared areas. But it is only significant when comparing individual parcels. When comparing the effect on the whole, the number is irrelevant.

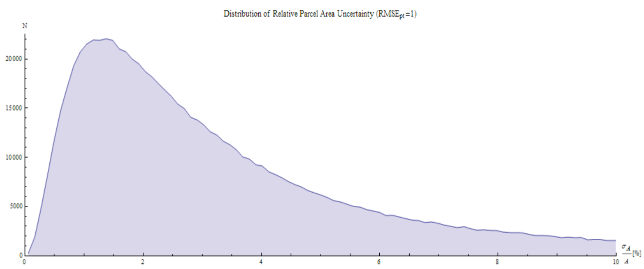


Figure 18: A number of parcels (Y axis) with specific relative area uncertainty (X axis)

9. CONCLUSIONS

All of the above written simulations and models are only theoretical models, based on assumptions which are not exact. Therefore the results should be treated with caution. However, these theoretical models show some problems, which can be observed also in practice. While performing ETS testing several member states have found lots of problematic cases, which are “faults” by ETS standards but cannot be attributed to any systematic error (e.g. old imagery, non-educated users, cheating) – they might fall in the category of technical errors which are related to what we have been researching.
Another important point we have noticed is that by performing ETS we are multiplying the initial technical error by 1.4 (or even more in the case of lower resolution imagery). It might be wise to reconsider the ETS techniques and allowed limits to compensate this error. One might also reconsider observing absolute errors instead of relative errors. At the end of the day, absolute errors can be directly compared to a value of

wrongfully distributed funds. Then we should be able to decide about the further course of actions. For example, if there are a large number of errors larger than 3% but they only account to several hundred EUR it is not practical to spend several thousand EUR to perform on-the-spot checks.

The legislation should be focused on improving the general accuracy of the system – member states should be motivated to have as detailed imagery as possible and most up-to-date data. However, at the current state of things, by being accurate, one also finds lots of small (and probably non-important) errors. This fact should not cause problems to the member states. It should not point them in the directions of using non-detailed data solely to be able to use larger tolerances and thus not find these small errors. It should do the opposite – congratulate the effort and reduce the amount of controls required.

10. REFERENCES

[1] Supplementary material, http://www.sinergise.com/en/articles/16/1/uncertainty-of-lpis-data-or-how-to-interpret-ets-results

[2] TopoCheck, spatial data validation tool, http://topocheck.com

[3] ETS Methodological Background, JRC, http://marswiki.jrc.ec.europa.eu/wikicap/index.php/ETS_Methodological_background

[4] Hejmanowska, B.: Validation of methods for measurment of land parcel ar- eas, 2005

[5] Hejmanovksa, B.: Reliability of polygon area measurments for LPIS QA, 2010

[6] Chrisman N. R. and Yandell, B. S.: Effects of point error on area calculations: A statistical model, Surveying and Mapping, 241 - 246, 1988

[7] Wu, H,, Liu Z. and Lin, L.: Positional uncertainty of manual digitization vertex based on simlulation test (Geoninformatics 2008 and Joint conference on GIS and Built Enviroment, 2008).

[8] Shi, W.: Principles od modeling uncertainties in spatial data and spatial analyses, 2010, CRC Press.