Positional Accuracy Improvement of Land Cadastre Index Maps in the Republic of Slovenia

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Key words: positional accuracy improvement, adjustment membrane model, Franciscan cadastre, index map, Slovenia

SUMMARY

Due to the increasing use of digital land cadastral data in the administration of the state, it is necessary to ensure adequate quality improvement of the land cadastral positional data. The Surveying and Mapping Authority of the Republic of Slovenia will provide positional accuracy improvement (PAI) of the land cadastral data with the project named "Positional Accuracy Improvement of Land cadastre Index Maps", managed within the Ministry of the Environment's project package "The Programme of eProstor (eSpace) Projects". The PAI of the land cadastral index map is performed by using neighbourhood adjustment – the method of membrane model based on a mechanical analogy and a mathematical derivation of Hooke's Law. PAI is based on the existing GIS cadastral layer (index map), i.e. the accurately measured coordinates of the existing and additional cadastral points. The results of the project will significantly contribute to the greater quality of cadastral geometric data, especially in the areas of lower quality of cadastral index maps. In this paper, we present the project, results, experiences and consequences for the owners.

SUMMARY (POVZETEK)

Zemljiški kataster je v Sloveniji temeljna prostorska evidenca o zemljiščih in predstavlja osnovo številnim drugim evidencam o prostoru. Obstoječi grafični podatki zemljiškega katastra ne omogočajo njihove polne in racionalne uporabe, ker jih omejuje predvsem slaba položajna natančnost in točnost, saj podatki izvirajo iz prve polovice 19 stoletja. Kvalitetnejše položajne podatke zemljiškega katastra za območje Republike Slovenije bo Geodetska uprava Republike Slovenije zagotovila s projektom »Lokacijske izboljšave zemljiško katastrskega prikaza« v okviru programa projektov eProstor. Lokacijska izboljšava podatkov zemljiško katastrskega prikaza se izvaja z membransko metodo homogenizacije, ki omogoča prenos izboljšave položajev merjenih točk, ki imajo kakovostne koordinate, na model zemljiško katastrskega prikaza v njihovi okolici na zvezen način. V tem prispevku je predstavljen projekt položajne izboljšave zemljiško katastrskega prikaza v Republiki Sloveniji, rezultati projekta, dosedanje ugotovitve in izkušnje ter vpliv rezultatov projekta na lastnike zemljišč.

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1. INTRODUCTION

The effective and easy implementation of processes in the area of spatial planning, building construction and real estate management requires modern IT solutions and high-quality spatial data. In the Republic of Slovenia, the land cadastre is the main spatial land record and forms the basis for a number of other spatial databases, consequently the quality of land cadastral data is of utmost importance. The existing cadastral geometric data do not provide for their full and rational use, as they are limited in particular by their poor positioning accuracy and unreliability. The Surveying and Mapping Authority of the Republic of Slovenia (hereinafter: the GURS) aims to improve the quality of data in real estate records in order to provide support to effective spatial and real estate management.

The highest quality positional (location) data on the land ownership boundaries are obtained by measuring the boundary stones (at boundary points) that represent land cadastral points (hereinafter: LCPs) with the prescribed accuracy in databases (e.g. in the procedures involving the services of land boundary regulation, parcel allotment, land consolidation and mass new measurements). However, the complexity of these procedures prevents the obtaining of positional data of appropriate quality for the whole territory of Slovenia, as these procedures are often associated with high costs. Accordingly, the GURS will provide higher-quality cadastral positional data for the whole country gradually over a period of three years by improving the quality of positional accuracy of land cadastre index maps (hereinafter: the ZKP), i.e. the graphical continuous data layer of parcel boundaries, in the context of eProstor projects with adjustment membrane method (eProstor, 2019). The GURS started to implement the tasks of the Positional Accuracy Improvement of Land Cadastre Index Maps project in early 2018. The Project is co-financed by the Republic of Slovenia and the European Union from the European Regional Development Fund and is implemented under the Operational Programme for the Implementation of European Cohesion Policy 2014-2020.

2. THE EXISTING STATE OF THE LAND CADASTRE IN THE REPUBLIC OF SLOVENIA

The actions taken two hundred years ago in the former Austro-Hungarian monarchy are relevant for the cadastral database of the Republic of Slovenia. At that time, expert documents for subsequent cadastral maps were produced within a very short period that continue to serve our needs to a large extent even today. Today's land cadastral data are based mainly on the Austro-Hungarian traditional Franciscan cadastre from the first half of the 19th century, covering the major part of present-day Slovenia's territory (the regions of Slovenian Carinthia, Styria and Primorska), and to the west (the right bank of the Soča river) on the French cadastre, and to the east (the Prekmurje region) on the Hungarian cadastre. The maintenance of land cadastre was carried out by drawing changes on analogue paper plans called maps. When the drawn-in changes became too dense and the content began to lack transparency, they were redrawn on new maps, i.e. the so-called map reproductions. This method of maintenance was used until the 1980s, when the reproductions on translucent foil were made for the major part of the country for the last time. In the 1990s, this was the basis for the digitalisation of the geometry of cadastral maps and the production of digital cadastral index maps and the ZKP as it is used today.

In the Republic of Slovenia, the land cadastre is the official land record where the land is geometrically presented by the concept of a "parcel", defined by the "polygon" data type, and the concept of a "parcel number" (parcel identifier), geometrically defined by a point data type, which must be located within the corresponding polygon. The basic unit for data management and storage is a cadastral municipality. The cadastral database is divided into a geometric data section and a descriptive (attributive) data section. In the geometric section of the land cadastre, two digital geometric presentations of land are managed: land cadastral index maps (ZKP) and land cadastre maps (ZKN).

Land cadastral index maps (ZKP) are lower quality geometric representations of all land boundaries in the form of parcels with parcel numbers and land under buildings located in the territory of the Republic of Slovenia. The ZKP's accuracy depends on the methods of measurement and scales of cadastral maps that were digitised between 1991 and 2003. The precision of digitised analogue maps is limited by the stage of technology available at that time and the lower-accuracy measurement methods used at the beginning of the last century, and therefore do not meet today's requirements. The positional accuracy of digitised cadastral maps is very heterogeneous and of poor quality in certain areas of Slovenia. However, the ZKP is the most detailed geometric digital representation of land distribution in the territory of the Republic of Slovenia and is a continuous layer covering the whole territory. Heterogeneous positional accuracy leads to a wide range of problems in the land administration system, such as, for example, the irregularity of the results of geo-processing operations – the geometric intersection with other spatial data content (actual use, intended use, site productivity coefficient, land rating, etc.).

The land cadastre map (ZKN) provides a higher quality geometric representation of land boundaries, as well as land under buildings, with parcels and parcel numbers, on the basis of higher quality coordinates of boundary stones (LCPs), measured by geodetic methods of prescribed higher accuracy, in the D96/TM state coordinate system (1996 geodetic datum 1996, transverse Mercator map projection). But the ZKN is not a continuous layer – does not cover the whole territory of Republic of Slovenia.
In view of the problems presented above and the duality of the representation of land geometric data in the land cadastral system, the GURS decided to perform the positional accuracy improvement of land cadastre index maps and to integrate such improved data of the ZKP into the existing higher quality ZKN subsystem, which will thus become a continuous layer covering the whole territory of the Republic of Slovenia.

3. PURPOSE AND IMPLEMENTATION OF THE PROJECT

The main objective of the project is to make the graphic data layer of the ZKN continuous when the project is completed, so that it can replace the existing ZKP in the procedures of efficient spatial management, thus providing better quality support to decisions and spatial management. The operational objective of the project is the positioning accuracy improvement of the ZKP in the territory of the entire country. The improved data on the positions of LCPs will be recorded in the cadastral database.

The positional accuracy improvement of the ZKP is managed and implemented by the GURS. At the operational level, the project is carried out by a team of experts employed with the GURS. Part of the project activities are carried out by the Geodetic Institute of Slovenia, which is responsible for the monitoring, administration and control of the project. The project also involves partner companies (hereinafter: the contractor) that provide additional data for improving the positional quality of the ZKP (coordinates of additional reference points and additional geometric constraints for maintaining relative relationships).

The implementation of the Positional Accuracy Improvement of Land Cadastre Index Map project has been in progress since February 2018 and is expected to be completed in October 2020. The project is being implemented in individual cadastral municipalities. The results of the improvement are registered on an ongoing basis in the land cadastre database and are immediately applied to other land administration procedures.

4. WORK METHOD AND EXPERT PLATFORM

The Department of Geodetic Engineering of the Faculty of Civil and Geodetic Engineering of Ljubljana researched and studied the usefulness of the adjustment membrane method for the implementation of mass positional (location) accuracy improvement of the ZKP in the Republic of Slovenia. A pilot project aimed at improving the quality of the land cadastre index map was carried out in the cadastral municipality of Črešnjice (Čeh M. et al., 2015a, 2017).

Experimenting with this method proved that is possible to improve the positional accuracy of traditional cadastral index maps of rural regions from an accuracy class of standard deviation of 2.0-5.0m to an accuracy class of standard deviation of 0.5-1.0m (Čeh M. et al., 2019). In view of the positive results of these studies, the adjustment membrane method was selected for the procedure of positional or location accuracy improvement of the ZKP in the Republic of Slovenia.

During the period of project preparation, the GURS, together with the Department of Geodetic Engineering of the Faculty of Civil and Geodetic Engineering at the University of Ljubljana, developed the work methodology and, with the generous assistance of the Faculty, found effective software for the implementation of the project (Čeh M. et al., 2015a, 2015b).

The adjustment membrane method facilitates the transfer of positional accuracy improvement of the measured LCPs (reference points) with high quality coordinates, to the ZKP model in a continuous mode. The method is based on a mechanical analogy of Hooke's Law that superimposes the ZKP geometry on the elastic membrane formed by a triangular irregular network (TIN). High quality measured LCPs represent the points on which this elastic membrane is tensioned (heterogeneous cadastral geometry is printed on it before the improvement), which is improved in the neighbourhood of tensioning points, based on the improved positions of measured LCPs and the introduction of additional geometric constraints (orthogonality and collinearity, measured distances from fieldbook data, etc.). The method provides for proximity fitting (Čeh M. et al., 2019), based on the model of mechanical membrane.

GURS obtained a licence for *Systra* software of the German company Technet GmbH from Berlin for the operational computer implementation of the positional accuracy improvement of land cadastre index maps. The *Systra* represents a powerful software tool allowing the geometric integration of geodetic observations and various data layers of geographic information systems (GIS) through the procedure of geodetic adjustment. In order to automate the process, the GURS, assisted by the domestic contractor, Geodetska družba, d. d., developed the *SysGeoProTM* software, which is an interface for the transfer and preparation of data between the land cadastre database and the *Systra* software. For the purpose of monitoring and supervising the process, the Geodetic Institute of Slovenia created the *IzbA* software, which is a system for monitoring, administration and control of all stages of mass implementation of the positional accuracy improvement of the ZKP.

5. OPERATIONAL PROCEDURE

The positional accuracy improvement of the ZKP is implemented on the basis of the existing cadastral data and additional data collected for the purpose of this project and provided by the contractor. Before the implementation of the positional accuracy improvement, appropriate conditions have to be provided. For this purpose, the GURS carried out a number of preparatory works (scanning the land cadastre archive, etc.). Among other things, the GURS carried out a thorough analysis of land cadastre records and removed many errors and irregularities that had accumulated over the many years of its maintenance.

5.1 Input data

The basis for the positional accuracy improvement of the ZKP are the data from the land cadastre (graphical and attribute data). In the process, the LCPs are analysed and divided into:

- reference (measured) points: LCPs with higher quality coordinates measured by geodetic methods and with digitized coordinates.
- subject (digitized) points: LCPs that only have digitized coordinates. Coordinates of subject points are unknowns in the adjustment calculation and their coordinates in the state coordinate system are determined by the adjustment membrane method.

In adjustment and homogenisation calculation, additional geometric constraints (observations) are also taken into account:

- rectangularity constraints on buildigs corners,

– measured distances from fieldbook data (archive)
– collinearity and
– straight line constraints for points from fieldbook data.

Figure 1: Land cadastre graphical data: – the ZKP (*SysGeoProTM*). KEY: reference (measured) points – blue, subject (digitized) points – yellow, the ZKP lines – black.

The use of an appropriate number of high quality reference points and their optimal distribution is important in order to achieve a quality adjustment and homogenisation result of the ZKP. The impact of reference points on the positional correction of subject points is decreasing with distance, therefore it is important to have evenly distributed high quality reference points throughout the entire area under consideration.

For the majority of cadastral municipalities, the condition of an even distribution of reference points cannot be satisfied by the existing measured points from the land cadastre databases. For this reason, additional data, i.e. geometric constraints (from fieldbook data), and additional measured reference points (field measurement), are used to properly densify the reference points network. These additional data for the densification of reference points network are provided by an external contractor in the form of coordinates of these additional reference points. The coordinates of these reference points in the D96/TM (E, N) state coordinate system are defined by measurements (the LCPs without coordinates from the archive), and in the event that the relevant fieldbook data are not available, they may also be defined on the basis of (photo)interpretation of IAS (analytical shading images recorded as

TIFF images with ground sample distance (GSD) 0.5 m × 0.5 m) and DOF (Digital ortophoto – aerial image with a GSD length of 0.5 m × 0.5 m).

Positional accuracy improvement of the ZKP is implemented in individual cadastral municipalities. However, buffer zones of neighbouring cadastral municipalities are also included in the improvement process in order to properly improve positional accuracy of the boundary points at the border of the cadastral municipalities.

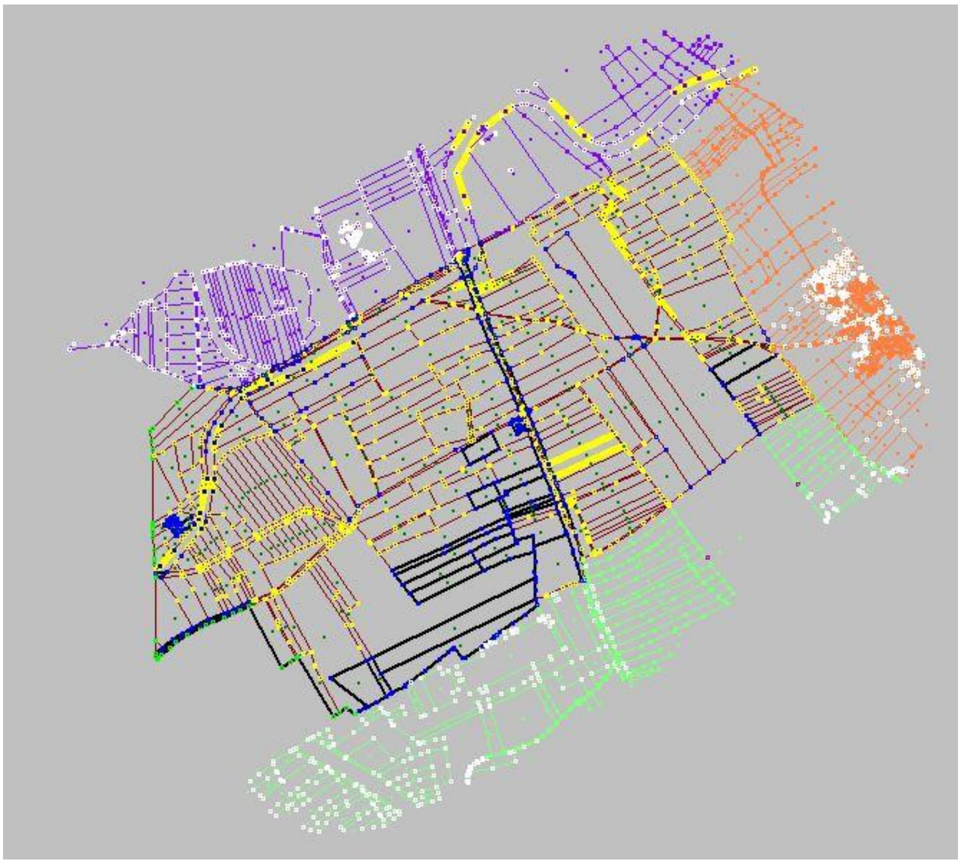

Figure 2: Project from the *SysGeoProTM* — preparation of input data before import into the *Systra* software package. An example of a cadastral municipality undergoing the process of positional accuracy improvement (presented in red), together with the buffer zones of the neighbouring cadastral municipalities included in the process (presented in purple, orange and green).

5.2 Calculation

The adjustment calculation started in *Systra* software with the setup of observation weights. The *SysGeoProTM* software prepares the input data by importing the data separately for each individual cadastral municipality into the *Systra* software in its own system, and the reference points in different groups. By doing so, different input standard deviations can be attributed to the datas pertaining to different systems and groups in *Systra*.

Reference points are held fixed in the processing operation, they are not adjusted and do not change their position after adjustment calculation. The input standard deviation for these points (σ_P) is set at 0.00 m. Additional reference points are not held fixed. Input standard deviation for the coordinates of these points depends on their determination method (Table 1).

Table 1: Input standard deviation (σP) in determining the position of additional reference points.

Method of determining additional reference points	σ_P
Determination of boundaries via DOF (photo)interpretation	1.00 m
Determination of boundaries via IAS interpretation	1.00 m
Field measurements of the boundaries	0.04 m

The input standard deviation for digitized coordinates or the input standard deviation for the land cadastral index map is determined on the basis of the calculated average of the displacement vector between the digitized coordinates (GE, GN) and the measured coordinates of reference points (E, N), and the determined minimum values, according to the type of maintenance of the ZKP (for coordinate maintenance mode = 0.50m and for non-coordinate maintenance mode = 3.00 m). If the value of the calculated average vector equals or exceeds the above-mentioned minimum values, the calculated value is taken into account in the improvement.

The calculation using the adjustment membrane method in *Systr*a is performed in several steps:

1. **adjustment calculation step: calculation of approximate values**
   In Step 1, approximate values for the coordinates that serve as default values for the next step of adjustment calculation with the conjugate gradient are determined for the unknowns, i.e. the coordinates and transformation parameters for the local systems. In the process of approximate value calculation, the automatic elimination of the most gross errors in observations is carried out (Baarda's data snooping).
2. **adjustment calculation step: indirect adjustment and analysis**
   In this step, observations are examined and the gross errors in observations are addressed. The output coordinates are calculated using indirect adjustment method by the Cholesky algorithm. In this phase, errors in observations are detected using a statistical analysis (the calculation of normalized residual-NV, which is the relationship between the correction in observation and the standard deviation of the correction in observation).
3. **adjustment calculation step: homogenisation**
   A successful analysis and the elimination of gross errors in observations are followed by proximity fitting with Hooke's membrane model. Here, the positional neighbourhood of points is taken into consideration. Also, the indirect adjustment already carried out in Step 2 is repeated. Digitized coordinates are adjusted, taking into consideration the input additional geometric constraints. Instead of observations of coordinates, differences in the coordinates of the triangle sides of the triangle network, which is set up between the LCPs in this step, are imported as observations.

After the indirect adjustment (after Step 2 of the calculation), particular attention is paid to data or result analysis. On the basis of calculated normalized residual, all observations for which the calculated normalized residual are higher than the threshold value of the normalized residual are examined, as these observations have a high potential for gross errors. The threshold value of the normalized residual is determined on the basis of experience and is set at 3.3.

If a gross error is found in the input data contained in the land cadastre database, this finding shall be reported to the Surveying and Mapping Office for rectification and elimination. The calculated normalized residual larger than the threshold normal residual are largely due to the poor or incorrect graphical incorporation of measurement data into the continuous data layer of the ZKP. If it is established in the procedure that the digitized coordinates (GE, GN) of reference points are grossly erroneous, their impact on the improvement of the neighbourhood points is excluded in the process. With the increasing distance from the reference points, the corrections of digitized coordinates of subject points are decreasing (the impact of reference points decreases with distance).

6. RESULTS

After adjustment calculations the results are analysed. The numeric results of the analyses after adjustment are in *Systra* output files presented in terms of error ellipses, graphical accuracy and reliability indicators. Results data are compared with those of initial state of the graphics to visually check the changes in position and the geometry of resulting data. The results are also topologically tested.

The results of the analyses mentioned above, made on already implemented cadastral municipalities, confirm that a positional accuracy improvement of the ZKP is achieved. The best way to confirm the accuracy of the result is to check it by means of accurate field survey of identical points. A comparison between measured coordinates and homogenised coordinates would confirm the realibility of obtain results. Such checking was carried out in cadastral municipality Črešnjice on the basis of 623 control points. The standard deviation of the ZKP before positional accuracy improvement was 2.39 m and after positional accuracy improvement 0.78m (Čeh M. et al., 2019).

The result of the project will be the improved positional accuracy of the ZKP for the whole territory of Slovenia. This will provide us with an integrated, continuous and topologically correct data layer of the land cadastre geometry, in which all boundary points of polygons representing the boundaries of parcels and land under buildings will have coordinates determined in the D96/TM state coordinate system (Figure 3 and 4). In the current land cadastre information system, the ZKP will remain unchanged and the existing ZKN will be supplemented (integrated) with the data from the improved (in terms of positional accuracy) ZKP, and will thus become a continuous geometric data layer. Due to the continuous and improved positional accuracy, the ZKN data layer has replaced/will replace the existing continuous graphical data layer of the ZKP in serving the needs of users.

Figure 3: The result of the improved positional accuracy of the ZKP (*SysGeoProTM).* KEY: reference points – blue, digitized points – yellow, ZKP lines before improvement – intermittent white, ZKP lines after improvement – black.

Figure 4: The ZKN after the implemented positional accuracy improvement and ZKP integration, as seen in the public viewer PREG.KEY: The ZKN obtained by measurements – red, the ZKP after positional accuracy improvement – blue.

7. DISCUSSION

7.1 Findings and experience gained

According to the findings to date, the result of the positional accuracy improvement of the ZKP depends primarily on:

- the appropriate number of reference points and their optimal distribution,
- the quality of the existing reference points (exclusion of lower quality sources);
- input standard deviation for the ZKP,
- adequately recorded status in the ZKP, and
- methods of land cadastral data maintenance.

The best results of the positional accuracy improvement of the ZKP are demonstrated in the field of construction land (in urban land use areas), where there is a higher density of reference points. Inferior results are obtained in forested areas, where there is only a small number of poorly distributed reference points.

The project will by all means lead to higher quality land cadastre data in Slovenia. Many errors will be eliminated, as this is the condition for the start of the improvement process and also the condition for the successful implementation of the positional accuracy improvement of the ZKP. Mathematical statistical analyses, facilitated by the method used, provide an effective tool for detecting gross errors in observations in the land cadastre database. These errors are then addressed in cooperation with the surveying and mapping offices.

A large part of the process of positional accuracy improvement of the ZKP is fully automated, facilitating rapid work and focusing on substantial issues rather than on simply carrying out the process.

The results demonstrate that by applying the adjustment and homogenisation method of the ZKP, a significant positional accuracy improvement in the graphical representation of parcels is achieved: in particular, the systematic positional displacements of the ZKP are efficiently eliminated, while consistently applying the principles of geodetic discipline (coordinate geometry methods, topology, adjustment, etc.).

In the future, the reconstruction of relative geometry high quality data from fildbook data of cadastral procedures, measured in local systems could also be included in the process. Although such data are being used in this phase of work, they are limited merely to those data that are located in areas without a sufficient number of reference points or with an inappropriate distribution of reference points from the land cadastre database, and that, in the event of gross errors in the ZKP, are located in smaller areas. These studies contain large amounts of high quality data that may be used in the future.

7.2 Applicability, impact and consequences

The process of positional accuracy improvement of the ZKP should not be equated with the administrative procedures of regulating or changing parcels' boundaries. The positional accuracy improvement cannot eliminate the inconsistencies between the recorded status of land boundaries in the land cadastre (parcels) and the actual distribution of parcels and the position of their boundaries in land space. Such inconsistencies can only be resolved by a new setting-up of the land cadastre, cadastral rearrangements (regulation of boundaries, adjustment of boundaries, land allotment and land consolidation) or judicial proceedings.

The results of the project do not affect property and real rights. Furthermore, the official data on the surface area of parcels are not altered either. However, with the positional accuracy improvement of the ZKP, and in consequence with the cross-section of the improved parcel geometry in the ZKN, the data on the type and percentage of the actual use of a parcel, the value of the land rating points, the value of the property and the calculation of cadastral income per parcel may be modified. The reason for this is the use of a method for determining the percentages of land surface areas, deriving from the "geometric cross-sections" of the land cadastre data (formerly the ZKP, now the incorporated ZKN) via other data layers.

As a new graphical continuous layer of the ZKN for the whole country is being created through the positional accuracy improvement of the ZKP, this will also affect other users and their implementation of land administration tasks such as the production of municipal spatial planning plans, the regulation of conditions for protected farms, the granting of agricultural subsidies, the calculation of forest road fees, the implementation of new spatial planning and building legislation, the regulation of rights to social transfers and the formulation of tax policies.

8. CONCLUSION

According to the results of the work carried out so far within the project, improving the homogeneity and the positional accuracy of the ZKP using the adjustment membrane method has proven to be an effective approach. In which we improve positional accuracy of the ZKP with data that we already have in our land cadastre database.

The implementation of the positional accuracy improvement of the ZKP project is being implemented in accordance with the set time schedule. By February 2020, this project will be completed in approximately 1,800 of the 2,698 cadastral municipalities in the territory of the Republic of Slovenia, accounting for approx. 67 % of all cadastral municipalities.

At the GURS, the procedure of the positional accuracy improvement of the ZKP is considered to be a process rather than a one-time effort. By obtaining additional data from the maintenance procedures applied to land cadastre graphical data or additional data that would be collected with the intention to serve in the positional accuracy improvement process in the future, the number of reference points and geometric constraints is increasing continuously. This in turn increases the possibilities of obtaining even better results by means of further improvement. Today, the experience gained in our work so far also ensures that with a set of new high quality measurements obtained by the adjustment method, the impact of these measurements is effectively transferred to the neighbourhood of the land under consideration.

We are of course aware that the procedure of new measurements cannot be replaced by the process of positional accuracy improvement of the ZKP and that the present project cannot eliminate all the errors that have accumulated in the past in the land cadastre database. However, with the optimal distribution of high quality reference points, the positional accuracy and homogeneity of the positional quality of the ZKP with membrane method can be significantly improved.

In addition to "mass" improvements, the new legislation in Slovenia also facilitates the implementation of positional accuracy improvements in smaller areas. In this manner, by obtaining additional (new) data for the purpose of improvements, problem areas can undergo further rectifications even after the completion of the "mass" improvement project.

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BIOGRAPHICAL NOTES

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