State Border Line Measurement with GPS – Measuring and Processing Experiences

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Key words: state border, GPS, transformation.

ABSTRACT

From surveying point of view the state border points are the first order detail points on the large-scale maps and data basis. Their re-measurement and maintenance is necessary regularly. The problem in Hungary is that the first determination of these important points was made nearly 80 years ago, in old fashion co-ordinate systems and map projections, which are not in use now. Also the accuracy of co-ordinates does not meet the requirements and the traditional surveying methods are not sufficient.

That is why in the last years we are using GPS technology for control and detail survey in co-operation with neighbouring Central European countries. We have experiences with static, kinematic methods under poor satellite visibility and lack field circumstances.

The 3D GPS co-ordinates are now transformed to official old co-ordinate systems resulting in decreased accuracy. We suggest that in the future the ETRS system (as the European implementation of WGS 84) should be the common reference for state border registry in all Central European countries.

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1. INTRODUCTION

However, in certain aspects, globalisation eliminates the state borderlines between the countries, the borderlines still determine the lives of the individuals. One can examine the borderlines according to their roles in history, politics, commerce or defence, but now we analyse them from the surveying point of view, from our own profession.

Though from surveying point of view, the points of state borderline are just the points to be measured and mapped, as any other detail points, the state border points belong to the first group in the hierarchy of border points. The prioritised handling of state borderline points can also be taken as a sample for the registration of other borderline points of lower order. Considering viewpoints of the history of our profession, it can be stated that both the measuring and the registration of the state borderline – influenced by the reference system, map system, measuring and computing technologies – always reflect the current professional and technical level at any time.

In the following, we would like to demonstrate the land surveying jobs concerning the measuring of the state borderline and the effects of the changes in technology on the example of Hungary, a small land situated in the heart of Europe. One could think that in case of a borderline, which has been existing for 80 years, mostly unchanged and properly marked in nature and the relationship with the neighbouring countries can be considered correct, there is no need to employ land surveyors anymore. We would like to prove that the surveyors do have and will have job also in the future, even in case of unchanged borderlines.

2. THE LEGAL REGULATION: HISTORICAL BACKGROUND

Changes in history or political situations – apart from technical conditions – basically determine the professional jobs. During the 20th century, Hungary became the scene of two world wars and various revolutions. Hungary's current borderline was formed in fact as a result of the *World War I*. The borderline was demarcated by the *Peace Treaty* signed on 4 June 1920, in the Little Trianon Palace of Versailles. The *Paris Peace Treaty* – signed on 10 February 1947 by the Allied Forces and Hungary, closing down the *World War II*, – just confirmed the borderlines demarcated in 1920.

In 1920, Hungary had common borderlines with five states. In line with the peace treaty, *International Borderline Demarcating Commissions* were set up for every section of the borderline. The Commission formed a political decision through voting, following which within 14 days the points of borderline had provisionally to be marked with stakes on the spot. These had to be mutually handed over and accepted by the representatives of the neighbouring countries. The technical activity itself, which took place between 1921 and 1926, will be discussed in details later on.

Apart from the peace treaties, other international agreements also influenced the marking out of the state borderlines. One of these was the *Venice Treaty* of 13 October 1921, which provided referendum in town *Sopron* (Western border of Hungary) and environs aiming to state the national status of the said area.
After signing those peace treaties, starting from the principle of inviolability of borderlines, technical-technological questions are regulated through bilateral contracts of the neighbouring countries. Those contracts are supervised in case of need, and they are approved on the highest level (governments, parliaments). For completing the contracts, joint commissions and technical commissions are formed, which held periodical (mostly annual) meetings.

It is worth mentioning shortly the political role of the Hungarian-Austrian border, as this section has been for forty years, between 1949 and 1989, also the borderline separating two world systems, called "*iron curtain*" by *Churchill* in his Fulton speech. As a result of Hungarian political decisions "to defend the socialism", between 1949 and 1959, a 6-8 m wide mine blockade was laid along the Hungarian-Austrian borderline, while a 30 km zone of the borderline was considered forbidden. Though the mines were later taken away, a new internal wire-fence and electronic alarm system was built at a distance of 2 km from the borderline between 1966 and 1970, to control illegal crossing of the frontier. In 1989, as a sign of easing of the tension between East and West, the ministers of foreign affairs of Hungary and Austria started demonstratively to dismount the fence, and finally the "*iron curtain*" was completely removed. In 1989, when – first time in the history – an American president (*Mr. G. Bush*, father of the current president of the US) visited Hungary, a piece of the "iron curtain" was given to him as a gift.
As a result of the political changes, which took place in Eastern Central Europe, Hungary has nowadays seven bordering countries (with five "new" ones among them), however, her borderlines remained unchanged. The total length of the Hungarian state borderline (*Fig. 1*) is 2 217 km, with 56 000 border points, within that with 23 000 marked points. There is a Section in the *Institute of Geodesy, Cartography and Remote Sensing – FÖMI*, in Budapest – which is responsible for all measurements and co-ordinating the periodical maintenance of the state borderline.

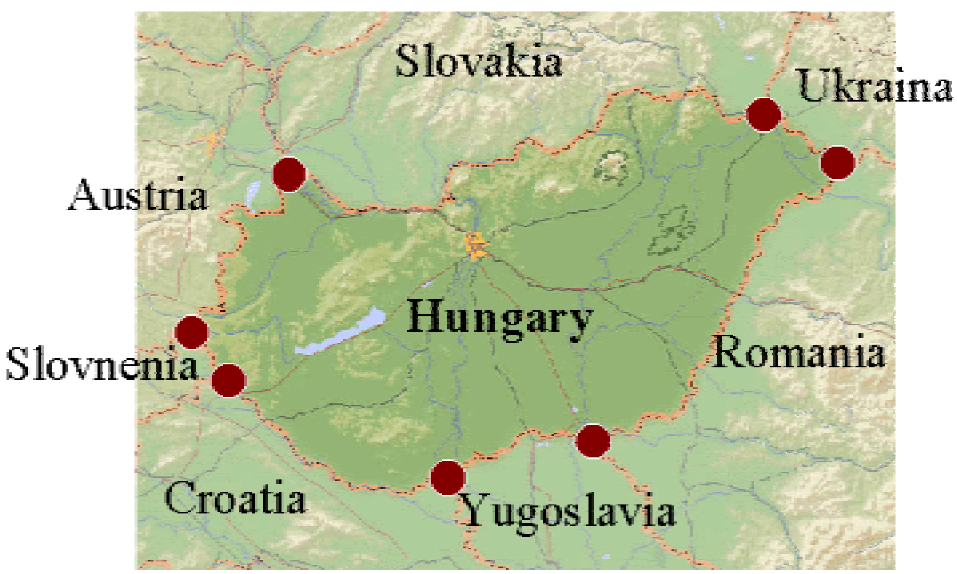

Fig. 1.
Neighbouring countries of Hungary and the so-called triplex border points.

Border lengths:
Austria: 356 km
Slovakia: 655 km
Ukraina: 137 km
Romania: 448 km
Yugoslavia: 166 km
Croatia: 355 km
Slovenia: 100 km

3. THE TECHNICAL-SURVEYING REGULATION IN THE PAST

3.1 Technical regulation in 1920

Studying the borderline documentation, one can admire our professional predecessors, who – 80 years ago, with pretty basic instruments – completed such an excellent job within a very short time. Considering the essence, their working plan would be the same today, as well:

- They compiled the technical instructions based on the collected experience.
- They specified not only the land surveying technology, but also the map legends, nomination of point stabilisation stones, font types and sizes (lettering) as well (*Fig. 2*). To ease understanding, the borderlines with the neighbouring countries were divided into main sections, sections and subsections.
- They determined and identified on map the borderline described on the basis of political decisions and the referendum.

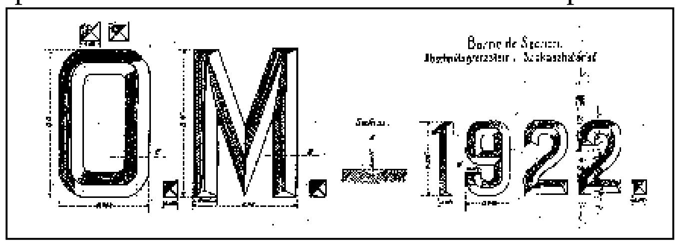

Fig. 2. The font types for border stones at the Hungarian-Austrian border (from 1922)

- The political state borderline was determined on the spot and marked provisionally with wooden pegs.
- The representatives of both neighbouring countries supervised the marking out on the spot. Records were taken, containing their remarks.
- Permanent marking, stabilisation with stone followed. An appointed representative of a non-interested country checked the placing of the border stones. Mutual visibility of the border stones had to be assured, on common sections so-called twin stones were placed. In swampy areas, separate special basement was prepared.
- Control point densification was performed: at that time it was triangulation with direction measuring (with a point density of 4-5 km) and then traversing. Their intention was to determine important points as polygon points.
- Border points were orthogonally measured. They also made detail survey along the borderline. The measurements, completed by one party, were checked by the other party.
- They defined the height of border stones through levelling, but not in every case.
- A special challenge was to define the border sections in water, in river. This is, e.g. the main navigable river-channel of the Danube between Hungary and Slovakia, or the current line of river *Maros* between Hungary and Romania. In this latter case, cross-sections were taken along the whole river section forming the border, and the line connecting the deepest points was received as the state borderline.
- Co-ordinates of control points and border points were computed.
- Map of the state borderline and its environs was prepared. They prepared the documentation in three languages (in the languages of the neighbouring countries plus in French).

3.2 Documentations

Documentation of the job performed in individual border sections is not the same, as it depends on what kind of base maps and base points are available, or the border section in question is in land or in water. It can be stated that beautiful maps and particular descriptions were prepared, corresponding to the expectations of that time, 80 years ago. List of the border documents:

- *Detailed Border Description.* This means not only the text itself from stone to stone, but also the co-ordinates, heights, description of the spot, distance and direction from the neighbouring border stone, the orthogonal measuring data, the map sheet number and the name of the settlement. For instance, on the Hungarian-Romanian border, in the description of the border section, one border mark has 37 attributes (columns).
- *Border Map or Border Sketch.* Its scale is 1:2880 in general, but between 1:5 000 and 1:25 000 anything else is figured. For describing the quality of the border, various agreed symbols were used. The borderline itself was marked and checked by both parties, but the environment was represented on their own sides only.
- *Maps and sketches of the water-border* sections. Maps of the river Danube were made at scale of 1:5 000.
- *General map* at scale of 1:250 000.

3.3 Reference- and map systems

For a quick performance of the borderline measurement in the 1920 years, they had to use the existing geodetic bases. The development of the horizontal control point network of Hungary started at the end of the 19th century, but the total network was not completed. That’s why a separate triangulation campaign was necessary, aiming at building up a chain of triangles of side-lengths of 4-5 km along the state border line. Theodolite was used for angle-measurement. Further point densification was solved through traversing. One-minute theodolite was used for angle-measuring, the accuracy of distance measuring was 0,5 m. Don’t forget: at that time, the map representation was the main aim, the map kept the surveying data, and 0,5 m was an acceptable accuracy at the given scale.

It is important to mention that the basic surface of the geodetic network was the *Bessel* ellipsoid, to which belonged various projections. All of them were characterised by dual projection, i.e., first from the ellipsoid to a sphere and from there to a projection surface. The one was a Budapest stereographic projection; the other was a cylindrical projection. There were three of this latter one to avoid major projection distortions. Due to this special situation, nowadays the Hungarian state borderline is officially registered and specified in four various projection systems and in many map systems.

4. THE TODAY'S TASKS OF STATE BORDER MEASUREMENTS

4.1 Technical tasks

Although the marking of the state border points and their documentation is ready, it does not mean that we have nothing to do. Even if the state borderline remains in principle unchanged, there are several practical problems left to solve:

– *Periodical maintenance of border points.* The visibility of border marks is an important requirement, so in certain periods (2-5-6 years) all border points are to be checked, identified, painted, and cleaned. It was an interesting task to update coats of arms, inscriptions, country marks in line with the changes of the country names. This went on in solemn, but friendly atmosphere at the triple border points (*triplex*). There are several triple border points, where peace park, statue park, recreation place were built, symbolising the friendship of the neighbouring countries.
– *Restoration/replacement of destroyed or damaged border points.* Those points accidentally damaged or destroyed by agricultural activity or transport, are to be restored/replaced. There are special points in the Lake Neusidler see (north-western Austrian borderline), where the ice demolished the original larch-wood posts. The main points are replaced by concrete islands, fortifications.
– *Additional border points.* Mostly in case of opening new border stations, or constructing new international highways or railway lines, the demand emerges for establishing additional border points. The visibility of the border points is very important at the border stations, as any event connected to place (e.g. an accident) has legal consequences.
– *Translocation of border points.* It is advisable to change the place of the border points, when regulating waterflows, forming new watershed areas according to the natural situation, or modify the original ones.
– *Change of areas, modification of borderline.* Regulation of border rivers for water management purposes, arrangement of roads can result in a new situation, which is mutually advantageous, after an agreed change of areas.

Fig. 3. Translocation of border point.

4.2 Surveying tasks

– *Repeated measurement of moving borderline.* As a result of the natural change of the riverbed, also the borderline will change, related to one of the selected lines of the river. So a new measurement is needed to register the changes, in line with the bilaterally signed state borderline contract. Based on the classical technology, the points of the cross-section and the depth of the riverbed were measured along a cable fixed on both banks of the river. After designing the cross section, they could define the co-ordinates of the deepest point. This method is time-consuming and expensive. The recent international contracts support the stabilisation of the moving borderline instead, i.e. the acceptance of a situation related to a certain date.

- *Re-measurement of the state borderline.* The new measurement is justified by the fact that in the past couple of decades, in Hungary and also in the neighbouring countries, new geodetic networks, new reference systems and map systems have been created, in which the state borderline has to be involved. Practical experience confirms that co-ordinates defined in the old systems cannot be transferred by 2D transformation into the new system. The reason is that the original surveys, compared to the current ones are not precise enough, and contradictions emerge. Nowadays, point densification is going on in a new control point network, with total stations and GPS. By the help of the up-to-date measuring technology, border points can be defined with an accuracy of some centimetres and loaded into digital databases. We expect the same results with state border points as well, while their original accuracy is about 0,5-1,5 m! New measurement is necessary – this is a conclusion that will be made in any country, sooner or later. It is understandable that every country prefers her own national system, as finally they will use the state border data in their own system. But the situation has radically changed with the appearance of the GPS technology, as a new reference system appeared at the same time, and it is uniform all over the world. So, the WGS84 system could be accepted as a natural consequence, in quality of a common reference system. The introduction of this could be a longer period of time. This topic will be discussed later.
- *Connecting neighbouring reference systems.* When planning and constructing cross-border highways, railway lines, water management objects, demand emerges many times for the connection of the individual national horizontal and vertical reference systems. Though it can be solved separately between two individual systems as well, it would be worth using WGS as an intermediate system.

5. GPS MEASUREMENTS EXPERIENCES

5.1 Static survey

We have been using GPS technology in Hungary from the beginning of the 1990s; some years following its introduction, the new method was tested in measurements of the state borderline. The advantages of GPS are evident in an area, which is poor in control points. It is cheaper, quicker and more comfortable than the traditional field measurement, as there is no need for visibility with the neighbouring points. The handling of the instrument is weather-independent and simple; its use is easy also in difficult ground (in lakes, in the glades among woods etc.) However, the use of GPS seems to be very simple, concerning preparation and organising, it still needs more care than the traditional ground method:
A good preparation means to fulfil various conditions. Earlier, it is necessary to collect all the control point data concerning the field in question, possibly in all co-ordinate systems. It is important to involve points of higher order, as those can safely be applied during further transformations. Since 1998, the *national GPS network (OGPSH)* with an average distance of 10 km has been available in Hungary. Such OGPSH-points are selected as GPS reference points, assuring the point determination in the *ETRS89 system.* As ETRS89 system points exist in every neighbouring country of Hungary, also a convenient crosscheck is provided through parallel observation of the selected reference points. Of course, it needs a measuring

campaign, harmonised with the foreign colleagues.

We visit the points to be measured on the spot, we make sure that the point is well visible, and there are good conditions for observation. Un-covering sketches (*sky-plots*) are made of the points being in partial covering. If the point is in a wooded area under complete covering, but its GPS measurement would be very important, then the use of the antenna-lifting instrument is considered. As the delivery of this instrument is complicated, and also difficult and time-consuming to determine the external point, this solution is applied in justified cases only. It is simpler to choose an external point in a not obstructed area, and to determine the border point with a total station. In such cases it is advisable to arrange a traditional measurement shortly before or after the GPS measurement, to avoid that the preliminary GPS-points would be demolished before measuring them.

It is very rare to have a ground, where the only use of GPS is convenient, so we should be prepared for the joint use of GPS and the total station. Bearing this in mind, high constructions (village church towers) are also determined: first preliminary points around the tower with GPS, then the tower itself, with theodolite and resection. These high points will be involved as orientation points during further traversing.

Fig.4. Static survey

Before static measurements, the measuring schedule (*organizational design*) is to be prepared. This is a complicated task of logistics: the job of measuring teams of two countries has to be harmonised. Viewpoints of planning: location of points to be measured, number of GPS receivers, their frequency, car and staff available, road conditions, satellite visibility, DOP value, obstructions, length of vectors to be measured… etc. With single-frequency receivers, our intention is to keep basic distance under 10 km. The measuring schedule and the field logbook are prepared in two languages. It is especially important to take field logbook in case of receivers without controller, because on the basis of the logbook one can identify the measuring files. Duration of the measurement is between 20 and 60 minutes. During measurement, the mobile communication (mobile phone) is vital, as any unexpected event can spoil the success of the campaign. In the past couple of years, we have carried out successful GSP measurements on state borderlines with Austrian, Croatian, Serbian, Slovak and Slovenian colleagues.

5.2 Kinematic survey

We managed to test kinematic measuring methods in two cases. The first one was an open area with good view, where the neighbouring border points can easily be reached on foot or by car. In this case, the "*stop and go*" method is optimal and economic solution. In general, 5 sec is selected as integration time, in this way; there is no need to stay longer on the point itself to be measured. The antenna is stabilised by a bipod (support). It is important to check the measuring results: we use various reference points, but to visit all the points independently with another receiver is a much better solution. It is well known that the optimal solution would be the RTK method (where the field quality assurance is solved as well), but at the moment – in lack of instrument – there is no chance for that. For the time being, we perform post-processing and static initialisation instead.

Fig. 5. Stop and go survey

The second case was the testing of the *continuous kinematic* method. For measuring river *Maros* as a moving border, we placed the moving GPS receiver in a boat, connected to an ultra-voice water-depth meter. The boat was moving, crossing the river in a zigzag line, recording the position and water depth in every 5 second. From the evaluation of the cross-sections we were able to determine the line connecting the deepest points, that was accepted as the state borderline for this case. It is easily understandable that this method is much more efficient than the traditional cross-sectioning.

6. GPS PROCESSING EXPERIENCES

The processing of GPS measuring results can be grouped like this: vector computation, computation of spatial co-ordinates, transformation into local system. Computations are made separately by the countries involved, then they compare the results and approve them. This is an individual task to transform the results into the national systems.

When *computing vectors*, spatial vectors were accepted only, with which the phase ambiguity could be determined as an integer (*fix solution*), and the value of ratio is conveniently high. Vectors measured between obstructed points, or the long vectors can be critical. Uncertainties can be eliminated in the best way by prolongation of the measuring time.

For *computing the spatial co-ordinates* it is necessary to use several given points, but it can be easily solved, if in both countries we measure on reference points with known co-ordinates. In the simplest case, we calculate mean value for new points measured from the two given points. It is the unambiguous and correct procedure, when we calculate the co-ordinates of the new points with 3D network adjustment. The contradictions inform not only on the measuring errors, but they also show the identity or framework errors of the reference system of both lands. For the time being, we are working in ETRS89 system in Europe. The errors of the national spatial systems can be about 1-2 cm, therefore, not much bigger (2-3 cm) corrections than that can be allowed for spatial vectors.

After that, the ETRS89 co-ordinates should be *transferred into three local national systems* at least. The first is the official borderline registration system, (which was valid in the 1920s, at the time of the original border-measurement); the other two are the current projection systems of the two neighbouring countries (formed mostly in the 1970s, serving as the basis of the current map systems). The national local systems (LS), especially the oldest one, are not homogeneous, are not so accurate as the ETRS89 system, therefore distortions can be expected. Transformation is performed on the basis of points of co-ordinates known in both countries (*common points*). That's why national controls are to be involved into the GPS measurements. Though it seems to be evident to use polynomial transformation models in cases like this, we do not consider them correct, because they easily eliminate the errors originating from accident mis-identification of common points. We prefer the generally used 3D similarity transformation instead.

The question emerges: what shall we do, if the point has no height in the national system, but co-ordinates only? (It is evident that 3-3 ellipsoid-centric co-ordinates are needed for spatial transformation.) We propose two solutions:
First: ETRS system points are projected to the surface of the WGS84 ellipsoid (i.e. eliminate the ellipsoid height), and a formal 3D transformation is performed, but in fact it concerns the ellipsoid-surface points only. The disadvantage of this solution is that we can give the points horizontal co-ordinates only, they will have no heights.
Second: at the beginning, those common points will only be involved into the transformation, which also have heights. In Hungary, all OGPSH-points have both very good ellipsoid- and orthometric (Baltic) heights, so it is advisable to use first OGPSH-points. At this first transformation, it is worth using the so-called *stepwise model (Fig. 6)*. The advantage of this is that horizontal and vertical heights can be separately handled, the gross height error (maybe of the antenna height or absolute height) does not influence the co-ordinates and no geoid-model is needed. The points with possible gross errors should be analysed separately. So, during the first transformation, the points of gross errors are selected. Baltic height values

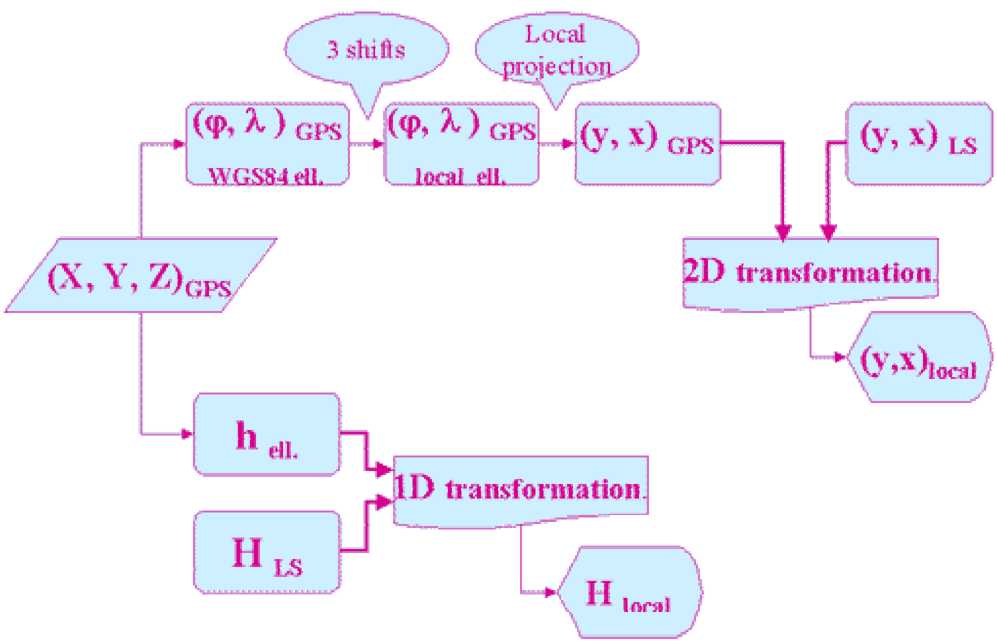

Fig. 6. Stepwise method

will be given to those common points, which had no heights formerly, or it was not correct (e.g. because it originated from the trigonometric height measuring). Then follows the 3D similarity model, in which no major contradictions can appear.

According to experiences, transformation errors can be 6-10 cm as a maximum. Because of the distortions of the previous national networks, the parameters can be valid in a smaller area (a district with a diameter of 20-30 km), so, local transformation zones are to be formed.

7. CONCLUSIONS, SUGGESTIONS

7.1 Conclusions

80 years ago, our professional fathers performed this work excellently: they set out and documented the state borderline on the level, corresponding to the level of that time.
The present official national reference framework for the registration of state border data is not accurate enough.
The new, existing European reference frame (ETRS89) is unified and homogeneous.
The present measuring technique (GPS) is more precise and more efficient than the old, traditional procedure.
Suitable transformation methods are available for computations from GPS into the local national systems.

7.2 Suggestions

The ETRS system should be the common reference for state border inventory in all Central-European countries. This will be the technical base for frontier regional development and collaborations.
Further initiatives and changes are necessary in legal regulation.

BIOGRAPHICAL NOTES

Dr. György Busics was born in 1953, in Szombathely, Hungary. In 1977 I was graduated as a surveying engineer at the Technical University of Budapest. For four years I worked as a field surveyor at the Cartographic Company. In 1981 I changed my work, since that I am a working fellow at the College of Geoinformatics in Szekesfehervar. I am responsible for research work at the college and lecturing on the BSc courses. My duties are: lecturing at GPS courses, organising field practice, supervising for BSc diploma students and Students' Scientific Circle papers, participating in international projects, developing distance learning material. I organise some other research and extra work in cooperation with other institutions to find out to suitable GPS technology. I am a member of Satellite Geodetic Sub-committee under Hungarian Academy of Sciences and fellow of Hungarian Society of Surveying, Cartography and Remote Sensing.