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Challenges and Harmonization of Local Datum Transformations within the Coordinate Reference Systems of North Macedonia

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Abstract:

Accurate, reliable, and interoperable coordinate reference systems (CRS) form the basis of all modern geospatial, surveying, engineering, and cadastral activities. In North Macedonia, the transition from historical national mapping frameworks to modern European standards has necessitated the development of transformation solutions capable of linking legacy data with contemporary positioning techniques, particularly those derived from GNSS observations. This paper reviews the legal framework governing the spatial and horizontal reference systems of North Macedonia and critically examines the technical and operational challenges associated with datum transformation between the Bessel-based national system and the ETRS89 standard. Furthermore, practical considerations, implementation methods, and recommendations for reducing cumulative field and design errors are presented, alongside a strategy for national harmonization through the adoption of a unified transformation parameter set.

The geospatial environment of North Macedonia is shaped by a dual reality: a long-established national coordinate reference system based on the Bessel 1841 ellipsoid and the Gauss–Krüger projection, and a modern legislative requirement aligning the country with the European Terrestrial Reference System 1989 (ETRS89). While ETRS89 forms the official spatial reference system under national law, a significant amount of spatial and infrastructure information continues to exist in the historical system. The coexistence of these systems has created a need for accurate, stable, and operationally practical transformation models to allow for seamless data integration, long-term consistency, and minimal distortions in engineering and cadastral applications.

Article 40 of the national Spatial Reference System law defines ETRS89 as the official three-dimensional terrestrial coordinate reference system for the Republic of North Macedonia. The adoption of ETRS89 ensures compatibility with contemporary European geodetic standards, accurate GNSS positioning, and long-term stability aligned with Eurasian tectonic dynamics.

Article 41 defines the horizontal reference system traditionally used in mapping, based on the Bessel ellipsoid (1841) with an origin point located in Hermannskogel. Positions within this system are expressed in two-dimensional geodetic latitude and longitude and then projected onto a plane coordinate system via the national cartographic system.

Article 42 establishes the Gauss–Krüger projection as the official state map projection with a 3° meridian zone, a central meridian at 21° E, a central scale factor of 0.9999, and standardized false easting and northing parameters. These standards have long ensured national uniformity but also represent a legacy system that predates satellite-based geodesy.

The transition from the classic Bessel-based CRS to ETRS89 introduces several key operational challenges:

1. Non-uniform historical distortions: Older geodetic networks contain accumulated observational and adjustment errors that vary spatially. This prevents the use of a simple universal transformation without location-specific corrections.
2. Local accuracy requirements: Engineering, cadastral, and construction projects often demand accuracies at the 10–15 cm level or better. Standard global seven-parameter solutions may not consistently meet this requirement.
3. Inconsistency across zones and regions: Changing projection zones or mixing data sources can introduce boundary mismatches, cadastral parcel offsets, and discontinuities in project design and infrastructure alignment.

4. Risk of operational errors: Field surveyors routinely face the risk of selecting unsuitable transformation parameters, leading to inaccuracies in stakeout, alignment, and infrastructure positioning.

These issues highlight the need for transformation models that are both technically robust and straightforward enough to be consistently applied across different organizations and regions.

North Macedonia has adopted two primary transformation methodologies:

1 Point-by-Point (MAKTRAN)

This approach uses a database of known common points in both reference systems. In a new survey, the surrounding control points are used to compute transformation parameters using either the Bursa-Wolf or Molodensky-Badekas models. In this method, transformation parameters are generated locally based on the best available neighborhood fit. But this is a one-way direction. If you want to do a stakeout in some areas, you will find that you need to decide which parameters to use.

2 Grid-Based Transformation

Transformation parameters are computed in blocks, typically 10 km × 10 km, allowing local variations in the old network to be absorbed. Each block contains fitted transformation coefficients based on control points within its boundaries. While offering high accuracy, this method requires careful implementation and data management to avoid edge discontinuities. In other words, you must be careful which zone is selected.

GNSS observations can be processed directly in ETRS89 and transformed into the national system using single- or multi-parameter transformations. Classical observations (traverse or resection methods) remain essential for infill surveys, requiring high-quality transformation parameterization to maintain consistency with GNSS solutions.

Surveying practice across North Macedonia confirms several recurring issues:

- 10–15 cm positional discrepancies may appear even when correct transformation parameters are applied, reflecting the historical imperfections of the legacy network.
- Boundary inconsistencies, particularly in project designs and expropriation lines, emerge when different organizations apply different transformation strategies or work across block boundaries.
- Construction site alignment errors can accumulate when subcontractors or inspectors rely on different transformation datasets or inconsistent software workflows.

Based on experience from large-scale infrastructure projects and national-level surveys, the authors recommend the adoption of a unified transformation parameter system. Key advantages include:

- Improved data integrity across all surveyors and institutions.
- Elimination of unnecessary calculations, reducing opportunities for operator error.
- Long-term stability irrespective of future technological evolution.
- Consistent national referencing, enabling problem-free integration of past, present, and future datasets.

A unified national transformation parameter set represents a strategic move toward sustainable and interoperable spatial information infrastructure.

The modernization of North Macedonia's geodetic infrastructure represents a necessary evolution toward fully integrated European and global geospatial standards. As legacy datasets continue to serve engineering, cadastral, and infrastructural needs, a reliable and harmonized transformation framework is essential to preserve positional coherence and operational effectiveness. A unified transformation standard, supported by legislation and widely implemented across public and private sectors, will ensure the integrity, accuracy, and sustainability of the national spatial reference system for decades to come.

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