Brief History of Low Distortion Projections

Earl F. Burkholder, PS, PE, F.ASCE email: eburk@globalcogo.com
Global COGO, Inc. – Las Cruces, NM 88003 URL: www.globalcogo.com
February 2015

This is an informal overview of development of low distortion projections (LDPs). Questions, comments, and suggestions for improvement to this summary are welcome.

1. Surveyors/mappers/engineers/photogrammetrists and others have a long history of working with spatial data and providing valuable services to society. Not discounting the contribution of geocachers, hobbyists, and other spatially literate persons, the role of qualified, licensed, certified, and/or regulated spatial data professionals remains critical to realizing the benefits of a reliable regional/national/worldwide spatial data infrastructure.

2. Prior to the "digital revolution," map projections were used to address the challenge of portraying a curved earth on a flat map. Although Gerard Mercator (1512–1594) generated much of his income from selling globes, he is remembered more for developing the conformal Mercator projection. A popular feature of his conformal world map published in 1569 was that a sailor could leave a port and, according to the map, sail a constant bearing to reach the destination.

3. Serious geodetic surveying in the United States dates from 1807 when President Jefferson hired Ferdinand Hassler as the first Director of the "Survey of the Coast," now the National Geodetic Survey (NGS). The history of excellence established by Hassler has continued for more than 200 years and spatial data users in the United States enjoy a comprehensive national network of reliable geodetic control.

4. NGS developed the State Plane Coordinate (SPC) system in the early 1930's for the purpose of providing plane surveyors a practical method for tying local plane coordinate surveys to geodetic monument positions given by latitude and longitude. Without going into details of grid scale factors, a distortion up to one part in 10,000 between a grid distance and corresponding geodetic distance was deemed acceptable on local transit/tape surveys.

   The state plane coordinate systems of the 1930's did not include ground level elevation in the design considerations. As practice evolved, the grid scale factor was multiplied by the elevation reduction factor to obtain a combined factor making it possible for distances (EDM measurements are typically more precise than 1:10,000) to be easily transformed between grid and ground.

5. Attempting to reduce the differences between grid and ground distances (on nominal plane surveys), Professor Ralph Moore Berry designed the Michigan State Plane Coordinate System (adopted in 1964) at an elevation of 800 feet – a large portion of the Michigan land mass lies within 200 feet of the 800 foot elevation. Several views/consequences of that design include:

   a. The grid/ground difference could be ignored on most plane surveys without consequence.
   b. With the advent of EDM distances (and where needed), procedures/equations for making the combined factor correction were both straight-forward and easy to use.
   c. But, it being a non-standard system and depending upon which information source was used, it was possible for the casual user to compute the grid/ground difference incorrectly.

d. My first employment out of college was surveying for high-voltage power lines and included computing hundreds of miles of control traverses using the state plane coordinate system. That provided the opportunity to become intimately familiar with SPC's and how they were being used in a number of states.

6. After I went back to grad school, my 1980 graduate thesis was "A Metric Map Projection for the State of Michigan." Although development of precise transformation equations on the NAD 83 was my primary focus, the issue of the grid/ground distance difference was a huge concern discussed in Appendix C of the thesis, www.globalcogo.com/MichGSF80.pdf. In particular, the point was made that, without due diligence, it was easy to compute the grid/ground difference incorrectly. That point of possible confusion was addressed by recommending that the GRS80 ellipsoid be used as the reference surface for the Michigan State Plane Coordinate System based on the NAD 83. That recommendation was adopted when the Michigan SPC law was revised.

7. I taught at Oregon's Institute of Technology from 1980 to 1993 and was privileged to take a sabbatical leave 1990/91. I spent most of the year at the University of Maine learning more about GPS and other consequences of the digital revolution. In an attempt to understand better how others handled the grid/ground difference, I polled all 50 state DOT's on practices being used at the time. Ultimately, I received responses from 46 of 50 states. The questionnaire and responses are tabulated in Appendix III of a paper, "Using GPS Results in a True 3-D Coordinate System" presented at the 1991 ASCE GPS Specialty Conference and published in the ASCE Journal of Surveying Engineering, Vol. 119, No. 1. Several important points (with current comments by EFB) from that paper include:

   A. The "true 3-D coordinate system" described in that paper eventually became known as the 3-D Global Spatial Data Model (GSDM). See www.globalcogo.com/gsdmdefn.pdf.
   B. There is no standardization as to the best way to handle the grid/ground difference. (Low distortions projections are one attempt at standardization. The GSDM is another.)
   C. The grid/ground distance difference can be handled in a cost-effective manner. (Lack of education and/or commitment to understanding basic geometry remains the largest obstacle to solving the grid/ground distance challenge.)

8. Nancy von Meyer wrote convincing arguments (www.globalcogo.com/vonMeyer1990.pdf) in favor of adopting County Coordinate Systems that were published in the June 1990 issue of the ACSM Bulletin. Given my interest in the grid/ground distance dilemma and because von Meyer did not include specific algorithms for the computations, I wrote a paper, "Design of a Local Coordinate System for Surveying, Engineering, and LIS/GIS," published in Surveying and Land Information Systems, Vol. 53, No. 1 (www.globalcogo.com/localcor.pdf). Given the variety of comments from the DOT's described above and given the various map projection choices available, the recommendation of adding a design elevation to the semi-major axis of the ellipsoid for existing map projections was viewed as a simple rigorous approach. That means no "new" transformation equations need to be developed or published and that the user is at liberty to specify any elevation for the local system.

9. In 1995 the Wisconsin State Cartographer's Office published a booklet, "Wisconsin Coordinate Systems" that includes information on the Wisconsin State Plane Coordinates (SPC) on NAD27, NAD83, UTM (Zone 15 and 16), and a Wisconsin Transverse Mercator on NAD27 and NAD83. The booklet also contains defining parameters for the 72 counties in Wisconsin. No transformation

equations are listed in the booklet but Burkholder's 1993 local coordinate system paper containing transformation equations is listed in the references.

10. The State of Minnesota also adopted a county coordinate system described in an October 1997 booklet, "The Minnesota County Coordinate System: A Handbook for Users" by Kenneth L. Whitehorn. This booklet describes prior work and includes careful explanations of mapping concepts related to state plane, UTM and local coordinates. The specific design elevation for each county system is listed as are transformation equations for Lambert, transverse Mercator, UTM, and oblique Mercator projections.

11. In 2009 the Wisconsin Cartographer's Office published "Wisconsin Coordinate Reference System – Second Edition" with the intent of making it less confusing for the end users of the Wisconsin County Coordinate System. The integrity of the original design remains intact but, in an effort to accommodate software vendors and to avoid confusion among end users, it was decided to re-design the algorithms (www.globalcogo.com/VonderoheGRS80.pdf) specifically to avoid changing the dimension of the underlying reference ellipsoid. The re-designed system comes very close (within 5 mm) of duplicating the results obtained using the original system.

12. The lessons learned in Wisconsin were applied in the design of the Oregon Coordinate Reference System in which the Oregon GPS Users Group in concert with the Oregon DOT and the NGS ultimately came up with a set of LDPs to serve the needs of the Oregon DOT as well as other spatial data users throughout the state. The 2014 authoritative document can be accessed at:

    ftp://ftp.odot.state.or.us/ORGN/Documents/ocrs_handbook_user_guide.pdf

    Michael Dennis was the LDP consultant for the project and comes highly recommended for his expertise. He can be contacted at mailto:mld@geodeticanalysis.com. The Oregon Coordinate Reference System document is very comprehensive and should be reviewed by anyone who might be serious about designing and using a LDP.

13. However, before committing significant time and/or resources to development of LDP's, interested persons are invited to consider another alternative that provides all the advantages of a LDP without some of the disadvantages – it is called the 3-D global spatial data model (GSDM) mentioned in number 7 above. The GSDM consists of a functional model (one set of equations world-wide) and a stochastic model for error propagation. The GSDM is based on the earth-centered earth-fixed (ECEF) coordinate system and is already in place. The primary obstacle to using the GSDM is deciding to. A comparison of the GSDM with a LDP can be found at: http://www.globalcogo.com/LDPvsGSDM.pdf.

14. A loosey-goosey question is – in what way are current localization practices different from a LDP and/or the GSDM – see www.globalcogo.com/localizationBM.pdf? On one hand, the practicing surveyor is indebted to the vendors for providing a GPS system that can be used (according to manufacturer's instructions) to collect digital spatial data, make surveys, and earn a decent living. On the other hand, surveying professionals should never capitulate to the vendors to decide how to run/operate a business because the vendors do not accept any liability or responsibility for possible misuse of their systems.