EVOLUTION OF MEANING FOR TERMS:
NETWORK ACCURACY AND LOCAL ACCURACY

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The concept of spatial data accuracy is not new but, given the digital revolution of the past fifty plus years, meanings of the terms "network accuracy" and "local accuracy" as related to spatial data have evolved due to the transition in practice from analog to digital applications. Normal procedure is to reference a source within a document and to list the sources alphabetically at the end under "references." This document is a list of references (with comments) in chronological order to show sequence of development. Others are invited to share insights and to offer clarifications. Additional examples and citations will be added as appropriate.

E.1. U.S. Bureau of Budget. 1947. United States National Map Accuracy Standards, http://nationalmap.gov/standards/pdf/NMAS647.PDF

The National Map Accuracy Standards (NMAS) have been beneficial for over 50 years as related to the quality of information the public could expect on a map showing both planimetric features for location and contours for elevation. The map provided analog storage for spatial data and human consumption of those data was likewise analog. The digital revolution has changed all that and issues of "Disruptive Innovation" (http://www.globalcogo.com/DisruptiveInnovation.pdf) have become a challenge for many. When using the NMAS, accuracy is tested by comparing the location of points in a data set with "positions as determined by surveys of a higher accuracy."

E.2. Mikhail, E.M. 1976. *Observations and least squares,* New York: Harper & Row.

Mikhail, E.M. and G. Gracie. 1981. *Analysis and adjustment of survey measurements*. New York: Van Nostrand Reinhold.

The term "precision estimation" is used in these two books to describe the *a posteriori* covariance matrix of the estimates of the parameters (computed coordinates). Subsequent practice uses the term "accuracy" when discussing standard deviations (square root of the variance from the *a posteriori* covariance matrix) in the context of a standard.

E.3. Federal Geodetic Control Committee (FGCC). John Bossler - Chairman. 1984. *Standards and Specifications for Geodetic Control Networks,* Rockville, MD: Federal Geodetic Control Committee.
http://maps.gis.co.brown.wi.us/web_documents/LIO/PDF/LION/GeographicFrameworks.pdf

The FGCC standards and specifications are written for horizontal control, vertical control, and gravity networks. Designations assigned to discriminate levels of quality include Orders (first, second, third) and Class (I, II) – the lower numbers being more precise. In each case the designators were applicable to the network in question – horizontal, vertical, gravity – but terms like global, relative, provisional, intended, absolute, and local were used as *adjectives* in the document to add clarity to concepts being discussed. Although these standards were written to be used with respect "to previously established control," Appendix B of this reference includes sections on "Global Variance Factor Estimation" and "Local Variance Factor Estimation."

E.4. Federal Geodetic Control Committee (FGCC). Wesley V. Hull – Chairman. 1988/9. *Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques* – Version 5.0. Rockville, MD: Federal Geodetic Control Committee. https://www.ngs.noaa.gov/PUBS_LIB/GeomGeod.pdf

The FGCC 1988/9 standards and specifications were written specifically for 3-D relative GPS positioning and supplement the 1984 FGCC document by adding three orders (AA, A, & B) more rigorous than First-Order. The 1984 standards were also improved by replacing the "distance accuracy standard" with relative positional tolerance. This permitted inclusion of a base error component to the standard in addition to the line-length dependent error component. Vertical is also discussed in terms of relative accuracies. Two possible "final" classifications are described as, 1) a "geometric" classification for a relative positioning network and 2) a "NGRS" classification for surveys tied into the local network survey control system. The concepts are discussed but the terms "network accuracy" and "local accuracy" were not found in the document.

E.5. American Society of Photogrammetry & Remote Sensing (ASPRS). 1990. *ASPRS accuracy standards for large-scale maps*. Bethesda, MD: American Society of Photogrammetry & Remote Sensing. http://www.asprs.org/a/society/committees/standards/1990_jul_1068-1070.pdf

One emphasis of these standards is that accuracy is to be applicable at ground scale. Horizontal accuracy and vertical accuracy are addressed separately with frequent reference to Item E.4. The ASPRS Standard contains the following quotes:

Horizontal: "When a horizontal control is classified with a particular order and class, NGS certifies that the geodetic latitude and longitude of that control point bear a relation of specific accuracy to the coordinates of all other points in the horizontal network."

Vertical: "When a vertical control point is classified with a particular order and class, NGS certifies that the orthometric elevation at that point bears a specific relation of specific accuracy to the elevations of all other points in the vertical control network."

Although not addressing relative accuracy in contrast to network or local accuracy, the ASPRS Standard states "map features are intended to possess accuracies relative to all other points appearing on the map.

E.6. Leick, A. 1993. Accuracy standards for modern three-dimensional geodetic networks. *Surveying and Land Information Systems*, 53 (2): 111-16.

Alfred Leick was the Chair of the ACSM Ad Hoc Committee on Geodetic Accuracy Standards and prepared the report at the request of the Federal Geodetic Control Subcommittee (FGCS) to review possible revisions to existing standards and specifications. The introduction of the paper states that *Standards* specify the absolute or relative accuracy of a survey and *Specifications* contain the rules as to how the standards can be met. The committee focused on the *Standards* portion, leaving discussion of the *Specifications* to another time. The committee met at the ACSM convention in San Jose, California on November 8, 1992. Burkholder was a member of the committee and participated in that meeting.

Two quotes from that 1993 report are:

- "The length-dependent principle has developed into a cornerstone in the philosophy and perception of geodetic networks. It is well suited for describing in simple terms the principle of neighborhood in geodetic networks."
- "The length-dependent characterization of geodetic networks, surprisingly, tolerates translation and even systematic errors. For example, a translation of the whole network does not affect the quality and shape of the internal geometry. If systematic errors build up slowly as the size of the network increases, large absolute position errors eventually may occur, even though in small regions the line-dependent accuracy might still be acceptable for many users. For many surveying projects, the network accuracy in the immediate vicinity of the project area is important, in order to assure relative position accuracy."

The 1993 report includes other issues such as use of Active Control Points (now known as CORS) and proposed position accuracy standards (millimeter, centimeter, decimeter, submeter, meter, and multimeter) as given in Table 4.

Report Conclusion: "The primary recommendation of ACSM's Ad Hoc Committee on Geodetic Accuracy Standards is to supplement current relative positioning standards, which are distance-dependent, with point-position accuracy standards."

E.7. Burkholder, E.F. 1997. Definition and description of a global spatial data model (GSDM), Washington, DC: filed with U.S. Copyright Office, http://www.globalcogo.com/gsdmdefn.pdf.

This paper identifies concise mathematical definitions for both network accuracy and local accuracy. Those definitions were intended to be compatible with Leick (E.5). Those same definitions have been used by the author in subsequent items.

E.8. Southeastern Wisconsin Regional Planning Commission (SEWRPC). 1997. *Definition of a three-dimensional spatial data model for southeastern Wisconsin*. Waukesha, WI: Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin. http://www.sewrpc.org/SEWRPCFiles/Publications/ppr/definition_three-dimensional_spatial_data_model_for_wi.pdf

Burkholder prepared this report for the Southeastern Wisconsin Regional Planning Commission (SEWRPC) published in 1997. An important part of the document is a paper (E.7) defining and describing the 3-D global spatial data model (GSDM).

E.9. Federal Geographic Data Committee (FGDC). 1998. *Geospatial positioning accuracy standards part 2: Standards for geodetic networks*, Reston, VA, Federal Geographic Data Committee, U.S. Geological Survey, http://www.fgdc.gov/standards/standards_publications.

Part 2 of the FGDC geospatial positioning accuracy standards "provide a common methodology for determining and reporting the accuracy of horizontal coordinate values and vertical coordinate values for geodetic control points." The standards apply to horizontal positions, ellipsoid heights, and orthometric heights. The document emphasizes the importance of high-quality surveys of points to be included in the National Spatial Reference System (NSRS). But, more importantly, the document adopts accuracy classifications (with slight modification) as proposed by Leick (E.5) and states:

- Local accuracy is best adapted to check relations between nearby points.
- Network accuracy measures how well coordinates approach an ideal error-free datum.

E.10 Federal Geographic Data Committee (FGDC). 1998. *Geospatial positioning accuracy standards part 3: National standard for spatial data accuracy*, Reston, VA: Federal Geographic Data Committee, U.S. Geological Survey, http://www.fgdc.gov/standards/standards_publications

Part 3 of the FGDC geospatial positioning accuracy standards supersedes, but does not necessarily replace, the 1947 National Map Accuracy Standards (E.1). The root-mean-square-error (RSME) is used to estimate positional accuracy which is tested by comparison of an observed position to that as determined by an independent source of higher accuracy. Accuracy is reported at the 95% (two sigma) confidence level and, typically, one estimate applies to all points within a given data set.

E.11. Burkholder, E.F. 1999. Spatial data accuracy as defined by the GSDM. *Surveying & Land Information Systems*, 59 (1): 26-30. http://www.globalcogo.com/accuracy.pdf

This peer-reviewed paper summarizes the definition and characteristics of spatial data accuracy as contained in the 1997 defining document (E.7). One goal for this paper was to consider the question, "accuracy with respect to what?" It appears that consensus in using the stochastic model portion of the GSDM is still evolving.

E.12. US Forest Service and Bureau of Land Management USFS/BLM. 2001. *Standards and Guidelines for Cadastral Surveys Using Global Positioning System Methods*, Washington, DC. https://www.blm.gov/cadastral/Manual/pdffiles/CadGPSstd.pdf

This document was prepared cooperatively by the U.S. Forest Service and the Bureau of Land Management to provide guidance to Government cadastral surveyors (and others) in a time when GNSS surveying capability was evolving from static to fast static to kinematic to real-time kinematic. It provides an excellent overview of GNSS capability at the time within the context of the accuracy needed for cadastral surveying. Appendix A of this document (E.12) references the FGDC 1998 accuracy standards (E.9) and includes detailed descriptions of both network accuracy and local accuracy.

E.13. Craig, B.A. and J.L. Wahl. 2003. Cadastral survey accuracy standards. *Surveying and Land Information Science*, 63 (2): 87-106.

Craig and Wahl note that "current cadastral survey accuracy standards are inadequate and need to be changed to reflect the way modern land surveys are conducted . . ." The paper contains a review and commentary on the FGDC use of Network Accuracy and Local Accuracy. Although Appendix A of the paper (E.13) contains an excellent summary of concepts related to Positional Accuracy, the authors conclude that implementation of "local accuracy" needs additional study with consideration given to options that resemble the ALTA/NSPS standards (E.23).

E.14. American Society of Photogrammetry & Remote Sensing (ASPRS). 2004. ASPRS guidelines, vertical accuracy reporting for Lidar data. Bethesda, MD: American Society of Photogrammetry & Remote Sensing.

https://www.asprs.org/a/society/committees/standards/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf

These guidelines were written specifically for use with Lidar technology. None-the-less the concepts are similar to conventional accuracy considerations. The guidelines discuss both relative and absolute vertical accuracies and the importance of recognizing characteristics of each. The importance of horizontal accuracy is discussed as related to the repeatable location of test points and as related to side slope conditions. The glossary section includes definitions for horizontal accuracy as being with respect to a horizontal datum and for vertical accuracy as being with respect to a vertical datum.

E. 15. Burkholder, E.F., 2004, "Fundamentals of Spatial Data Accuracy and the Global Spatial Data Model (GSDM)," U.S. Copyright Office, Washington, D.C. http://www.globalcogo.com/fsdagsdm.pdf

This paper was written in response to a call for papers from ASPRS for papers to be included in a special issue of PE&RS journal. This paper (E.15) was reviewed but not published by ASPRS. Much of the material included in this paper can be found in Chapter 12 of the 2nd Edition of "The 3-D Global Spatial Data Model: Principles and Applications."

E.16. Burkholder, E.F., 2008, The 3-D global spatial data model: foundation of the spatial data infrastructure, CRC Press, Boca Raton, FL. https://www.crcpress.com/The-3-D-Global-Spatial-Data-Model-Foundation-of-the-Spatial-Data-Infrastructure/Burkholder-Burkholder/p/book/9781420063011

The first edition, (E.16), contains the mathematical definitions of network and local accuracies as given by Burkholder (E.7). Chapter 12 of the 2nd Edition of the book will contain an example that is updated from the 1st Edition and Chapter 14 will contain a new comprehensive example of computing and using the mathematical definition of network accuracy and local accuracy.

E.17. Soler, T, and D. Smith. 2010. Rigorous estimation of local accuracies. *Journal of Surveying Engineering*, 136 (3): 120-25.

Soler & Smith note that "the concept of local accuracy, although intuitive, has not received the mathematical attention it deserves." The paper (E.17) generalizes the treatment of network and local accuracy as given by Burkholder (E.16) by deriving "exact" equations for computing local accuracy based upon the errors of each X/Y/Z component at each of two points defining a vector.

E.18. Burkholder, E.F. 2012. Discussion of "Rigorous estimation of local accuracies" by T. Soler and D. Smith, *Journal of Surveying Engineering*, 138 (1): 46-48.

The material on local accuracies as in published in Burkholder (E.16) is defended as being complete, correct, and rigorous.

E.19. Soler, T. and D. Smith. 2012. Closure to discussion of "Rigorous estimation of local accuracies" by T. Soler and D. Smith, *Journal of Surveying Engineering*, 138 (1): 48-50.

In a closure to the discussion of Rigorous Estimation Soler & Smith mount forceful arguments in favor of the "exact" method for computing local accuracy. It seems that their computation of "exact" local accuracy uses a different functional model equation than that used by Burkholder in (E.16).

E.20. Soler, T., J. Han, and D. Smith. 2012. Local accuracies, *Journal of Surveying Engineering*, 138 (2): 77-84.

According to the authors, "The objective of this study is to evaluate the different approximations in the technical literature that are used to compute the variance-covariance matrix of local accuracy." The discussion is extensive.

E.21. Burkholder, E.F., 2013, Standard deviation and network/local accuracy of geospatial data, U.S. Copyright Office, Washington, D.C., http://www.globalcogo.com/StdDevLocalNetwork.pdf.

This paper suggests that the authors of the Discussion and the Closure (E.18 and E.19) talked past each other in promoting competing arguments related to computing local accuracy. The mathematical definition of local accuracy in Burkholder (E.16) is validated by using an independent method not requiring use of rotation matrices. (E.21) also provides specific examples for short, medium, and long lines (1 km, 20 km, and 100 km) that show very nearly identical results for both the methods espoused by Burkholder and by Soler and Smith. As an aside, the paper also shows conclusively that, using either method, local accuracies can be significantly better than network accuracy.

E.22. American Society of Photogrammetry & Remote Sensing (ASPRS). 2014. *Positional accuracy standards for digital geospatial data*, Version 1.0. Bethesda, MD: American Society for Photogrammetry and Remote Sensing.

http://www.asprs.org/wp-content/uploads/2015/01/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf

The stated objective of this document "is to replace the existing ASPRS Accuracy Standards for Large-Scale Maps (E.14) and the ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data (E.15) to better address current technologies. This standard includes positional accuracy standards for digital orthoimagery, digital planimetric data and digital elevation data." It is a comprehensive document and includes definitions for accuracy, horizontal accuracy, local accuracy, network accuracy, positional accuracy, and others. It also states, "all accuracies are assumed to be relative to a published datum and ground control network used for the data set as specified in the meta data." These standards represent significant advances in use of modern/digital technologies but stop short of recognizing evolving practice with respect to use of on an integrated 3-D spatial data model. With only minor modifications, these standards appear to be compatible with definitions of network and local accuracies as defined by the GSDM. Specifically, the GSDM contains additional detail showing how network and local accuracies are determined.

E.23. American Land Title Association and National Society Professional Surveyors (ALTA/NSPS). 2016. *Minimum Standard Detail Requirements for ALTA/NSPS Land Title Surveys*. Washington, DC and Frederick, MD: American Land Title Association (ALTA), Washington, D.C. and National Society of Professional Surveyors.

http://c.ymcdn.com/sites/www.nsps.us.com/resource/resmgr/ALTA_Standards/2016_Standards.pdf

Members of the American Land Title Association® (ALTA®) need reliable documents as part of the basis for insuring title to land purchased by a client. Among others, the measurement standard is to meet the Relative Positional Precision estimated by the results of a correctly weighted least squares adjustment of the survey. Because of ambiguity "with respect to what" some confusion exists as to whether that standard can be met using network accuracy as obtained from the least squares adjustment. It appears (see Chapter 14 of the 2nd Edition) that the intent of the ALTA/NSPS Relative Positional Precision standard can be met more appropriately using local accuracy as defined and computed using the GSDM.

E.25. National Geodetic Survey (NGS). 2016. *NGS data sheet.* There is a link – dsdata.txt – near the top of each NGS data sheet. Silver Spring, MD: National Geodetic Survey. http://www.ngs.noaa.gov/datasheets/

When looking at a specific data sheet, the dsdata.txt link leads to information related to content of each NGS data sheet – including information on network and local accuracies. "For publication purposes, the network accuracy of a control point is a value that represents the uncertainty of its coordinates with respect to the geodetic datum at the 95% confidence level." Separately, "The local accuracy of a control point is a value that represents the uncertainty of its coordinates relative to other directly connected, adjacent control points at the 95% confidence level. This value represents the relative positional error which surveyors can expect between survey marks in a locality. It also represents an approximate average of the individual local accuracy values between this control point and other observed control points used to establish its coordinates although, in general, all of the immediately surrounding stations will not necessarily have been used in the survey which established the original coordinates."

Without taking exception to the prerogative of NGS (E.25), using the mathematical definition of network accuracy and local accuracy in (E.16) gives slightly different options:

1. As described in Chapter 1, there is a mathematical difference between the accuracy of a point (datum accuracy) and the accuracy of derived point-pair geometrical quantities such as directions

and distances (horizontal and vertical) between points using equation 1.36.

2. If no covariance values are available, the functional model equations 1.34 and 1.21 will provide geometrical answers with no standard deviations associated with the derived values.

3. Using equation 1.29 and 1.36 in addition to equation 1.34, the covariance matrix of a network solution provides accuracy computation options for the user that include:

    a. Datum accuracy of a point is given by equation 1.29. The local reference frame values for datum accuracy are obtained using equations 1.31 and 1.32.

    b. The 3-D local accuracy of an inverse between two points is obtained by using the full covariance matrix in equation 1.36. This value is point-pair specific and makes no distinction whether the points were directly connected or not. Of course, the correlation values between points reflect the geometrical strength (or not) of a direct connection.

    c. Network accuracy is obtained for an inverse computation if the correlation portion of equation 1.36 is not known or is not available. Two versions of network accuracy are determined by whether or not correlations are known between X/Y/Z components at a station. If those correlations are not known, the network accuracy value represents a computation based only on the standard deviations of the components.

Another important consideration is that points determined by separate projects (campaigns), but referenced to the same datum, have no correlation and therefore no local accuracy estimates are available. In that case, based upon datum accuracies at each point, network accuracies are the only estimates available for the relative position of one point with respect to another.