# ADDENDUM I: GENERAL GUIDELINES AND BEST PRACTICES

This addendum contains general guidelines and best practices that can serve all users of the ASPRS Positional Accuracy Standards for Digital Geospatial Data.

## A: REPORTING NOTES FOR DELIVERED PRODUCTS

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The ASPRS Positional Accuracy Standards for Digital Geospatial Data encourage truth in reporting when delivering geospatial products or services. This section provides examples of reporting notes to accompany delivered products. Subsections provide specific reporting guidelines for various categories of deliverables.

All accuracies should be reported as “tested to meet” or “produced to meet” in accordance with ASPRS Positional Accuracy Standard for Digital Geospatial Data, Section 7.15. To provide clients with the required metadata to support the proper use of geospatial deliverables, the following notes are suggested to be included in reports for the various types of deliverables described herein:

### A.1 Notes Related to Geospatial Deliverables in General

1. The elevation data provided was ***tested to meet a vertical accuracy of xxx (units) RMSE, using xxx checkpoints*** in clear unobscured areas, to support the generation of a ***x-(units) contour interval*****.**
2. The delivered elevation data is the source for any delivered derivative products (e.g., contours). The project’s delivered elevation data should be utilized as the sole source for creating any additional derivative products or subsequent computations.
3. This map was produced by photogrammetric methods using: (pick all that apply)
    a. Aerial lidar
    b. Aerial photogrammetry
4. The following sensors were utilized to collect the data for this project:
    a. Aerial Imagery Sensor
        i. Sensor Make
        ii. Sensor Model
        iii. Calibration date
    b. Aerial Lidar Sensor
        i. Sensor Make
        ii. Sensor Model
        iii. Calibration date
5. The following software products were utilized during the creation of the deliverables:
    a. Trajectory Processing
    b. Lidar Data Processing
        i. Calibration
        ii. Classification
        iii. Data Extraction
        iv. Data Validation

    c. Imagery Processing
        i. Aerial triangulation (e.g., Inpho, Socket Set, Pix4D)
        ii. Orthomosaic production (e.g., Inpho, Socket Set, Pix4D)
        iii. Stereo compilation (e.g., ISAT, Socetset)
        iv. Data Validation
    d. Compilation
        i. Stereo viewing/extraction (e.g., ISAT, Socetset)
        ii. Lidar point cloud extraction (e.g., TopoDOT, TerraScan)
        iii. Data Validation

6. Ground control and/or checkpoints were provided by:
    a. Firm name, address, phone number, and license number
    b. Signing surveyor name and license number
7. Ground control and/or checkpoint coordinate values are as follows:
    a. Provide coordinates in local state plane or client-requested coordinate system.
    b. ALWAYS also provide coordinates in Lat/Long/Ellipsoid Height to allow for validation of any coordinate transformations or reprojections.
8. GPS positional data was observed on/between the dates of ***mo/day/year*** and ***mo/day/year*** utilizing a ***make/model*** receiver. The grid coordinates of the Fixed Station(s) shown were derived using a ***describe network*** (e.g., Local Static Control, VRS network of CORS stations) referenced to ***datum (year), epoch (year), geoid (year)***.
9. The positional accuracy of the GPS vectors is: ***Horizontal x.xx (units), Vertical v.vv (units), Combined Grid Factor: 0.xxxxxxxx centered on Fixed Station xxxx as shown hereon***.
10. Accuracies of horizontal control points are reported as being ***xxx (units) RMSE with a standard deviation of xxx (units)***. Individual point statistics can be found in ***Appendix X.*** A Coordinate Quality report can be utilized to provide individual point statistics.
11. Accuracies of vertical control points are reported as being ***xxx (units) RMSE with a standard deviation of xxx (units)***. Individual point statistics can be found in ***Appendix X.***
12. Delivered products are referenced to the following spatial reference system:
    a. Horizontal Datum with epoch
    b. Vertical Datum with epoch and reference geoid
    c. Projection (UTM, State Plane, etc.)

## A.2 Notes Related to Aerial Imagery Deliverables

1. Date of Aerial Imagery Capture, ***Month Day, Year***.

2. The imagery was ***collected at xxx (units) nominal GSD*** to support the production of orthorectified digital maps with ***xxx (units) GSD***.

3. The accuracy of aerial triangulation which was performed ***using xxx ground control points and XYZ software***, was found to be ***$RMSE_X$ = xxx, $RMSE_Y$ = yyy, and $RMSE_Z$ = zzz***.

4. Describe the source of the elevation surface utilized to produce the orthophotography and any modifications thereof made by the consultant.

***5.*** This imagery mapping product was ***tested to meet a horizontal accuracy of xxx (units) $RMSE_H$, using xxx checkpoints.***

6. Note: If a client specifies a legacy standard, add a comparison to the legacy equivalent, e.g., ***"which is equivalent to the ASPRS Accuracy Standards for Large-Scale Maps (1990) ASPRS Class 1 at a map scale of 1:2400."***
7. Compiled vector features have been ***tested to meet a horizontal accuracy of x.xx (units) RMSE, using xxx checkpoints***. in clear unobscured areas. Planimetric features in areas delineated as "visually obscured" may not adhere to this accuracy.
8. Compiled vector features have been ***tested to meet a vertical accuracy of x.xx (units) RMSE, using xxx checkpoints*** in clear unobscured areas. Planimetric features that lie in areas delineated as "visually obscured" may not adhere to this accuracy.
9. Report sequence of orientation angles: ***The exterior orientation angles rotation sequence is:***
    a. Omega, phi, kappa
    b. Other sequences
10. Report camera integration on aircraft: ***The camera was oriented with the image positive y-axis in the direction of flight***.

### A.3 Notes Related to Aerial Lidar Deliverables

1. Date of Lidar Capture, ***Month Day, Year***.
2. Lidar data was collected nominally at ***xxx points per square meter (or xxx points per square foot)*** resulting in an equivalent ***xxx cm (or xxx foot) nominal point spacing***.
3. This lidar mapping product was ***tested to meet a vertical accuracy of xxx (units) $RMSE_V$ using xxx checkpoints in non-vegetated terrain***.

## SECTION B: ERROR NORMALITY TESTS

**Contributor: Dr. Christopher E. Parrish, Oregon State University**

### B.1 Creating the Normality Test

Following an accuracy test, it is recommended to assess and report whether the errors[1] are normally distributed (i.e., whether they are well modeled by a Gaussian distribution). This assessment can provide context to the accuracy test results, and, in some cases, can help uncover issues that can be addressed, once detected. For example, if the error distribution is non-normal, this could indicate the presence of blunders or large systematic errors, which should be further investigated.

The first step in testing the normality of the error distribution is a visual test, which is performed by plotting and inspecting a histogram of errors. Histogram plotting functions are available in any number of spreadsheet software packages and programming languages. An example of an error histogram is shown in Figure A-1. This example is from testing the accuracy of an airborne lidar point cloud covering a portion of the Oregon State University (OSU) campus, using 87 field-surveyed checkpoints. The

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[1] In keeping with the terminology convention used throughout these standards, in this addendum, we use the term "errors" where, strictly speaking, we mean "residuals."

checkpoints were surveyed using a combination of RTK GNSS and total station observations, with a least squares adjustment subsequently performed using a commercial software package.

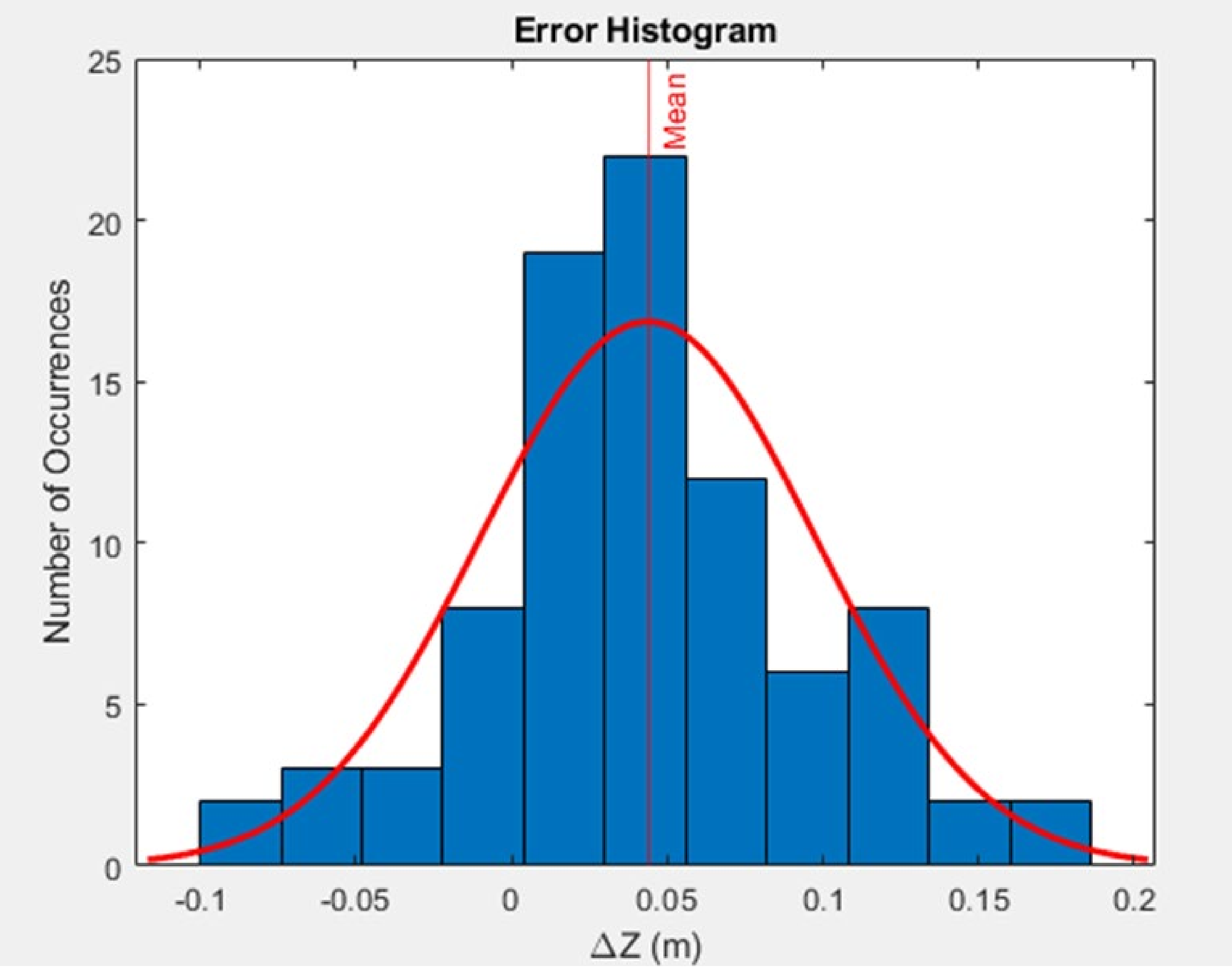
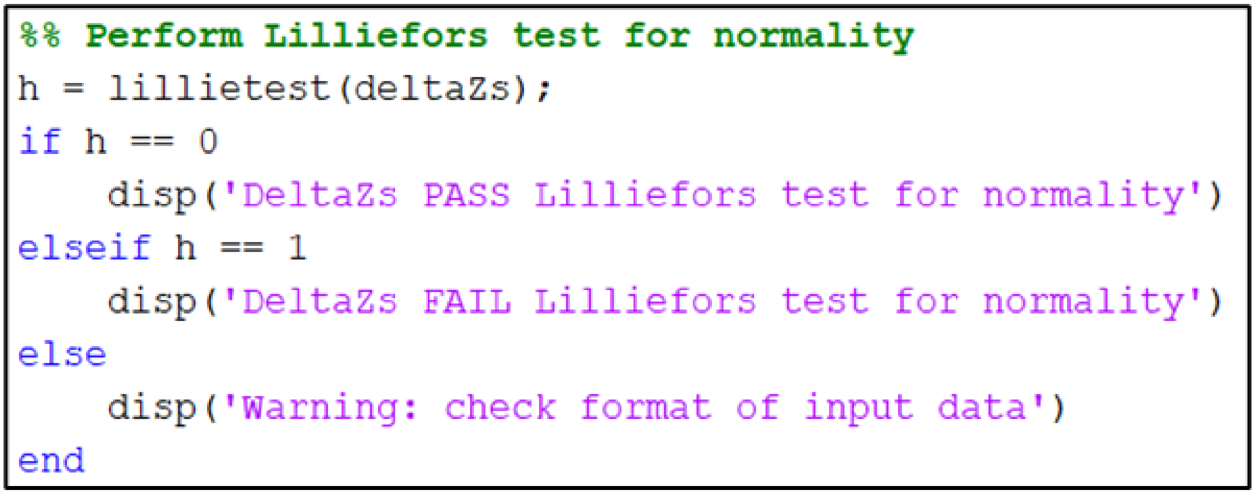


**Figure B.1 Example of an error histogram. The orange curve is a fitted Gaussian distribution. The vertical line denotes the location of the mean. This histogram has been normalized, such that the area under the plot is equal to one.**

Important items to look for in the visual test include:

1. The mean should be near zero, as a large (positive or negative) mean indicates the presence of bias in the data.
2. There should be no spikes far from the mean, as these would indicate the presence of outliers.
3. The distribution should be symmetric about the mean (not positively or negatively skewed).
4. The general shape of the error histogram should approximate the “bell-shaped curve” of the normal (Gaussian) distribution.

Following the visual assessment of the error histogram, the next step is to perform a quantitative normality test. Lilliefors test for normality is recommended. The Lilliefors test is based on, but includes improvements to, the well-known Kolmogorov–Smirnov (K-S) test. Importantly, it is available as a built-in function in commercially available spreadsheet software packages and programming languages (Figure A-2). Another well-known and widely used normality test is the Shapiro-Wilk (S-W) test.



```
%% Perform Lilliefors test for normality
h = lillietest(deltaZs);
if h == 0
    disp('DeltaZs PASS Lilliefors test for normality')
elseif h == 1
    disp('DeltaZs FAIL Lilliefors test for normality')
else
    disp('Warning: check format of input data')
end
```

**Figure B.2 Lilliefors test for normality implemented in MATLAB.**

## B.2 Interpreting the Normality Test

There are many reasons why errors may not be normally distributed, and it is important to recognize that failing a normality test (the visual and/or quantitative portion) does not necessarily indicate a problem with the data, the checkpoints, or the test. However, assessment the results of the normality test can often help uncover issues that can be addressed. For example, errors that fail the normality test may lead to further investigation, in which it is discovered that incorrect boresight calibration parameters were applied in processing the data. In this hypothetical example, perhaps the original data met the required accuracy, as specified in the contract, but reprocessing the data with the correct boresight parameters applied leads to even better accuracy and normally distributed errors. As another hypothetical example, assessment of the normality test results may lead to discovery of issues with one or more checkpoints. It is improper and in violation of these standards to exclude checkpoints from the accuracy test, without justification, simply because their corresponding errors are large. However, analysis of checkpoints for which the corresponding residuals are more than two three standard deviations from the mean may provide important insight. Perhaps, in a particular airborne lidar project, there was a two-week time gap between the checkpoint survey and aerial survey, and it is discovered that a parking lot, in which two of the checkpoints were located, was repaved in this interval. As another example, it might be discovered that one of the checkpoints, which was surveyed with RTK GNSS, was near a tall chain-link fence, and subsequent analysis of the GNSS data may indicate that the checkpoint coordinates were affected by multipath and poor satellite geometry. In these examples, if the accuracy test is repeated with these checkpoints withheld, the correct procedure is to clearly state in the accuracy report exactly which checkpoints were withheld and to provide a detailed justification.

In analyzing the error histogram shown in Figure A.1, visual analysis confirms that the error distribution looks reasonable, although the mean of 4 cm indicates a positive bias (i.e., the lidar data are, on average, 4 cm too high with respect to the checkpoints), and the distribution is slightly positively skewed. Visual assessment indicates a lack of outliers. This error distribution passes Lilliefors test for normality. However, this test data set does not satisfy the criterion of mean error, $\mu < 25\%$ of the RMSE, which is discussed Section 7.2 of the ASPRS Positional Accuracy Standard for Digital Geospatial Data. In this case, the mean error is 64% of the RMSE, indicating that the RMSE is dominated by a large bias, which could be further investigated.

### B.3 Reporting the Normality Test

It is recommended that the error histogram be included and discussed in the accuracy report to provide context to the reported accuracy statistics. The accuracy report should state the type of normality test performed (e.g., Lilliefors test or Shapiro-Wilk test). If the error distribution fails the normality test (visual and/or quantitative portion), this should be stated and discussed in the report, including any findings from subsequent analysis, such as in the examples given above.

## SECTION C: LIDAR DATA QUALITY VERSUS POSITIONAL ACCURACY

**Contributor: Dr. Qassim Abdullah, Woolpert, Inc.**

Users of the standard must be aware of the difference between elevation data quality and positional accuracy. An accurate lidar point cloud does not necessarily result in accurate modeling of the terrain or accurate volumetric calculations. Elevation data is also judged by the degree to which it represents the terrain detail. In many instances, users of lidar data focus on point cloud accuracy as specified by sensor manufacturers, ignoring the equally important aspect of point density as it relates to terrain roughness or smoothness.

Terrain modeling methodology (e.g., polygon-based Regular Triangulated Network (RTNs) or Triangulated Irregular Network (TIN) versus Voxel-based Network) also affect the terrain model quality. Terrain analysis is sensitive to the software represents the point cloud as a TIN, a gridded surface or an RTN. Methods than involve gridding of the data are sensitive to grid cell size (post spacing), and lidar point density is an important factor when choosing grid cell-size.

Figure 1 clearly illustrates the relationship between terrain roughness and point density. While the point cloud in this example may have vertical accuracy of $RMSE_V$ = 10 cm, TIN interpolation based on surrounding points of low point density places the vertical position of point A at point A’ resulting in a vertical error of 2 meters in this example. The remedy is to obtain the point cloud at a higher density such that it more accurately represents the terrain detail. Using a low-density point cloud to represent terrain with high frequency undulation results in substantial inaccuracy in the volume estimation regardless of what software or modeling algorithms are used. Smoother terrain within lower frequency undulation can be adequately represented with a lower density point cloud. Very smooth or flat terrain can be accurately modeled using a point cloud with nominal post spacing (NPS) of a few meters or coarser.

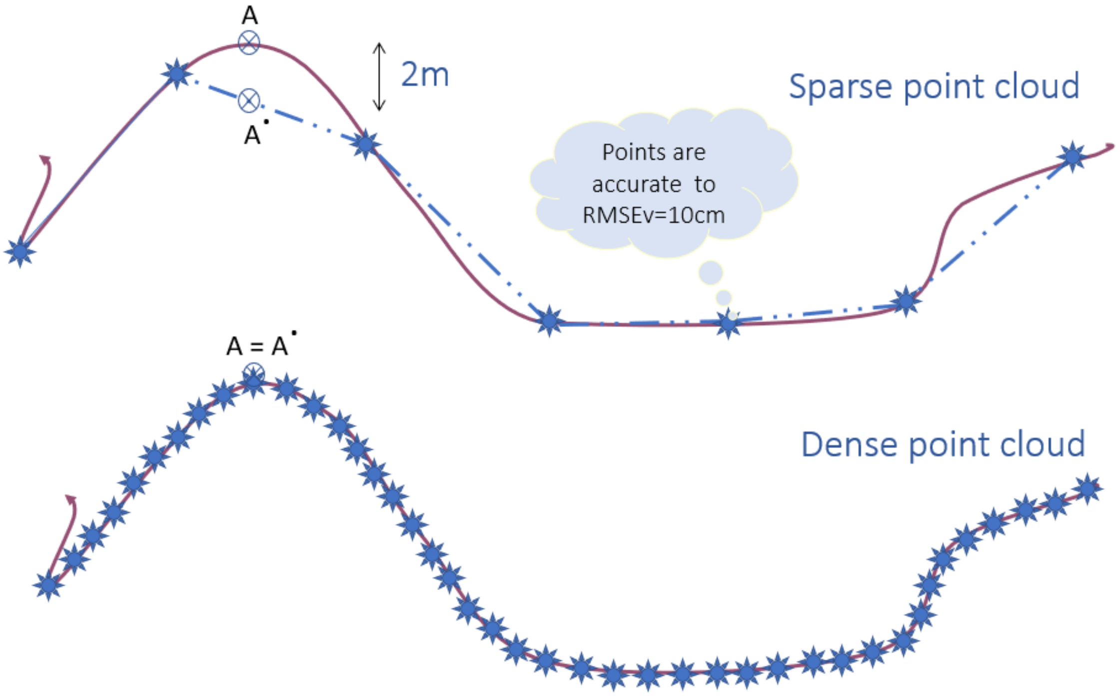


**Figure C.1 Terrain Model Quality as a Function of Point Density and Vertical Accuracy**

When a user is unsure of the point density required to accurately represent the project terrain, it is recommended to use the Nyquist frequency, which is well-known and widely used in signal processing. The Nyquist frequency (cycles per second) is the frequency whose cycle-length (or period) is twice the interval between samples. To avoid aliasing, the sampling rate must less than half of the Nyquist frequency.

Applying this principle to terrain modeling, let us assume that undulation “rate” of the terrain represents the Nyquist frequency, and the nominal point spacing represents the sampling rate needed to model the terrain without aliasing. If we want to accurately model rocky terrain where spikes caused by these rocks appear on the average every 30 cm, the nominal point spacing of the lidar data used to model this terrain should be 15-cm or less.