NCDOT

GIS Unit

Data Compilation Section

SPECIFYING ROAD LENGTH

A Technical Report

By

Hardee Cox
John Farley
Terry Norris
William Rasdorf
L.C. Smith
Chris Tilley

June
2006

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Background

One of the most important attributes of NC roads and highways is their length. This attribute is used for numerous purposes, for data inquiries to meet the needs of other units within and without the NCDOT and to drive the numerous applications that are used to conduct the business of the NCDOT. The correctness and accuracy of this attribute are both important.

The purpose of this white paper is to define what is meant by the term length, to define the different lengths of interest to the NCDOT, to identify the lengths that should be affiliated with the LRS database, and to identify the lengths that should be affiliated with the GIS linework. In doing so the GIS Unit seeks to clarify these terms for both internal and external technical users. This report is directed at those technical users who are familiar with and use these concepts on a regular basis. It is not intended for the casual reader.

Length Definitions

There are numerous interpretations of the word length. The purpose of this section is to introduce and define length terms and other related measurement terms. Five key spatial measurements used by the GIS Unit, and which are of interest to the LARS project, are as follows:

Measured length	3-D	Slope (S)
Petition length	3-D	Slope (S)
Projected length	2-D	Horizontal (H)
Calculated length	3-D	Slope (S)
Elevation	1-D	Vertical (V)

When using these terms the words length and mileage are often used interchangeably and are herein considered to by synonymous.

Figure 1 illustrates the relationship between these lengths and measurements.

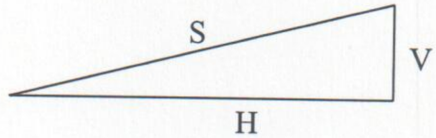

Figure 1: Slope Distance

Measured length is a length obtained by measurement. This length is usually measured using a distance measurement instrument (DMI) while driving along the 3D road section under consideration. *Measured length* may be acquired by Data Compilation Section personnel in two ways. The first is by actual field measurement. It may also be obtained from petitions or construction plans. If it is the latter, these documents contain lengths that have been field measured by others.

Petition length is a length that appears on petition documents whose purpose is to add roads to the state system. As noted above *petition length* is usually obtained using DMI.

Projected length (H) is the 2-D length of a 3-D line that is projected down onto a flat surface as would be the case in a paper or GIS map. The roadway alignment that is stored in the GIS or on the map is a projected 2-D alignment. This means that the planar alignment of the roads is accurate (based on a photo revision of all state maintained roads) but the third dimension (elevation - V) is projected to the earth's surface. The length of the resulting projected road (that obtained directly from the GIS linework) is referred to as projected 2-D length. This value is used in conjunction with *elevations* (V) to obtain a *calculated 3-D length* (S).

$$S^2 = H^2 + V^2$$

This calculation results in a highly accurate 3-D road centerline distance referred to as the *calculated length* (S). By being able to perform this calculation the NCDOT can eliminate the need to drive along North Carolina roads using DMI to measure mileages.

Any *calculated length* (S) should be equal to the *petition length* which is a 3-D slope road centerline length that has been field measured using DMI and thus is a *Measured length*. That is, the calculated S that is believed to be the true length of a road centerline should equal the length we measure it to be within a reasonable tolerance.

Data Quality

To calculate an accurate S using H and V both H and V must themselves be accurate. The standard for S is *measured length*. The standard for accurate is if the *calculated length* is within 0.01 mile of the *measured length*.

Since a calculated S can be compared to measured length it is easy to compare them and determine accuracy. Because the majority of all projected 2-D roads in the GIS have been photo revised the projected 2-D alignment of the roads should, for the most part, be quite good. Thus, H is as accurate as it possibly can be at the present time without a significant additional statewide study of roadway alignment. This leaves only the question of how accurate V is, the LIDAR obtained elevation.

Numerous studies were undertaken to validate the LIDAR elevations for this application. These are reported in the following sections. Furthermore, the attachments to this report provide backup documentation for some of these studies.

Elevation Data

The elevation data used by the GIS Unit has been derived from LIDAR data. The LIDAR data was obtained by the Flood Plain Mapping Project conducted by FEMA. FEMA has been collecting LIDAR data since the year 2000. Because the floodplain mapping project is nearly complete the majority of NC counties have been mapped using LIDAR and their data is available for the determination of LIDAR elevations. The result of the FEMA mapping project is a set of data referred to as a point cloud. That is, the data set consists of numerous points whose 3-D location is specified.

The point cloud is cleaned through a number of quality control procedures and is converted by the GIS Unit to a Digital Elevation Model. The result is a 20 meter LIDAR data DEM. For counties in which LIDAR mapping has not been completed, 30 meter USGS DEM data, rather than LIDAR, is used. For the DEM's, each 20 or 30 meter LIDAR grid cell represents a single elevation. That is, a single elevation is assigned to the entire cell.

Mileage Verification Tests

Attached to this report are two papers that present the results of studies comparing DEM data and DMI (*measured length*) data. These results show that the DEM data, when used to calculate 3-D mileages, compares favorably to the measured DMI data.

On the basis of these studies and their results an additional study was made to compare LIDAR data to DMI data. But instead of using a LIDAR DEM the study went directly to the original LIDAR point cloud data as a data source. In doing so it was possible to identify data points lying directly on the road surface. Using these points road surface *elevations* (V) were obtained and *calculated 3-D mileages* were determined. Again, when compared to DMI data (*measured length*), the results were very good with small differences as reported below.

On the basis of the accuracy results of these tests it was recommended that *calculated 3-D mileages* be stored with the GIS lines and in the DCS LRS database.

New Tests

In April 2006 a new test was proposed for Madison County. The purpose of this test was to compare the *calculated 3-D mileage* of state maintained roads in all of Madison County with a *projected 2-D mileage* obtained from the GIS. The goal of this proposed study was to determine how similar or different the *projected 2-D* and *calculated 3-D mileages* actually are.

The proposed Madison County test was not conducted. Instead, a statewide test was conducted. The test utilized a LIDAR point cloud obtained from the USGS NC Floodplain Mapping Project. As noted earlier, GIS Unit personnel converted the point cloud to a 20 meter square LIDAR DEM. Thus, this study did not identify points lying directly on the road surface. Rather it used the elevations of the grid cells in its calculations. This is a very different approach than that used in the previous studies.

The findings of the statewide test are that over the entire state maintained road system of 78,844 *projected 2-D miles* from the GIS linework the additional difference between *projected 2-D* and *calculated 3-D* was 4 miles for Interstates (in each direction) and 107 miles for all state maintained roads. These "extra" mileages are added to the state system mileage of record which is presently a mix of *projected 2-D* and *measured 3-D mileages*. When this is done for interstates there is nearly an exact match between the *calculated 3-D mileage* for interstates and the *projected 2-D length*.

Total *Projected 2-D*	Total *Calculated 3-D*	Mileage Difference	% Difference
78,844 (All with Interstates)	78,951	107	0.14
1079 Interstate only	1083	4	0.37

One additional comparison was made. All interstate highways in NC have been physically measured using DMI. The difference between *calculated 3-D mileages* and DMI *measured mileages* (this is largely what is in the Universe file along with some *petition* and construction plan *mileages* but these too are *measured mileages*) over the entire NC interstate system was found to be 0.25 miles each way. This is, for all NCDOT uses and applications, considered to be a negligible difference.

Map Line Length

In the late 1990's the Mapping Section of the GIS Unit undertook a project to photo revise all the state roadway CAD map lines (projected 2-D lines). These map lines (on paper or a computer monitor) represent roads. One attribute of these lines is their length given in units of miles. The photo revision project took about 2 years to complete. When the project was finished all roads were then correctly aligned with only a few alignment problems remaining. Foremost among these was the problem of identifying the precise end of dead end roads. Since the photo revision project has been completed, numerous methods have been suggested for solving the dead end road problem and satisfactory solutions have been adopted by the unit. But aside from this special case, the actual 2-D alignment of the many remaining roads was considered to be accurate. This project provided accurate roadway alignments and *projected 2-D mileages* and was the catalyst for obtaining *calculated 3-D mileages* once LIDAR data emerged and became available.

Existing Road Length

Since the photo revision project was completed new lines have been added to the state highway network and thus, to the linework representing that network. Originally, about 78,344 *projected 2-D miles* of road were photo revised. Approximately 500 miles of linework have since been added to bring the state's 2005 total *projected 2-D* and *measured 3-D mileage* to 78,844 miles. Thus, by far, the majority of the state's highways were correctly aligned in the original photo revision. However, because of the added miles and because of other changes it is estimated that in reality about 90% of the state's roads have been correctly photo revised and were accurately aligned at the end of 2005.

A unique situation arises for the 500 newly added miles in that they were added by using both 3-D lengths from petitions and 2-D lengths from construction plans. Thus, the state's roadway network presently consists of both *projected 2-D*, *petition 3-D lengths* and some small mix of other mileages. This is a problem because not all roads are represented in the same way.

It was not possible to readily identify these newly added or modified roads and rectify this situation so that absolutely all roads can be assured to be projected 2-D lines. However, given that there are so few roads that are not correctly represented (about 10%) there really is no need to further address the situation. It's impact on the overall state road mileage is negligible as was shown above. At the present time (2006) all mileages for all roads are *calculated 3-D mileages.*

Mileage History

Type	Mileage	Time	Source
Interstate	1083	Pre 1998	Measured 3-D
All other S.M.	77,761	Pre 1998	Projected 2-D
New	500	1992-2005	Petition 3-D

Business Process for Storing New Lengths in the Database

All existing map lines are currently viewed as *projected 2-D* lines. All future lines will be added as *projected 2-D* lines as well. This will be done using a tool that enables the technician to take either a *measured 3-D length* or a *petition 3-D length* and draw it as a *projected 2-D length.* In doing so all lines are then consistently stored as *projected 2-D* lines. Thus, when the *calculated 3-D lengths* are determined these should match the original *petition* or *measured 3-D lengths.* In this manner complete consistency is ensured.

Lengths are currently stored in three places. These are in the link node database, in the GIS, and in the LRS database. Over time the link node database will no longer be used. At that time lengths will be stored in only two places. An important question is what length must be stored in these locations?

Since January of 2004 the mileages entered for all new roads have been obtained from either petitions or construction plans. From this time on, for all state maintained roads, the *calculated 3-D mileage* is to be stored in the database. This will be done for the entire 78,844 miles of state maintained roads. Using calculated mileages has been an objective of the GIS Unit early in the LRS project. This objective has now been met. All of the previously documented advantages of doing so will now accrue to the Unit.

Future Mileage

Type	Mileage	Time	Source
Interstate	1083	2005-P	Calculated 3-D
All other S.M.	77,761	2005-P	Calculated 3-D
New	500	2005-P	Calculated 3-D

The net result is that highly accurate 3-D mileages will be stored in the GIS and in the database for all roads. These will be *calculated mileages*. It is these *calculated 3-D mileages* that will be used to calculate 3-D mileposts. It is the 3-D milepost that will be made available to external customers. It is appropriate to provide these 3-D mileposts, as these are the mileages that most accurately reflect field conditions. Thus, the roadway network is being modeled as accurately as possible with the present technology. It also should also be noted that the lengths that have been stored in the universe file will no longer be used.

Conclusions

The majority of the members of the committee believe that the difference between *projected 2-D mileages* and *calculated 3-D mileages* (based on LIDAR data) is small enough to ignore in eastern NC and in parts of the piedmont. However, for both consistency and accuracy, it was decided that *calculated 3-D mileage* should be maintained in the GIS. The attachments to this report, particularly the first, provide support for these conclusions.

The results of both previous and new tests indicate that *calculated 3-D mileages* are highly accurate when compared with *measured length*. Furthermore, it was found that *projected 2-D length* did not differ all that much from either *calculated* or *measured 3-D lengths*. This reflects on the fact that the majority of the roads in NC lie in relatively flat areas as evidenced by their flat to gentle slopes. Thus, few issues might arise except in western NC when these mileages are subject to further review.

Also in conclusion the committee observes that any number of mileages could be stored in the database as attributes. In particular, both *projected 2-D* and *calculated 3-D mileages* could be stored in the database and on the linework. However, for simplicity and clarity only calculated 3-D lengths will be stored in the present database.

The GIS Unit must adopt operating procedures for establishing and communicating the validity and accuracy of this data.

Recommendations

The committee recommends that *calculated 3-D mileages* be stored in both the GIS and the DCS database at the present time and to meet the near term NCDOT needs. The committee also recommends that as 3-D GIS modeling tools become more readily available, that the NCDOT highway network should be modeled in 3-D. Only *calculated 3-D mileages* are to be stored in the database. Projected 2-D lines are to be stored in the GIS as is currently done. These must be photo revised or photo edited to ensure their planar accuracy. A GIS transition from projected 2-D to 3-D will not be made at this time. Instead, the *calculated 3-D length* will be generated and stored in both the GIS and the database. All mile posting is to be obtained from *calculated 3-D mileages* as GIS shape files in real time or via hard copy in batch mode.