North Carolina Department of Transportation
Geographic Information Systems (GIS) Unit

NCDOT Highway Milemarker Inventory and Integration with the Linear Referencing System (LRS)

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Abstract:

The NCDOT GIS Unit was approached by the NCDOT Pavement Management Unit (PMU) to assist in the creation of a statewide highway milemarker inventory. The highway milemarkers presented a prevalent and consistent set of features for use as highway reference points, which could be used to help PMU track pavement deficiencies. The NCDOT GIS Unit soon realized that the milemarkers could be incorporated in the coordinate linear referencing method, already supported in the NCDOT LRS. Following equipment testing and training with the GIS unit, PMU performed all field data collection with mapping grade differential GPS. As data was processed, PMU employed milepoint reference values of highway milemarkers in the LRS to help track pavement condition across some of North Carolina's most vital roadways.

This article outlines the GPS method testing, training, data collection, data processing, and finally potential applications of these data within NCDOT.

Introduction:

The highway milemarker inventory effort was begun in early 2006 as a joint effort between the NCDOT Pavement Management unit and the NCDOT Geographic Information Systems unit. The Pavement Management unit was interested in capturing the location of all highway milemarkers for use as reference points along the state maintained transportation network. These new reference points would provide a new method for locating features along the network without investment in new equipment or drastic changes to inventory methods.

The NCDOT Linear Referencing System provides a centrally maintained transportation network upon which event data from multiple sources can be related. Customers may 'hang' their event data on the network by compiling data in one of the four supported linear referencing methods or LRM. These linear referencing methods include Route and Milepost, FTseg and Offset, Coordinate Route, and Intersection and Offset. Of these methods, all of them could be used for data capture by the Pavement Management unit. However limitations were notice with each method when compared to the typical field operations of the PMU, especially with respect to interstates.

Controlled access and high volume traffic flow make inventorying any features on a divided highway dangerous to say the least. As an example consider a 0.5 mile section of pavement deficiency whose location along the route was to be recorded by field staff. We'll take a look at how data would be compiled through each of the four Linear Referencing Methods.

Route and Milepost: The field staff would have to start at the beginning of the route and measure the beginning and ending distance of said pavement deficiency. If a short route is in question, there is little problem. But what if the feature occurs around milepost 30 of a 40-mile long route. Considerable driving time would be wasted in recording the location of that feature as the from/to measures would be based on the entire length of the route.

FTseg and Offset: Defined by intersections and county boundaries a FTseg is the basic building block of any route within the LRS. As opposed to Route and Milepost, the entire route does not have to be measured to capture the location of an event. Only a measurement from the nearest intersection was needed. The concern with this is field staff are not aware of the FTseg identifier number when traversing a route. The FTseg is an internal database identifier and the only way to know the correct FTseg ID was for field staff to bring digital maps to the field to help with identification. Given the requirement for expensive devices like mobile GIS receivers, PMU could not pursue the FTseg and Offset LRM.

Coordinate Route: Allows the use of explicit coordinates and the route information to locate features along the routes. This method is also as costly as FTseg and Offset for the same reasons. PMU could not afford mapping grade GPS receivers and the supporting infrastructure to apply this LRM.

Intersection and Offset: This method has similar drawbacks as the FTseg and Offset, and Route and Milepost methods. Time spent in orienting the measurements to intersections can be costly. Sometimes Interstate intersections can be several miles apart or access control issues may limit travel direction also decreasing the efficiency of data capture.

Upon consideration of the four linear referencing methods we realized using highway milemarkers as reference points would allow efficient and low cost data capture by PMU field staff. Equipment already owned by PMU could be used to reference distances by PMU field staff, more specifically a Distance Measuring Instrument or DMI. The only concern was that the GIS unit did not posses a comprehensive set of milemarker features, thus the data collection initiative was conceived.

The next question was how were the milemarker locations to be collected? The milemarkers were not visible in aerial photography and that ruled out any possibility of heads up digitization. Investigation with other NCDOT entities did not reveal any other milemarker inventories either. Using GPS was clearly the best way to collect the locations of the highway milemarkers. The GIS unit already possessed a mapping grade GPS and the staff was available to manage the data collection effort. PMU offered field staff to be trained by the GIS unit and to collect the milemarker locations. From this point, the two groups began to work together to find as efficient solution for GPS location of the highway milemarkers.

Data Collection Methods- Testing and Implementation:

At the outset of the project there was no clearly defined protocol for collecting the GPS location of such a massive number of signs. Consideration would have to be given to the safety of the field staff as well as their efficiency in collection. The first method tested was to employ an integrated laser rangefinder with the GPS. Some preliminary tests were set up to test the function and accuracy of the laser.

To test the laser under simulated field conditions some adjustment had to be made in how the laser was employed. A typical setup for this type of GPS location is to mount the laser directly below the GPS antenna. Thus, the ranged distances originate from the phase center of the antenna. An apparatus is supplied with the laser rangefinder that allows both the laser and GPS antenna to be mounted to a range pole. When setup properly, this design looks similar to a shepherd’s staff.

To GPS features with the ‘proper’ laser setup, the field staff was going to have to be outside the vehicle. Given the number of features to be located and their orientation along the highways it was decided another approach would be used in the laser/GPS setup. We mounted the GPS antenna to the top of the vehicle just above the passenger seat. Doing so would allow the data collector to range targets with the laser while remaining in the vehicle for safety purposes. The small amount of error induced into the location by misaligning the laser from the antenna was going to have to be accepted by all involved parties.

The first test was very simply to see if we could range some targets with the laser and see if corrected points were appropriately plotted on aerial photography. The test involved the location of four targets with the laser/GPS. A DOT facility that appeared clearly on aerial photography was chosen for the test.

A control group of four points at each corner of the building were GPS located without the laser. These points would server as a baseline for comparison with the laser GPS results. Twelve positions were recorded at each of the test targets. Then they were differentially corrected and the result averaged to represent the target feature. These four test points were then exported to shapefile format. When plotted over aerial photography each point was visibly located on the target. Confident that our GPS was working correctly we moved forward with laser testing.

Each corner of the building was then located using the laser rangefinder and GPS. This test was performed from within a vehicle to simulate field conditions as described above. The location of each target was recorded between two and four times. The data were then differentially corrected and plotted along side the control points. The distance between each target and its laser result were compared. (See Table A)

Table A:

Control Point	Laser Point 1	Laser Point 2	Laser Point 3	Laser Point 4	Average Distance
1	189	156	171	213	**182**
2	13	25	-	-	**19**
3	147	160	163	-	**157**
4	4	65	-	-	**35**
				Total Average:	**98**

Based on the results shown in Table A, it was decided that the laser technique was only somewhat promising, providing good results with two control points and poor results with the other two control points. Possible explanations of the error included poor GPS constellation geometry and/or strong electromagnetic interference produced by powerlines and other ambient ferrous materials near the test site.

Given the inconclusive results of the first test a second test was designed to test an actual field implementation of the laser technique. An interstate near our office was chosen as a test site. Our test plan involved collecting the GPS location of several consecutive milemarkers from within the vehicle. All GPS and laser settings were maintained from the first test.

In performing the second test of the laser technique some interesting issues were discovered. We found that it was somewhat difficult to actually range a target from inside the vehicle. Since each point would be ranged from within the vehicle, we sometimes found it difficult to actually range the correct target. The most prevalent issue was ‘overshooting’ the narrow milemarker sign and ranging another object some distance behind the sign. Although this was to be expected, we realized that there could be many laser points taken for the same sign which may cause undue confusion in later processing of the field data.

Another concern that presented itself during this test was the relative accuracy of the laser in capturing an accurate bearing to the target. We noticed considerable misplacement of test points when plotted over aerial photography. Our expectation at the time was that sometimes a passing vehicle or ambient ferrous metals would disrupt the function of the lasers internal magnetic compass. Upon review of the second tests results we decided to abandon the laser technique and focus on a more traditional GPS method.

A basic requirement of keeping field staff within the vehicle had been agreed upon by both the PMU and GIS units prior to the laser tests. At first glance the laser technique could have helped us meet this objective. However the overall accuracy affected by the consistency of the equipment's operation led us to the final GPS data collection method.

The agreed upon method involved mounting the GPS antenna to the top of the vehicle and consistently aligning the vehicle with the milemarker signpost as the GPS location was recorded. To obtain consistent results the antenna was mounted directly above the passenger seat and when a milemarker was encountered the window frame of the vehicle was aligned with the signpost. Performing the location in this manner would allow the GPS location to be recorded at a point along an imaginary line that extended perpendicularly from the centerline of the roadway through the milemarker signpost. Of course each point would not represent the actual location of the milemarker signpost, only the relative location of the signpost along its respective route. The lateral offset distance was of no concern so long as the GPS point was between the centerline of the road and the milemarker signpost. Typically, point locations were recorded within 10 feet of the sign with the vehicle parked along the shoulder.

Following the testing phase the training phase was initiated. The PMU field personnel were taught how to implement the GPS data collection method from the vehicle. Each unique county, route, and direction would be recorded in a separate file. E.g. Mecklenburg county I-85 would consist of two files: one representing the northbound segment and one representing the southbound segment. In the event that a unique route segment could not be captured in only one file, the data would be merged through ad hoc processing following differential correction of the two related files.

A data dictionary was designed to supplement the GPS location information. These attribute fields were designed to mesh with existing data fields of the LRS. See the bullet points below for a description of the data dictionary by data field and their components:

RTE: A five-digit route number describing the route classification and number.
Ex.) I-40 = 10040 or US 70 = 20070 or NC 50 = 30050

PRTE_TYP_NM: Represents the primary route type name
Ex.) Normal, Business, Alternate…etc…

SUBRTE_DRCTN_NM: represents the direction of travel/inventory.
Ex.) Northbound, Southbound, Innerloop, Outerloop etc…

FTR_TYP_NM: Represents sign type, Either countyline marker or highway milemarker

FTR_ID: Represents the mile number printed on the signpost.

Offset: Represents the linear offset distance in feet. (+) Means ahead of sign along direction of inventory. (-) Means before sign along direction of inventory.

Data Correction Effort:

Once the field staff was underway with data collection, the GIS units' involvement shifted from a training and design role to a supporting role. Each week data were returned from the field, a data transfer would be performed between the GIS office and PMU field staff. Notes per each data file were transmitted to the GIS unit at the same time, and the data correction effort would begin.

Data were differentially corrected on a per rover file basis. Doing so allowed the technician to choose the best base station for correction. Differential correction was performed using the base station closest to the data collection site. In most cases a base station within 20 miles of the respective route would be chosen. In some cases not all features could be differentially corrected.

If a majority of the features for a particular rover file could not be corrected another base station within 50 miles was chosen for correction. In the event a small number of the points could not be corrected, these data were maintained with their autonomous GPS locations because it was better to have a poorly placed point than none at all.

As part of the data correction effort, position averaging was employed for each milemarker. Twelve positions were recorded per milemarker and then averaged to create an explicit coordinate for each sign. Each position was recorded at five-second intervals that resulted in a target occupation of approximately one-minute. During this time, the field staff was able to remain inside the vehicle and record pertinent attribute data for the milemarker.

Following the differential correction phase, an export to ESRI shapefile format was performed. The exported shapefile includes all user entered data fields from the data dictionary. In addition to the data dictionary fields, a number of GPS related attribute fields are also exported. These may assist in answering any questions concerning accuracy in the future.

At this point the GPS data had been QC checked and prepared for visualization in ArcMap. The next step was to relate the point features to their respective routes. This step is performed using Linear Referencing tools from the ArcGIS ArcToolbox and in conjunction with a custom model prepared by the GIS unit staff. Following is a brief step by step explanation of how the milemarker data were related to the linear route coverage files. These route data are created annually as a snapshot of the state maintained highway system and contain milepost measures for use in dynamic segmentation applications.

For each set of unique county, route, and direction milemarkers an explicit matching route feature was selected and saved as shapefile. The ArcToolbox linear referencing tool: Locate Features Along Route is employed to create a milepost value for each milemarker. Since this operation is based on a countywide granularity, the milepost for each milemarker represents the distance along the route from the beginning of its respective digital route. The output of this operation is a database table.

The database table was defined as the deliverable for the PMU group however the data still needed to be corrected for linear offsets recorded by the field staff. Field staff recorded these offsets when the GPS was unable to capture positions. This issue is due primarily to obstruction of the GPS satellite signals. To assure that as many milemarker locations as possible were captured; a DMI was employed to measure the linear distance traveled ahead or behind the milemarker signpost. When the GPS obtained a quality signal again, the linear distance traveled along the route was recorded and the GPS location recorded with the device. Since the recorded GPS location of these offsets did not represent the actual location of the signpost the linear measurements were converted to miles and the milepost values were adjusted accordingly in the output database table. The model performs this calculation on the fly.

Once the offset data are corrected the database tables per county, route and direction was saved as the PMU deliverable. However the model continues processing of the data tables to recreate an updated shapefile of the milemarker features. The ArcToolbox linear referencing tool: Make Route Event layer was used. A temporary layer is created then exported as a new shapefile. The result is offset corrected point type shapefiles of the milemarkers. Finally the individual shapefiles are merged into a statewide file based on route classification.

Integration with the NCDOT Linear Referencing System:

In performing the processing steps detailed above, the milemarker data has been partially prepared for integration with the network. The final step in this processing is to relate the corrected milemarker point features to the linear datum using a spatial join. Point data will be matched to their respective FTseg, and mileposts along FTseg calculated. These two data items, FTseg and milepost along FTseg are critical to the inclusion of the milemarker data to the LRS.

This effort is still in the QC stage. Approximately 95% or more of the interstate milemarker points are ready for integration with the LRS. As issues among the core components of the LRS are rectified, this percentage should reach 100% within the next year. The completed interstate milemarker file has also had impact beyond the LRS. Several customers have been provided the spatial representation of the interstate milemarkers. These customers include North Carolina Division of Emergency Management, NCDOT Highway Stormwater Program, various local governments, and the Federal Highway Administration.

Project Status and Conclusion:

At the time of this writing, all of the interstate milemarkers in North Carolina have been inventoried, differentially corrected and processed to create the PMU deliverable. US and NC highways data collection is well underway with over 50% of the US routes inventoried. These data are in the correction phase of the cycle and should be completed by fall of 2007.

When this project is completed, there is a potential for the data to be applied as a new Linear Referencing Method in the LRS. At minimum, the project stands as proof of concept for integration of GPS point data with the LRS.

References:

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