Integrating Applications and Databases with NCDOT Linear Referencing System

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Abstract

The NCDOT Linear Referencing System (LRS) released in the August of 2006 provides a framework to integrate fragmented applications and databases. It consists of a collection of databases and application systems, serving as a central repository of the North Carolina state-maintained transportation network with topology and geometry. Integration with the LRS will enable easier manual and automated solutions for referencing a wide variety of roadway attributes to the transportation network. These solutions would update or refresh the location reference information in departmental database systems and therefore greatly improve the data quality, data consistency, and lower the maintenance costs.

This article will discuss the Location Referencing Methods supported by NCDOT LRS version 1.0 and derive integration options. A few case studies will also be presented.

Background

The route number and milepost information has been maintained in many separate applications and database systems throughout NCDOT. These databases reference a wide variety of information to the State maintained road system. Route system changes occur regularly, including route number renaming and milepost value adjustments. These changes must be propagated to the various databases. However, there was no consistent or automated mechanism for updating or publishing the changes. As a result, information in these databases may not consistent with each other. For example, the same route number and milepost locations may contain conflicting information.

This issue can be resolved by properly integrating these applications and databases with the recently released NCDOT LRS [1] [2]. The approach of integration for each application system can be different based on its primary linear referencing method and requirements. In-depth understanding of each linear referencing method, related conventions and implications becomes critical for the planning and development of each integration solution.

Introduction to NCDOT LRS and Related Standards

The NCDOT LRS consists of a collection of databases and application systems (Figure 1), serving as a central repository of the North Carolina state-maintained transportation network with topology and geometry. It is maintained and made available by the GIS Unit. The first release (LRS 1.0) has a front end for data entry, combining two applications. The ArcGIS Data Maintenance (ADM) tool set [3] allows maintenance and visualization of the line work in Geodatabase format. The LRS Access and Reporting System (LARS) [4], on the other hand, enables data entry and reporting, in tabular format, of the Linear Datum, network change history and the state maintained route number system.

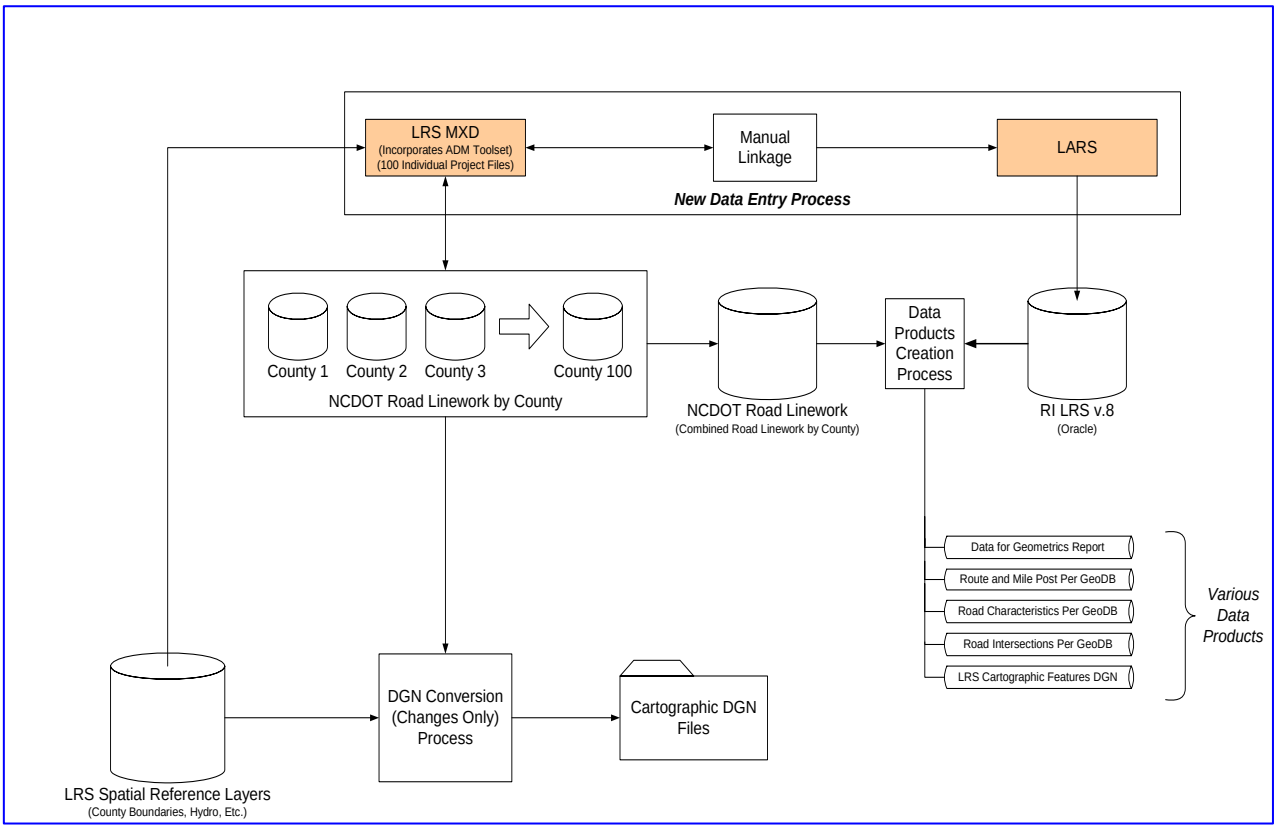

Figure 1: The NCDOT LRS consists of a collection of databases and application systems, serving as a central repository of the North Carolina state-maintained transportation network.

The design and implementation of the LRS 1.0 are subject to a set of comprehensive requirement [1]. To meet the technical challenges of building an enterprise LRS and support NCDOT specific operational needs, we utilized much of the result from the NCHRP 20-27(2) (National Cooperative Highway Research Program [5]). We also adopted the naming convention and some of the concepts from the proposed Framework Transportation Identification Standards [6] when this proposed standard was under public review.

The first few years of the twenty-first century are full of opportunities and overlapped efforts in the field of GIS-T [7]. The three national geospatial initiatives, the Federal Geographic Data Committee (FGDC), Geospatial One-Stop (GOS), and The National Map, combined with other standard bodies and efforts such as ANSI (American National Standard Institution), National ITS Architecture and the implementation of the National Spatial Data Infrastructure (NSDI), presented confusion to the geospatial community. Inevitably, the geospatial community has undergone a serious of efforts to redefine the program boundaries, realign activities and to harmonize standards. Below is a brief list of the development history of the Framework Transportation Identification Standards,

August 1994:	Milwaukee Wisconsin Workshop on a Generic Data Model for Linear Referencing Systems (NCHRP 20-27), re-iterates the concept of linear datum.
October 1994:	FGDC Ground Transportation subcommittee Position on LRS stated “Any transportation network databases developed as part of the National Spatial Data Infrastructure (NSDI) framework include and populate, as part of their core data all key LRS attribute fields”
October 1997:	GIS-T Enterprise Data Model with Implementation Choices by Kenneth J. Dueker and J. Allison (Al) Butler, provided an example to implement LRS with Entity Relational Data Model [8]
December 2000:	Ground Transportation Subcommittee, FGDC published the Framework Transportation Identification Standards for public review, formulated the concepts of Framework Transportation Segment (FTSeg) and Framework Transportation Reference Point (FTRP) [7]
2000-2001:	Transportation Data is identified as one of the seven Framework Core Themes. The development of the Framework Transportation Identification Standards is superseded by the development of Geographic Information Data Content Standards by the Geospatial One-Stop. It was re-stated that the “Permanent feature Ids facilitate relation of external information to the data” for the Framework Core Data Themes.
May 2001:	Environment Research Institute System (ESRI) UNITRANS Data Model [9].
August 2002:	INCITS (InterNational Committee for Information Technology Standards) Technical Committee L1 Takes Lead on GIS Framework Standards [10].
December 2003:	The responsibility for further development of Framework Data Standard transferred from Geospatial One-Stop back to FGDC [7].
April 2006:	INCITS L1 Ballot on Framework Data Standard Closes.

As of writing, the INCITS Secretariat has designated Framework Data Standard as INCITS 436 for ANSI Board of Standards Review (BSR) and submitted a notice for ANSI public review, to be published in the March 16, 2007 edition of the ANSI Standards Action bulletin.

To review the making and the content of the new Framework Data Content Standard is out the scope of this article. It is worth pointing out that even though the requirement for unique, permanent identifications is recognized, the standard does not currently define a mechanism for the generation of unique identifiers. The building blocks of the standard are named as TRN_segment (Transportation Segment) and TRN_Point (Tranportation Point) instead of FTSeg and FTRP as proposed in the original ID standard [11] [12].

Location Referencing Methods Supported by LRS 1.0

LRS version 1.0 presently supports the following four linear referencing methods

a. Route and Milepost
b. Intersection and Offset
c. Generation1 (G1) FTseg and Offset
d. Coordinate Route

It should be noted that variations on the basic concepts presented in this article may be implemented by those using the supported referencing methods. The most commonly implemented concepts are presented here.

Route and Milepost

Route and milepost referencing is a common method of specifying and identifying locations within and among DOTs. Figure 2 illustrates an example of the use of milepost referencing to refer to a point X on an example network.

Mileposting is a conceptual measurement system wherein distances are measured from the start of a route within counties. For interstate routes, however, mileposting is measured from the start of the route within the state and the counties. If a route does not cross a state or county boundary the mileposting begins at the point the route starts. Increasing mileage generally occurs in easterly and northerly directions. In the example of Figure 2. the milepost of point X is 1.30 miles on NC 42. In this case the mileposting begins at point A which is on a county boundary.

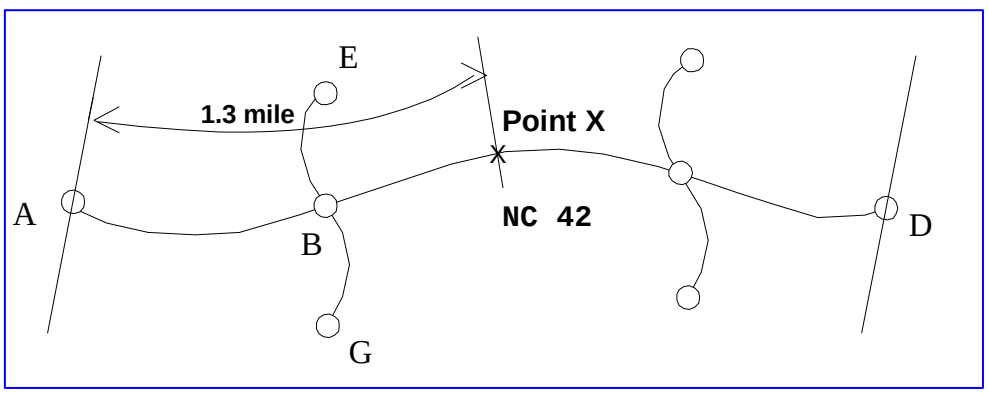

Figure 2: Specifying a point location using milepost referencing.

Generation 1 (G1) FTseg and Offset

G1 FTseg and offset is the primary method of specifying and identifying location in the LRS. The reader is referred to Figure 3 for an example.

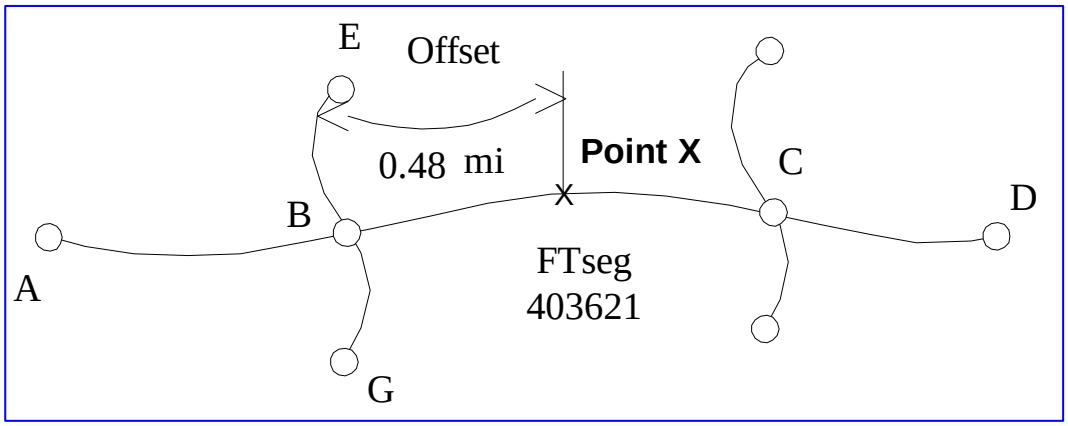

Figure 3: Specifying a point location using FTseg and Offset Distance.

The G1 FTseg and offset method utilizes a segment and node model of the transportation system. Each line between nodes is referred to as a Framework Transportation Segment (or abbreviated as Ftseg [6]). G1 means that the FTseg is an original one that was created when the network itself was initially created or it is a newly added segment that did not previously exist. Each node is referred to as a Framework Transportation Reference Point (FTRP) [6]. Nodes may exist only at state and county boundaries, at intersections, at divided highway junctions and at the ends of roads. Each node and each segment are given permanent unique identifiers. Our approach to the generation of unique identifiers is similar to the Globally Unique, Meaningless Identifiers proposed by the Framework Data Standard [11]. This approach is not very user-friendly at the data tier. On the other hand, the route feature information presented to the end user at the application tier can be improved by using the meaningful route names and street names.

To precisely specify a point location using the FTseg and offset method, one must specify three items:

FTseg ID	403621 (between nodes B and C)
FTRP ID	B
Offset distance	0.48 mi

Note that FTseg and FTsegment are interchangeable terms. The FTseg ID is the identifier of the FTseg on which the point lies. The FTRP ID is an identifier for one of the FTsegment's end nodes. This would be the end node from which the offset is measured. The offset then is the mileage distance from the identified node to the location in question along the FTsegment.

Note that the example shown in Figure 3 is that of locating a point. A segment would be identified similarly using two end points. The segment end points should be measured from the same end node.

Intersection and Offset

Intersection and offset referencing is the primary method of specifying and identifying location in the field. The reader is referred to Figure 4 for an example.

To precisely specify a point location using an intersection one must specify four items:

Route of interest	NC 42 (between nodes A and D)
Intersecting route	NC 39 (between nodes E and G)
Offset distance	0.48 miles
Direction	East

The route of interest is the identifier of the route on which the point lies. The intersecting route is an identifier for the route from which the offset is measured. The offset then is the mileage distance from the intersecting route to the location in question along the route of interest.

Note that the example shown in Figure 4 is that of locating a point. A segment would be identified similarly using two end points. The segment end points may be measured from the same intersection or they may be measured from a different intersection.

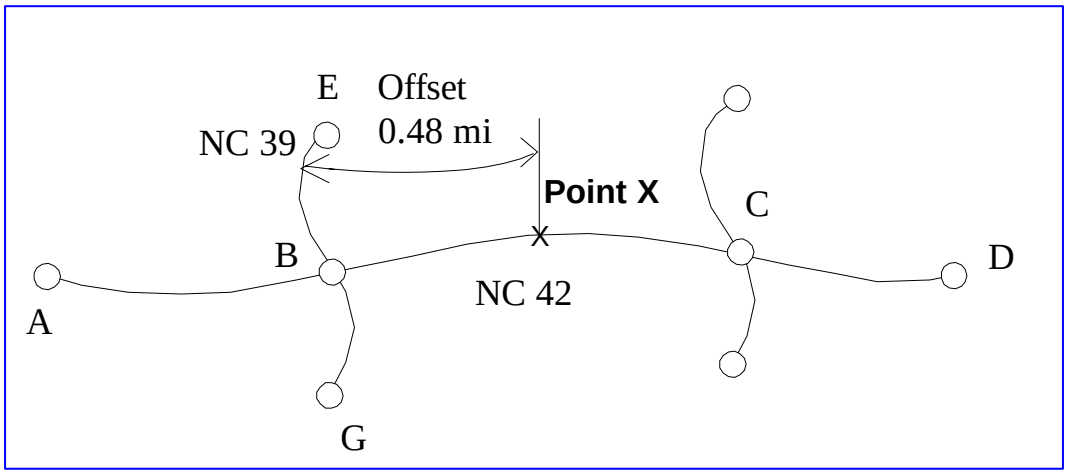

Figure 4: Specifying a point location using an Intersection and Offset.

Coordinate Referencing

Coordinate referencing is an increasingly popular method of specifying and identifying location in the field with more widely adoption to the GPS technology. The reader is referred to Figure 5 for an example.

To precisely specify a point location using coordinates one must specify two items:

North coordinate	35°40’15”

West coordinate 77°25’30”

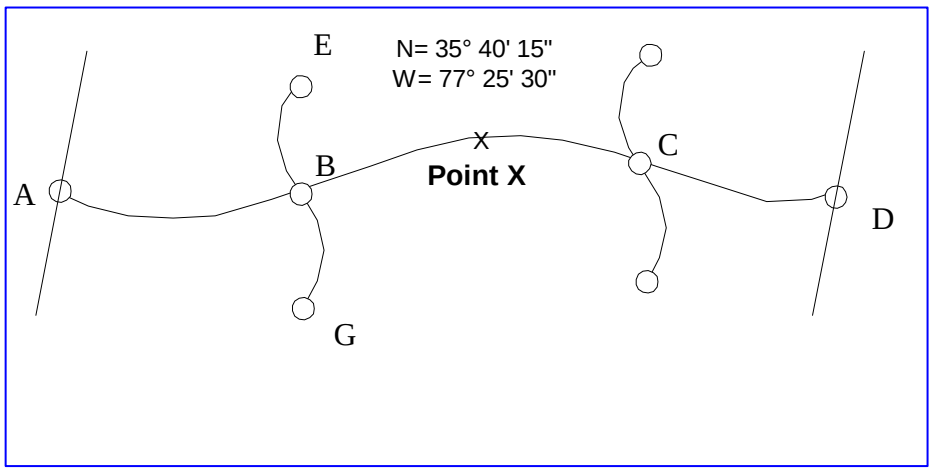

Figure 5: Specifying a point location using coordinates

Behavior of Location Referencing Methods

This section analyzes the behavior of each supported location referencing method. It illustrates what happens when typical operations are applied. In particular, it illustrates how the choice of referencing methods would impact the event data or the information referenced to the LRS. The result of this analysis can help decide what Location Referencing Method to choose while plan for the integration of a database or application.

1. Route and Milepost Referencing Method

1.1 Impact of Adding Segments

Consider an attribute that is referenced by the milepost referencing method. The following table is used to illustrate a proposed change to a route

Feature	*Route*	*Milepost*
Crash 100	ABCD	3.00 mile
Crash 101	ABCD	0.00 mile

Table 1: Two events by milepost referencing method

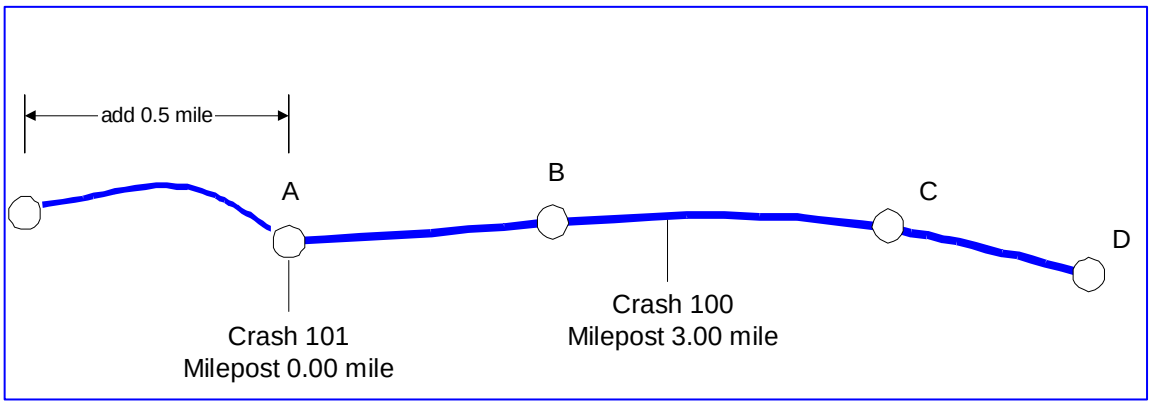

Figure 6: Add a half mile long segment at the beginning of a route.

Suppose we add a half mile long segment at the beginning of the route. The milepost values for the two events need to be changed. The reason is that milepost referencing for attributes or events is dependent on the lengths of all the preceding and self-inclusive segments on the route.

1.2 Impact of Re-calibration of Segments

Re-calibration refers to changing the geometry of the network through changing the FTseg length. This change is made when a more accurate value (from a petition or field measured) than the current one is available. This operation is called re-calibration of FTseg.

In the same situation as in Table 1, suppose we recalibrate the length of FTseg AC from 5.20 to 5.30 miles or from 5.20 to 5.10 miles. In either case, the above event record for Crash 100 would need to be changed. On the other hand, the above event record for Crash 101 would not need to be changed.

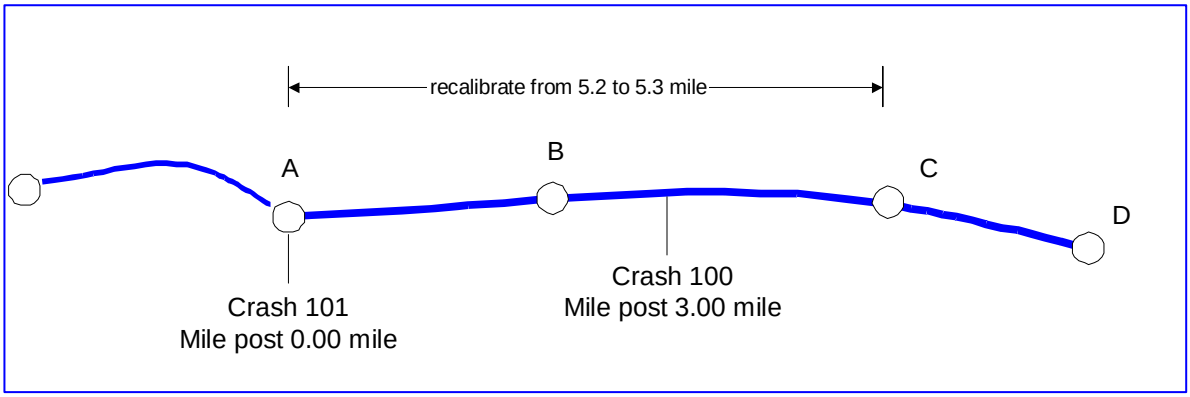

Figure 7: Re-calibrate FTseg AC from 5.20 to 5.30 miles.

For the same reason, if we apply any of the changes, such as remove a segment or rename part of a route, event location reference to all associated attributes need to be changed. In addition, there is no simple rule for doing so that is universal to all event data. The fluctuation of the milepost values makes it difficult to maintain any event data sets using route milepost as a fundamental referencing method unless milepost values for the events are constantly updated. In other words, changes to the event data have to be coded or programmed based on the requirements.

This makes the milepost referencing method acceptable only for decision support or data warehouse types of relatively static systems, such as NCDOT PMS-GIS Interface [13]. For an online transactional system, because event location references must be synchronized with road network changes in near real-time, a messaging system should be used in application integration. To implement the milepost referencing method, however, adds cost and complexity to both software and the databases of LRS. Instead of using it, integration with the LRS affords a unit with an opportunity to use a more stable identification of a transportation feature (G1 FTseg id) for event or attribute references.

To support applications that use the milepost referencing method, we need to publish the NCDOT road network represented by routes as LRS data products (Figure 1). To display and analyze any other event or attributes would require a dynamic segmentation of the event table with the network feature class. Before creating a feature event with ESRI GIS Desktop product ArcMap we must ensure that the event data set is updated or synchronized with the network feature class.

As a result, the conventional milepost referencing method works properly only for the data sets that have a defined interface with the LRS – either a database interface like PMS or an application interface such as the Road Inventory Module. The milepost referencing method is simply not recommended for any offline systems.

1.3 Time Stamped Milepost Referencing

Suppose an attribute is referenced by milepost referencing method as shown in the following table.

Feature	*Route*	*Milepost*	*Date*
Crash 100	ABCD	3.00 mile	09/05/2004
Crash 101	ABCD	0.00 mile	03/21/2005

Table 2: Two events by time-stamped milepost referencing method

Theoretically, the event milepost references as shown in Table 2 can be transformed to G1 FTseg referencing or to the milepost referencing for the time of transformation. This method can be used on the condition that the LRM conversion tools that are able to handle temporal data are defined and developed.

2. Generation1 (G1) FTseg and Offset Referencing Method

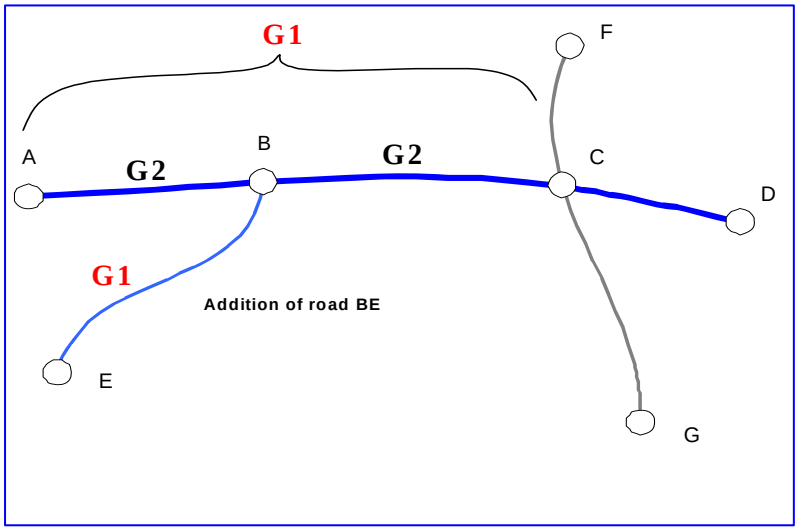

Figure 8: Generation 1 (G1) FTSegs and maintenance of the Linear Datum

As stated in document [1], the Linear Datum is managed through the use of the NCDOT ArcGIS Data Maintenance (ADM) tools. Each segment of the state maintained road network is assigned a Generation 1 (G1) FTseg identifier (id) when it is newly created.

Once added to the Linear Datum, a G1 FTseg will always remain in the LRS as originally defined. Thus, customers can expect significant stability to the network model. As illustrated in the diagram above, the addition of a new system road BE, which intersects with the existing road ABCD, does not split G1 FTseg AC. Instead, a new G1 FTseg BE and two new Generation 2 FTsegs (AB and BC) are added to the Linear Datum. The original AC G1 FTseg remains unchanged. Point B is a new FTRP as defined by the intersection of the roadways.

2.1 Impact of Adding Segments

No change is needed in the customer's data for their events if new segments are added or removed from the route. The following table is used to illustrate this.

Consider an attribute that is referenced by G1 FTseg and Offset method. The following table is used to illustrate a proposed change to a route

Feature	*Point*	*G1 FTseg*	*Distance from Point*
Crash 100	C	CD	0.50 mile
Crash 101	A	AC	1.20 mile

Table 3: Two events by G1 Ftseg and Offset Reference Method

Suppose we add a half mile long segment at the beginning of the route. The above records would not need to be changed. The reason is that (G1) FTseg and Offset referencing for attributes or events is independent of the lengths of segments on the route.

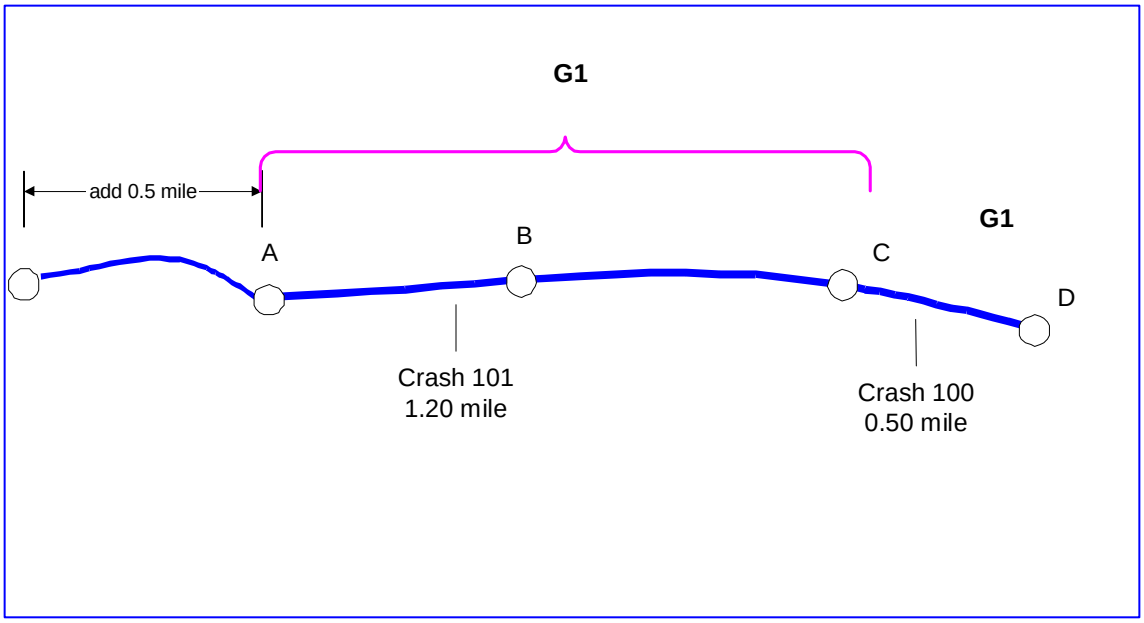

Figure 9: Add a half mile long segment at the beginning of a route.

2.2 Impact of Re-calibration of Segments

If an attribute is referenced to a G1 FTseg with a measured offset that is independent of the FTseg length, no change is needed in the customer's data for their events if there is a change in length of the FTseg. Suppose that the length of FTseg AC is 2.50 miles but that this value is found to be incorrect. If we recalibrate FTseg AC from 2.50 to 2.60 mile, the above crash record as in Table 4 does not need to be changed. Also, if we recalibrate FTseg AC from 2.50 to 2.30 mile, the above crash record does not need to be changed either.

Feature	*Point*	*G1 FTseg*	*Distance from Point*
Crash 100	C	CD	0.50 mile
Crash 101	A	AC	0.70 mile

Table 4: Two events by G1 Ftseg and Offset Reference Method

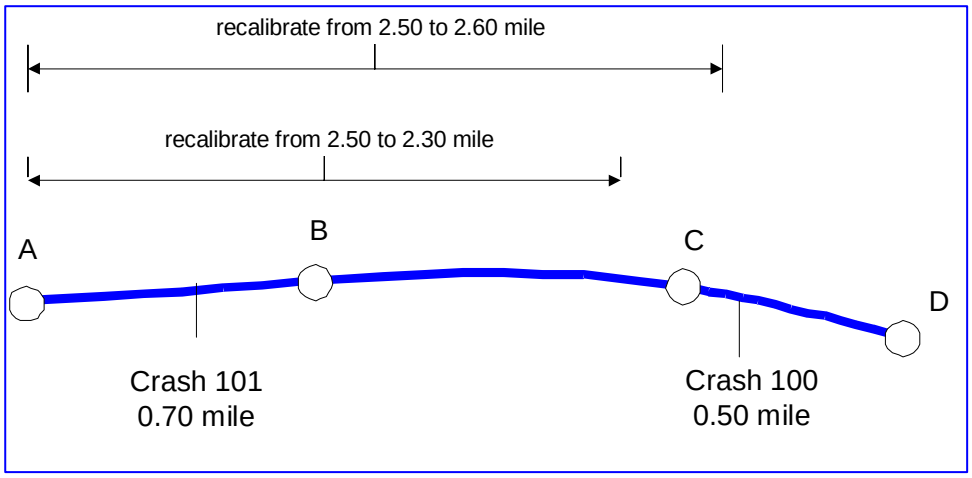

Figure 10: Re-calibrate FTseg AC.

2.3 Impact of Additional Requirements

If an attribute is referenced to a G1 FTseg with a measured offset that is dependent on the FTseg length, changes may be necessary in the data set. The following table is used to illustrate this.

Feature	*Point*	*G1 FTseg*	*Distance from Point*
Stop sign	A	AC	2.49 mile

Table 4: An event by G1 Ftseg and Offset Reference Method

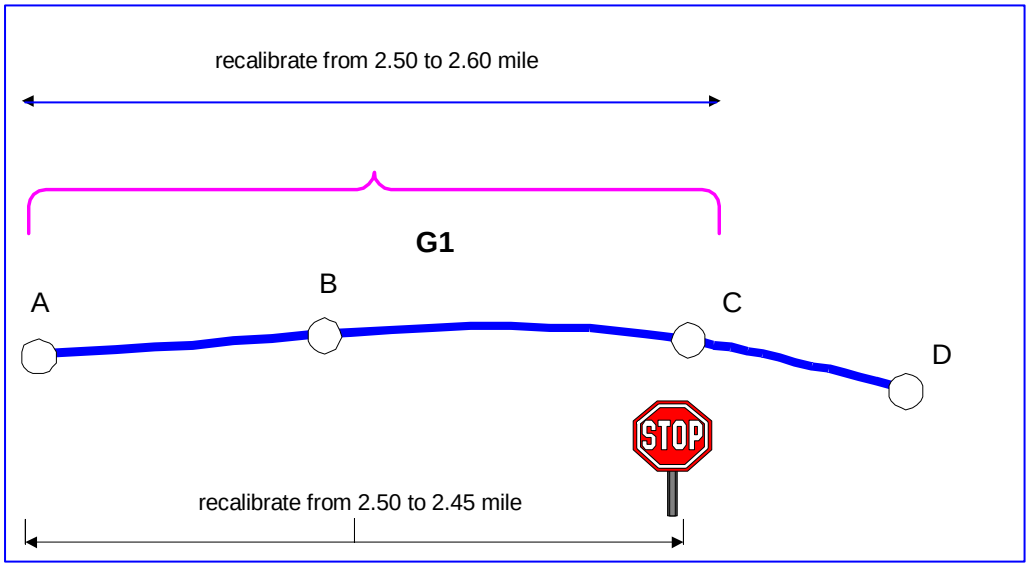

Figure 11: Re-calibration of segment makes the stop sign appear on the wrong side of an intersection.

In case of stop sign location events, we should at least require that the stop signs appear on the correct side of the intersection. Suppose that we recalibrate FTseg AC from 2.50 to 2.60 mile. The above record could possibly change. An investigation must be conducted to determine if the change should occur. Prior to the re-calibration the distance from the sign to point A was 2.49 miles, on the left side of the intersection C. After the change, a distance of 2.49 miles still put the sign on the left side of the intersection C. The additional requirement is satisfied, even though a distance of 0.11 miles from the intersection C seems improper. On the other hand, if we recalibrate FTseg AC from 2.50 to 2.45 miles the above record certainly must be changed, because a distance of 2.49 miles from point A makes the stop sign appear on the wrong side of the intersection.

Additional requirements may pose an impact on the event data with G1 Ftseg and the offset referencing method. However, the impact can be mitigated by choosing the event measurement method that is independent of the segment length. In the case presented above, if the stop sign is measured from the nearest intersection, the offset distance is independent of the FTseg length. Re-calibration would not be an issue for the stop sign event.

2.4 Network Attributes

All network type attributes such as route definition as illustrated in Table 5 that require maintaining connectivity should only be referenced to the whole link, or to the FTsegs to avoid connectivity issues. Other referencing methods can be used but careful thought should be given before implementation.

Route	*Sequence*	*Ftseg*
US1	1	AC
US1	2	CD

Table 5: Route definitions for network type attributes that require maintaining connectivity

In summary, the G1 FTseg and offset distance referencing method works well with events recorded in any database format, online or offline, as long as the attribute is referenced with a measured offset that is independent of the FTseg length. G1 FTseg network as representation of the road network accommodates a large set of requirements and customers because of its relative stability.

3. Intersection and Offset

The intersection and offset referencing method relies on the route names that are used to describe a location.

Feature	*Intersection*	*On Route*	*Offset*
Crash 100	NC 64 and SR 1002	NC 64 East	1.00 mile
Crash 101	NC 64 and SR 1002	NC 64 East	0.70 mile

Table 6: Two events by Intersection and Offset

The event location reference needs to be changed when the routes are renamed or re-numbered. Therefore, this referencing method has similar drawbacks to the route-milepost referencing method. Unless an integrated user interface is available, this reference method should not be used to store event reference information.

4. Coordinate Referencing

A coordinate referencing method, such as a GPS survey of interstate mile markers, results in a set of point coordinates that locate the feature or event of interest. GIS software can be used to relate or reference such events to the state maintained road system. Changes to FTsegs do not affect the coordinate route referencing method. No special support is needed for this referencing method. ESRI ArcGIS tools are sufficient for this type of data be referenced to the LRS.

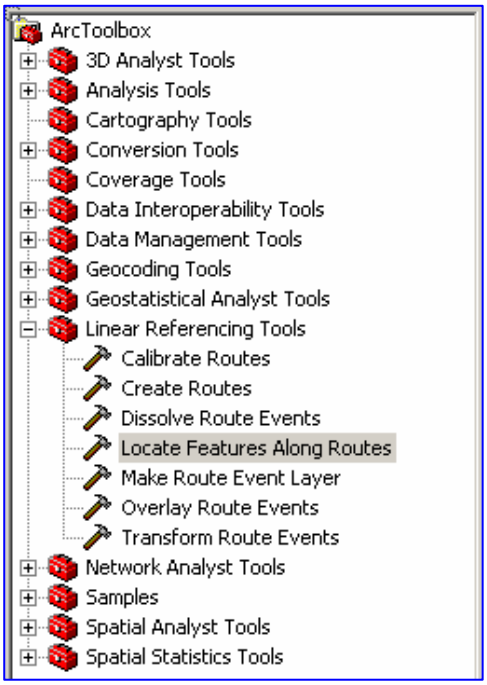

Figure 12: Linear Referencing Tools can be used to reference coordinate data to NCDOT LRS.

NCDOT LRS Integration Examples

1. Reference or relate business data or events to the physical transportation network utilizing the G1 FTseg and offset referencing method

Using this option, customers directly insert G1 FTseg identifiers and offset distances into their databases. It is especially recommended that new data development projects should adopt this approach. Existing databases may be converted to this referencing method with conversion tools. Once the conversion is achieved, the maintenance of the location reference information in these databases is minimal.

The Traffic Engineering Accident Analysis System (TEAAS) is an example. The TEAAS database stores traffic accident locations for reported crashes. The location description in crash reports is a typical intersection-offset referencing method which naturally fit into the G1 FTSeg offset referencing method. It is planned for TEAAS to adopt the G1 FTSeg offset referencing method so that the crash location are tied to the physical transportation network instead of changing street names or route numbers.

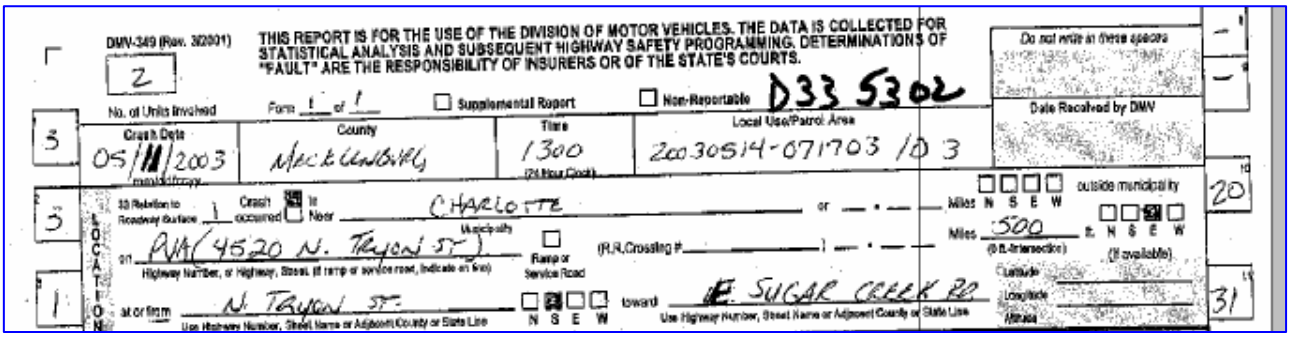

Figure 13: The location description in crash reports is a typical intersection-offset referencing method.

Another example in Figure 14 demonstrates the current format of Bare Pavement data. When the route names are changed, such as SR 1004 is renamed to SR 1006, the event data must be modified. Conversion of this format to a special case of G1 FTSeg-offset referencing method should reduce the data maintenance effort.

1	Div.	Dist.	County	Route	Begin Intersection	End Intersection	Snow Sect	Mat. Stora	Segment Length
2	5	2	Granville	I-85	NC 96	Vance Co. Line	1	Main. Yarc	9.2
3	5	2	Granville	I-85 S	NC 96	NC 56	2	Main. Yarc	13.2
4	5	2	Granville	I-85 N	NC 96	NC 56	3	Main. Yarc	13.5
5	5	2	Granville	US 15 N	SR 1004	Virginia State Line	6	Main. Yarc	16.3
6	5	2	Granville	NC 56	I-85	SR 1103	7	Main. Yarc	9
7	5	2	Granville	NC 56	NC 50	Franklin Co. Line	8	Main. Yarc	9.7
8	5	2	Granville	NC 56	I-85	NC 50	9	Main. Yarc	2.7
9	5	2	Granville	NC 50	NC 56	Wake Co. Line	10	Main. Yarc	9.3
10	5	2	Granville	US 158	US 15 W	Person Co. Line	11	Main. Yarc	12.3
11	5	2	Granville	NC 49	NC 96	Person Co. Line	13	Main. Yarc	1.8

Figure 14: Example of Bare Pavement data that should adopt G1-FTSeg offset referencing method

2. Reference or relate business data or events to one of the milepost referencing methods through database integration

Many databases are currently referenced to one of the milepost referencing methods. If it is necessary to continue to utilize a milepost referencing method, an automated refresh or update database interface should be developed.

Conceptually, the NCDOT LRS database should provide to departmental databases a transaction log that contains a record of all spatial changes made to the network. The departmental databases should then refresh or update their referencing system periodically by reading the transaction log and making the documented changes. In this case, the integration of business system and LRS is achieved through the use of a database interface. This is an acceptable model for decision support type of systems because of the implementation and architecture requirements [14].

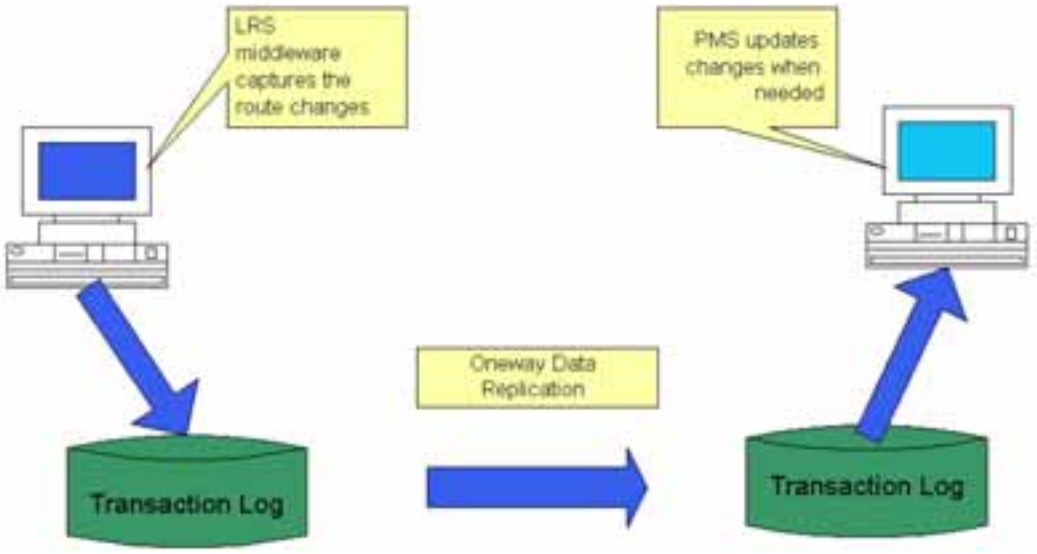

Figure 14: LRS Transactions are replicated to PMS through a database interface.

NCDOT Pavement Management System (PMS) - GIS Interface is a database integration example of using milepost referencing method. This database interface between PMS and LRS is to automate the update processes of the route number and milepost information in the PMS database. All changes to the route number system are captured and logged in a transaction table. The Transaction log is replicated to PMS database server by an Oracle materialized view so that a processing package within PMS can update its route number system when needed [13].

Conclusion

There are many options for customers to integrate their data and applications with the NCDOT LRS, depending on the business and technical requirements of the specific application system. The key issue of integration is the persistent storage format of the event data. In large GIS implementations, spatial data is often the source of issues. It is highly recommended for both online or offline databases to be referenced or related to the physical transportation network through the use of the G1 FTseg and offset referencing method. This option will significantly reduce the cost of application development and long term system maintenance.

NCDOT LRS implementation adopted the concept of a stable identification for the transportation features. The LRS database design followed the naming convention by the proposed ID standards and uses globally unique, meaningless identifier similar to one of the options in the newly developed Framework Data Standard, which is to address the data content issues.

Acknowledgement

We greatly appreciate the support from the NCDOT LRS Task Force. Many comments from the Task Force members are incorporated into this article. Thanks to Cynthia McCleary for many of the diagrams and Dana Nibby for assisting in writing the LRS Integration Guide, which leads to this article.

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