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

LINEAR REFERENCING SYSTEM (LRS) INTEGRATION GUIDE
Version 1.0

LRS Task Force
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http://www.ncdot.org/it/gis

REVISION HISTORY

Date	Responsible	Revision Purpose
2/15/06	Jun Wu	Draft 1. Added milepost and FTSEG LRM
4/7/06	Jun Wu	Draft 2. Added cover page, integration options, etc.
5/12/06	Jun Wu	Team review. Incorporated comments on linear referencing methods
8/11/06	William Rasdorf	General revision and comments
8/22/06	Dana Nibby and Jun Wu	Incorporated comments from subcommittee
8/25/06	John Farley, Hardee Cox, Chris Tilley, Jun Wu, and Dana Nibby	General revision of document
8/30/06	Jun Wu	Rewrite the description about database structure
09/08/06	Cindy McCleary	Added diagrams for LRM's
09/14/2006	Jun Wu	Revision for committee comments
09/19/2006	L.C. Smith	Revision and issues
09/20/2006	NCDOT GIS Unit LRS Task Force	Approved for LRS Version 1.0 release

LRS Integration Guide

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Introduction

This document briefly describes concepts and defines terms related to the implementation of NCDOT LRS (Linear Referencing System) version 1.0. It primarily explains the benefits and limitations of LRS-supported Linear Referencing Methods (LRM) from which the integration options and recommendations are derived. The goal of this document is to present an overview of the LRS database structure, discuss the linear referencing methods currently used in NCDOT, and provide integration options and best practices to potential users of the LRS.

The intended audience includes NCDOT customers interested in the integration of applications or databases with the LRS.

It is recommended that readers familiarize themselves with the NCDOT LRS Project Definition [1] and the NCDOT LRS Road Linework Feature Class Attribute Definitions, Topology Rules, and Attribute Domains documents [2]. A comprehensive list of recommended references is located at the end of this document.

The Need to Integrate with NCDOT LRS

Currently, route number and milepost data are maintained in many separate applications and database systems. 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 is no consistent or automated mechanism for updating or publishing the changes. As a result, information in these databases is not consistent with each other. For example, the same route number and milepost locations may contain conflicting information. For this reason, data is difficult to update and impossible to integrate.

Due to the nature of the milepost referencing method employed and the design of the mainframe Universe File, maintenance of location referencing information is labor intensive. Integration with the NCDOT LRS will enable easier manual and automated solutions for referencing a wide variety of information 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.

The NCDOT LRS is a central repository of the NCDOT transportation network with topology and geometry. It is maintained and made available by the GIS Unit. By using it, other units can focus on maintaining their specific data rather than having to maintain the road network. Furthermore, they can have confidence that the LRS road network is the most up-to-date and accurate available.

Spatial data sets that capture a variety of information are needed for making digital maps. The NCDOT LRS, coupled with GIS tools, will significantly improve the process of making customized digital maps. GIS tools will also provide visualization and spatial analysis capabilities. In fact, these may provide greater utility to users than hard copy maps.

In summary, application and database systems that maintain location referencing information about state maintained roads should pursue integration with the NCDOT LRS to reduce maintenance labor cost, reduce production cycle time, and improve data quality.

LRS Database Structure

The LRS database has components that capture the physical State maintained road system and the posted routes. It also contains functionality enabling a user to perform system integration, linear referencing, and cross attribute queries.

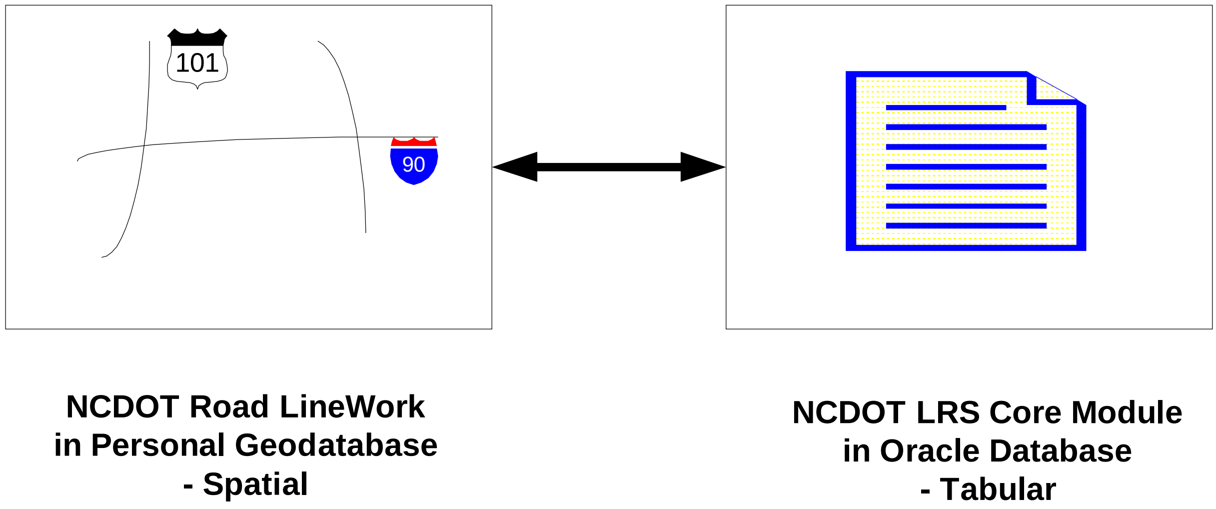

Figure 1: LRS database contains spatial and tabular databases working together to support functional requirements.

From a high level viewpoint, the NCDOT LRS contains two major databases. These are the NCDOT Road Linework Geodatabase and the LRS Database Core Module.

The NCDOT Road Linework Geodatabase is the spatial database for the NCDOT highway network. The geodatabase is comprised of line features and their associated attributes that represent the NCDOT State maintained road network. This geodatabase will initially be maintained using the ESRI "Personal Geodatabase" format. "Personal" refers to using Microsoft Access as the database for storing coordinate related information. Future enhancements to the NCDOT LRS will include implementation with Spatial Database Engine technology (ArcSDE), which uses Oracle as its associated Relational Database Management System (RDBMS).

The LRS Database Core Module captures the State maintained road network in tabular format to accommodate the NCDOT LRS operational requirements. It has a set of related sub-components that model the transportation network, the NCDOT route number system, and the change histories of both.

Conceptually, the NCDOT LRS can be viewed as a system with a few functional components that interact with each other.

Linear Datum

The linear datum is a collection of database objects which captures both the geometry and the topology of the transportation network. The linear datum consists of a Geodatabase feature class and a set of relational database tables that effectively model the transportation network. The linear datum provides a mechanism to relate the tabular data of a wide variety of transportation events to the network. It also provides support for transformations among linear referencing methods. It contains Framework Transportation Segment (FTSeg) [4] and other related tables.

Posted Route

The posted route component captures the route number and route classification of the state maintained route system. It also relates the route numbers to the physical location of the road system so that the route number change history for any given road segment can be maintained.

Location Referencing Methods Used in the LRS

LRS version 1.0 presently supports the following four linear referencing methods [1].

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

Each of these referencing methods will be described in the following sections. It should be noted that variations on the basic concepts presented below may be implemented by those using these 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. 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 a county boundary.

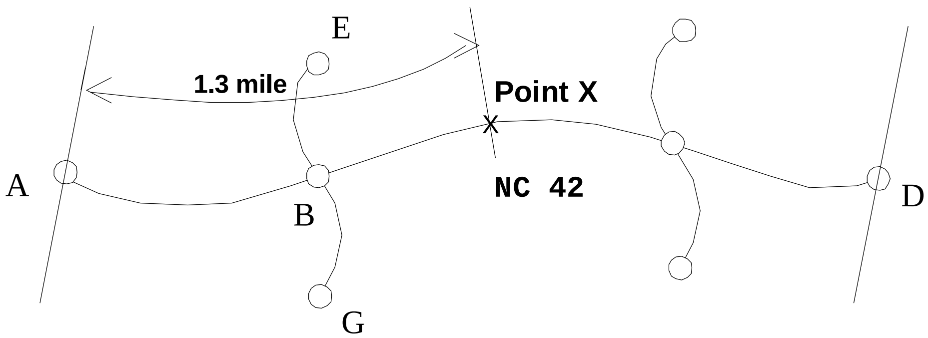

Figure 2: Specifying a point location using milepost referencing

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.

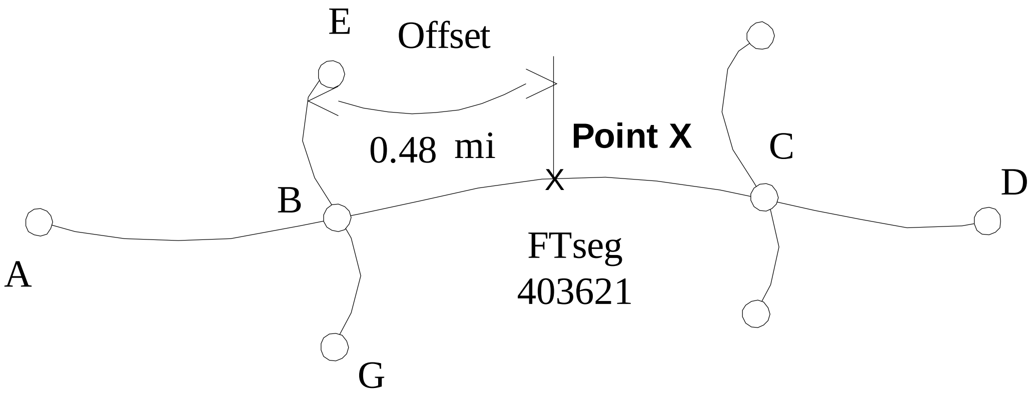

Figure 3: Specifying a point location using FTseg and Offset Distance

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 [4]). 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) [4]. 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.

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.

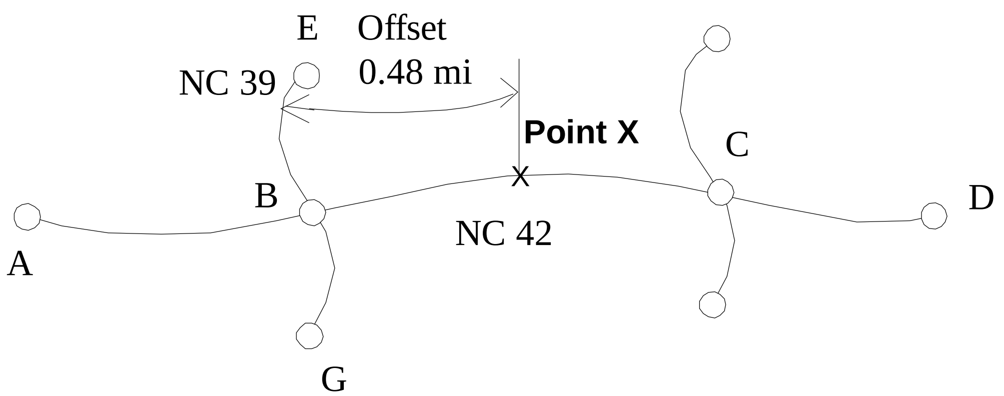

Figure 4: Specifying a point location using an Intersection and Offset

Coordinate Route

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

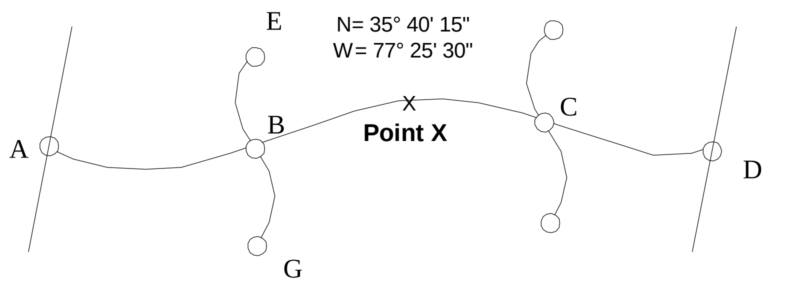

Figure 5: Specifying a point location using coordinates

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

North coordinate	35°40′15″
West coordinate	77°25′30″

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.

Case 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

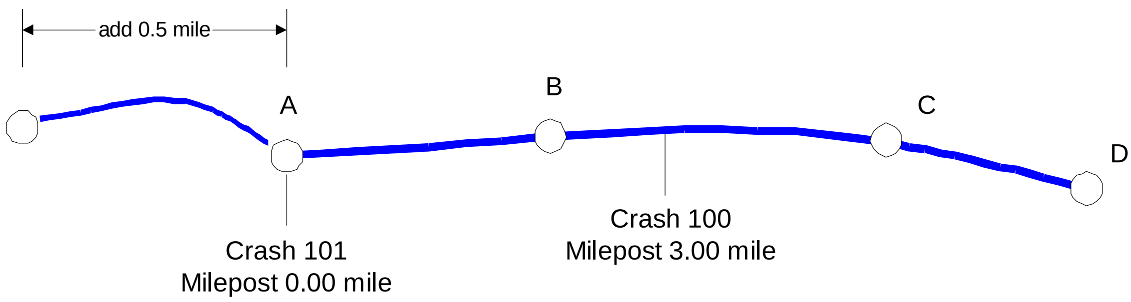

Figure 6: Add a half mile long segment at the beginning of a route.

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.

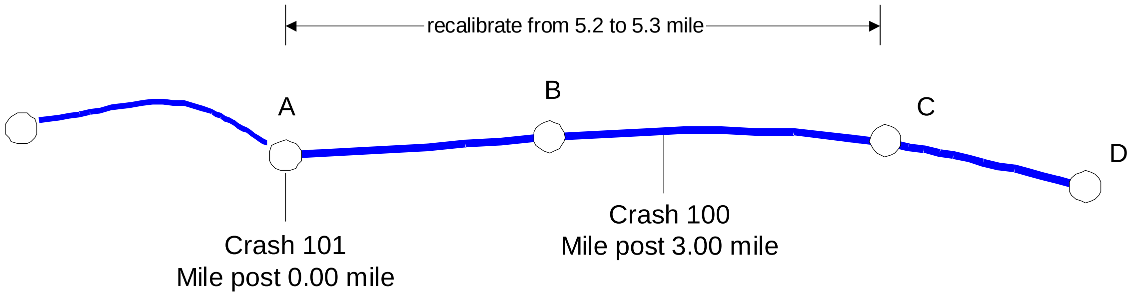

Figure 7: Re-calibrate FTseg AC from 5.20 to 5.30 miles.

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.

There is no simple rule for doing so that is universal to all event data. In other words, changes to the event data have to be coded based on the requirements. The PMS-GIS interface is a model designed for decision support systems. For an online transactional system, because event location references must be synchronized with road network changes all the time, a messaging system should be used in application integration.

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. This makes the milepost referencing method acceptable only for decision support or data warehouse types of relatively static systems. 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. 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 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 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 non-relational database type of 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 are defined and developed.

Case 2. Generation1 (G1) FTseg and Offset Referencing Method

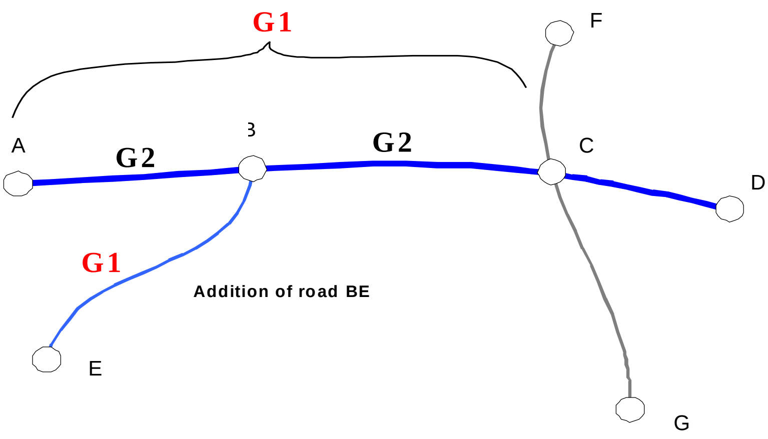

Figure 8: Generation 1 (G1) FTSegs and maintenance of the Linear Datum

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.

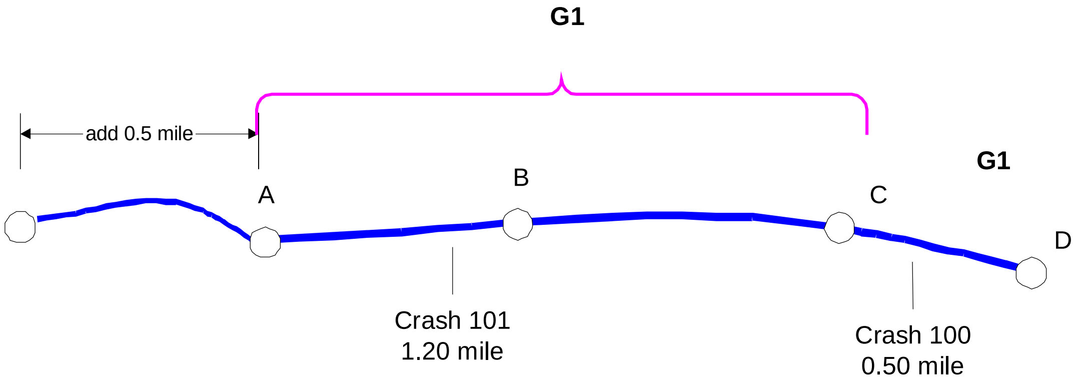

Figure 9: Add a half mile long segment at the beginning of a route.

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

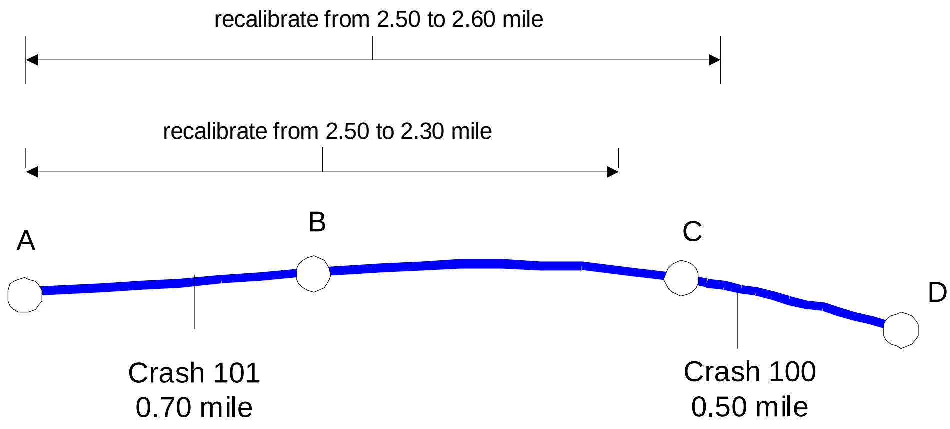

Figure 10: Re-calibrate FTseg AC.

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

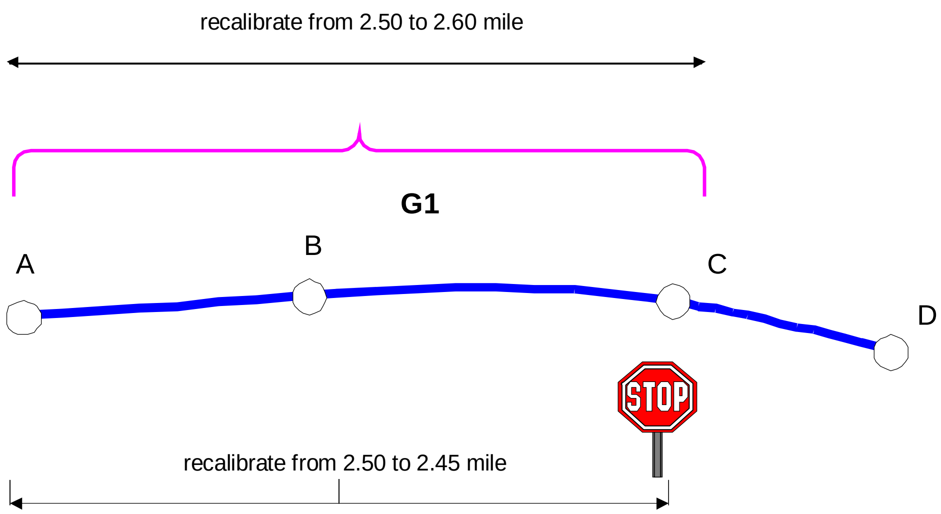

Figure 11: Re-calibration of segment makes the stop sign appear on the wrong side of an intersection.

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.

Case 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.

Case 4. Coordinate Route

A coordinate route 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. ArcGIS tools are sufficient for this type of data be referenced to the LRS.

NCDOT LRS Integration Options

Three options for customers to integrate their data and applications with the NCDOT LRS are presented.

Option 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 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 this is achieved, the maintenance of the location reference information in these databases by users is minimal. Instead, all maintenance of the network topology and geometry is handled by the GIS unit.

Using this option will enable mapping and analysis of the data using feature rich GIS tools.

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

Many databases are in fact 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. An example of this option is the PMS-GIS Interface System.

Option 3: Reference or relate business data or events to one of the milepost referencing methods through application integration

The same result as the option 2 can also be achieved by integration at the application level. Instead of a database interface, a messaging mechanism can be employed so that all changes in either system are communicated and processed in near real time. This option requires both systems to be compliant with an N-tier architecture and a messaging service needs to be incorporated. An example of this option is the Road Inventory Module.

A more practical approach for many users of the NCDOT LRS might be to time stamp their existing databases and archive them. At that point they could adopt the G1 FTseg and offset referencing method and implement their system using that new method. This would entail four steps.

Step 1: At some point in time all databases are time stamped and archived.
Step 2: Chose a new LRM.
Step 3: Make system changes related to the adoption of the new LRM.

Step 4: Make a one time conversion to the chosen referencing method.

Recommendations

A number of recommendations are made for NCDOT units wishing to utilize the LRS. The first is that they reference or relate their business data or events to the physical transportation network through the use of the G1 FTseg and offset referencing method as is done in the LRS. This conceptual integration option is highly recommended for both online or offline databases.

Second, the current state route numbers are convenient in describing routes, however they are not suitable for identifying physical locations of attributes. All attribute data should be referenced to the LRS using G1 FTsegs.

Third, stable G1 FTseg ID's will be published and explicitly used as unique identifiers for all physical road segments, current or historical.

Fourth, network type of attributes that require maintaining connectivity should only be referenced to the whole FTsegs.

Finally, there is a need to develop transformation or conversion tools for Linear Referencing Methods (LRM) to support system transition for LRS integration. The reason is that many DOT event datasets will most likely be synchronized with a snapshot of the LRS and time stamped so that the conversion to the preferred referencing method can be performed.

References

[1] "LRS Project definition version 1.0", 2006, LRS Task Force, GIS Unit, NCDOT, Raleigh, NC.
[2] "NCDOT Road Linework Feature Class Attribute Definitions, Topology Rules, And Attribute Domains," 2006, LRS Task Force, GIS Unit, NCDOT, Raleigh, NC.
[3] "A Conceptual Design for the Iowa DOT Linear Referencing System", Alan Vonderohe, January 2000.
[4] "NSDI Framework Transportation Identification Standard -- *Public Review Draft*", FGDC-STD-999.1-2000
[5] "Implementing the Enterprise GIS in Transportation Database Design", J. Allison (Al) Butler and Kenneth J. Dueker, URISA Journal, Vol. 13, No. 1, Winter 2001