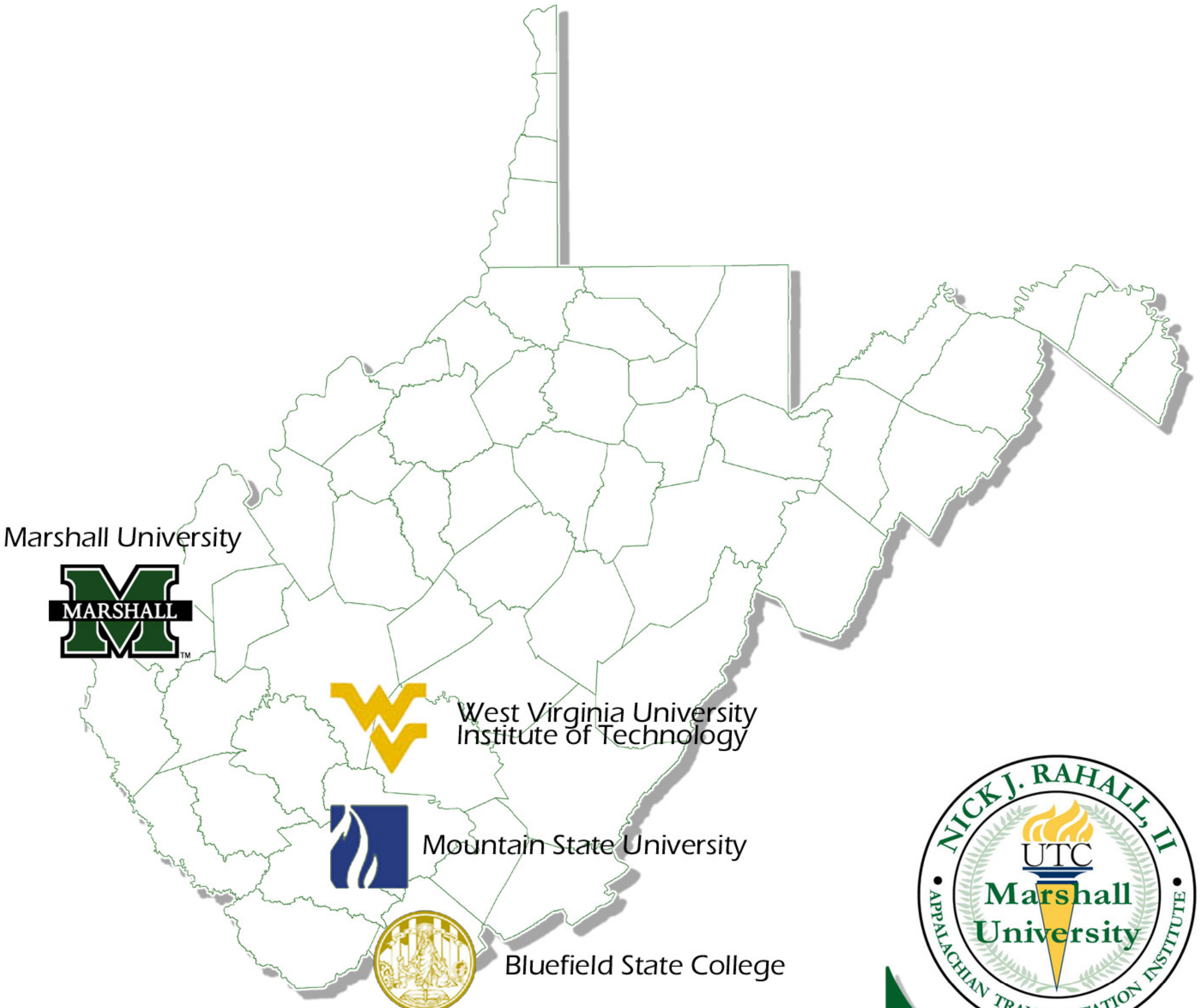
Project Number: RTI 210031

Feasibility Study of Integrating WVDOT Linear Referencing System Center Line with Statewide Addresses and Routing Information



NICK J. RAHALL, II
UTC
Marshall University
APPALACHIAN TRANSPORTATION INSTITUTE

Marshall University

West Virginia University
Institute of Technology

Mountain State University

Bluefield State College

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
RTI 210031		

4. Title and Subtitle Feasibility study of Integrating WVDOT Linear Referencing System Center Line with Statewide addresses and Routing Information	5. Report Date May 2010 6. Performing Organization Code RTI
7. Author(s) Sang Hong Yoo, M.S, M.S.E, GISP	8. Performing Organization Report No. 210031
9. Performing Organization Name and Address Nick J. Rahall II, Appalachian Transportation Institute at Marshall University, PO Box 5425, Huntington, WV. 25703	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address US Department of Transportation Research and Innovative Technology Administration 1200 New Jersey Avenue, SE Third Floor, East Building E33-461 Washington, DC 20590	13. Type of Report and Period Covered FINAL 14. Sponsoring Agency Code USDOT

15. Supplementary Notes

16. Abstract

State DOTs use road centerlines to manage extensive transportation system data such as road physical conditions, traffic measurements, and highway projects. The WVDOT has recently completed a GIS base map project to create a linear referenced road centerline, and wants to develop a single , comprehensive, statewide road centerline dataset that can serve the entire DOT GIS needs. The objective of this project is to review technical issues regarding the feasibility of road network integration in West Virginia which incorporates linear referencing, addressing, and routing capabilities. This study reviews existing transportation models and identifies implementation issues as well as DOT needs. The study shows that the revised/improved UNETRANS data model can be successfully implemented accommodating WVDOT RIL system requirements. Using the advantage of Edit and Publish geodatabase design practices, the DOT can continuously develop and perfect the data model and migrate from the old system in stages. Creating and maintaining a statewide dataset that includes the attributes (e.g., one way roads, turn restrictions, etc.) required to support full automated routing (traversing) would be challenging and costly. The DOT should approach the routing requirement as a long-term project and develop an action plan.

17. Key Word	18. Distribution Statement
GIS	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FEASIBILITY STUDY OF INTEGRATING WVDOT LINEAR REFERENCING SYSTEM CENTER LINE WITH STATEWIDE ADDRESSES AND ROUTING INFORMATION

Rahall Transportation Institute
RTI 210031
Federal Project #: STP-2006(065)E
State Project #: T699-GIS-1
Authorization #: UE2265G

Prepared for
West Virginia Department of Transportation

May 2010

Sang Hong Yoo, M.S, M.S.E, GISP
Research Associate

The Nick J. Rahall II. Appalachian Transportation Institute
Marshall University
Post Office Box 5425
Huntington, West Virginia 25703

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of exchange. The U.S. Government assumes no liability for the contents or use thereof.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the accuracy of the data presented herein. The contents of this report do not reflect the official views or policies of the West Virginia Department of Transportation. The use of trade names does not signify endorsement by the authors.

Table of Contents

Table of Figures

1. Introduction

1.1 Problem Statement

The West Virginia Department of Transportation (WVDOT) has initiated and completed a GIS base map project to create a continuous linear referenced road network centerline using the Roadware videolog GPS points and lines and the West Virginia State Addressing and Mapping Board (WVSAMB) unattributed disconnected road centerlines with the Straight Line Diagrams (SLD) provided by WVDOT.

High-quality road centerline data is a foundation layer for many GIS-related projects. Moreover, State DOTs use road centerlines to manage extensive transportation system data such as road physical conditions, traffic measurements, and highway projects. A lot of DOT data can be associated with a location along a road network via geographic coordinates or location range, with location often expressed as linear distance.

Road centerlines can be used for a variety of purposes from cartographic to analytical. Depending on the attribute information tied to the graphical data, road centerline databases can support geocoding (address matching), routing, and various types of network modeling. WVDOT currently does not have appropriate road centerline attributes to support these capabilities. The objective of this project is to review technical issues regarding the feasibility of road network integration in West Virginia which incorporates linear referencing, addressing, and routing capabilities. This study will (1) identify and review existing transportation models, as well as DOT data needs; (2) create an integrated road network pilot; and (3) identify requirements for data integration.

1.2 Objective

The objective of the proposed study is to review technical issues regarding the feasibility of road network integration in West Virginia which incorporates linear referencing, addressing, and routing capabilities. This study will (1) identify and review existing transportation models, as well as DOT data needs; (2) create an integrated road network pilot; and (3) identify requirements for data integration.

1.3 Scope

Task 1 – Identify and review existing transportation data and models, as well as DOT data needs, to develop a shared road network.

Review and assess federal, state, regional, local, and commercial transportation data to determine opportunities for cost-savings, to identify best practices and lessons learned, and to review existing transportation data models. Where necessary, seek advice from transportation experts of the public and private sectors to assist in developing a shared road network model for West Virginia.

Task 2 – Create an integrated road network pilot

Using information compiled from Task 1, develop a sample road network in West Virginia which shares the same geometry and combines linear referencing, addressing, and routing capabilities from the best available transportation databases. This task will result in an enhanced LRS data model that incorporates additional data and functionality.

Task 3 – Identify requirements for data integration

Identify minimum requirements necessary to create a shared road network. The seamless, comprehensive network will include all roads and support linear referencing, addressing, and routing. Integrated solutions may incorporate transportation data from both public and private sources.

1.4 Deliverable

Rahall Transportation Institute (RTI) and West Virginia University (WVU), the latter acting by and through the WVU GIS Technical Center (WVUGISTC), will collaborate together to recommend strategies and direction to attain the goal of integrating DOT linear referencing, addressing, and navigable transportation network. The recommendation will address minimum requirements such as resources and methods of integration. RTI will concentrate on the topic of a navigable transportation network and WVUGISTC will focus on the topic of integration of linear referencing and statewide addressing.

The principal deliverable of this project will be a Shared Road Network Feasibility Report. This report will include the following deliverable components:

1. Review of existing transportation databases to include coverage area and capabilities. The data coverage, schema, and unique capabilities of existing transportation models will be compared and contrasted: linear referencing (WV DOT), addressing (E-911 SAMS), and routing (NAVTEQ, etc.). This component of the report will answer the question: "What transportation databases and capabilities exist now in West Virginia?"

2. Complete an integrated road network study for a small geographical area. The integrated road network will share the same geometry and combine linear referencing, addressing, and routing capabilities from the best available transportation databases. As part of this component, the existing LRS model will be extended to incorporate addressing and routing capabilities. The revised data model will be published in the report. This component of the report will answer the question: "What will a shared data model (geometry and attributes) for LRS, addressing, and routing look like and how will it function?"

3. List requirements and recommendations to create an integrated road network. This component will identify the basic data and organizational requirements to develop an integrated road network in West Virginia. It will also provide recommendations on how this data model will be updated and maintained by multiple data stewards. This component of the report will answer the question: "To transition to a production phase, what are the data/organizational requirements and projected costs to complete a seamless, comprehensive, statewide road network that includes all roads and supports linear referencing, addressing, and routing?"

2. WVDOT Linear Referencing System

2.1 History

Transportation agencies such as Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) have developed Linear Referencing System (LRS) for transportation facilities to manage and maintain information on transportation infrastructure. NCHRP Synthesis of Highway Practice 21 defined a location reference system as "a set of office and field procedures that include a highway location reference method." The concept of a system included a means of transformation among various methods. A linear referencing system is one type of location referencing system. NCHRP also defined a location referencing method as "a way to identify a specific location with respect to a known point." Milepoint, reference post, and engineering stationing are methods and the policies, records, and procedures that relate these methods are the system (Highway Research Board and National Academy of Engineering 1974).

As part of the WVDOT Program Planning and Administration Division reorganization in November 2007, the previous Roadway Records and Statistics and the Highway Performance Monitoring System (HPMS) were combined to form the Highway Data Services (HDS) unit and positioned them under the direction of the Geospatial Transportation Information (GTI) Section. The HDS unit is solely responsible for processing addition, change or abandonment requests from the Districts and updates the roadway inventory records as Commissioner Orders are issued. Improvements are also updated to the Roadway Inventory File as received either from the Districts or by way of field notes generated by the regular field crew inventories. The HDR also maintains other roadway history records such as maps, scroll records, microfilmed documentation, correspondence files and official Commissioner Orders in the work area. The GIS unit, another GTI unit, is responsible for maintaining software and hardware of the Road Inventory Log (RIL) (West Virginia Department of Transportation. GTI 2009).

Similar to other highway agencies, the WVDOT has developed RIL, a mainframe application, to manage its LRS since the 1970s. the WVDOT RIL is a transportation network database defined and maintained in tabular form in an unnormalized mainframe database, also known as a flat file database. Routes are defined to match to named or numbered routes, which DOH is responsible for. Records of transportation assets or activities on or along the route are maintained in a tabular form with a fixed number of attribute fields due to flat file database limitation. Figure 1, (Litteral 2007), shows how DOT manually updated roadway changes to the RIL, SLD, and Maps to reflect field conditions. The RIL can't maintain a record of historical changes but is able to take a historical snapshot at the end of each year. Currently no tool is available to manage data integrity.

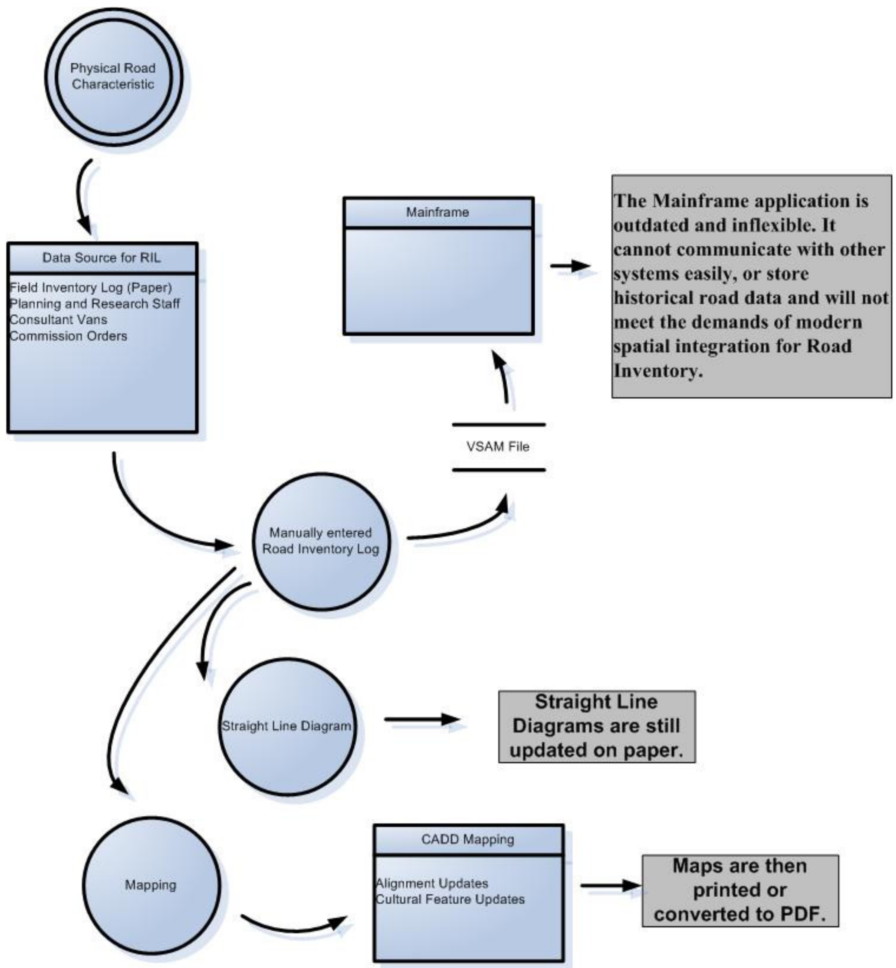


Figure 1. Road Inventory Log Process Diagram

2.2 Linear Referencing Methods

A linear referencing method is "a location referencing method in which a location is specified as occurring at some distance from known point along a linear feature" (for example, 20 miles from the beginning of Interstate 64) (Federal Highway Administration and GIS/Trans. Ltd 1999). A LRM specifies locations along a linear network and there are two common methods transportation agencies adopted. The base-offset method, also known as route mile point method where mile points are used, uses the accumulated/measured distance (or offset) from the beginning of the route/traversal. The second common method, the reference point method, utilizes a measured offset relative to a series of reference points along the route/traversal (Highway Research Board and National Academy of Engineering 1974; Federal Highway

Administration and GIS/Trans. Ltd 1999; Easa, Chan, and American Society of Civil Engineers. Geographic Information Systems Committee. 2000).

State DOTs and the Federal Highway Administration (FHWA) have used the route-milelog LRM since they created the Highway Performance Systems (HPMS) in the early 1970s and almost all state DOTs have a route-milelog LRM database as a result of it (Butler 2008). West Virginia is not an exception. The WVDOT has been using a named route-milepoint LRM since it took over roads from Counties in 1930s and hasn't changed how they specify locations along roadways. It is a principal LRM and the only LRM being implemented.

2.3 RIL Improvement Project

The GTI has initiated a RIL improvement project, one of many enterprise LRS improvement projects with the goal of modernizing technology. Because the current RIL is a mainframe flatfile database that presented many problems preventing the GTI from fulfilling their organization objectives, the GTI developed a new RIL based on a Relational Database Management System (RDBMS). In addition, the GTI and RTI have developed a prototype online editing and mapping solution for the WVDOT's RIL database. The assessment of the prototype recommended additional requirements, feature upgrades and troubleshooting as well as some basic training and documentation. These issues will be addressed in the next phase.

The system will extend current roadway coverage in RIL to all public roads and improve integration with ongoing GIS implementation. It will also capture some transportation facilities such as ramps, intersections, and divided highways currently not inventoried in the system. It will provide easier historical data tracking and a better and more flexible platform for other applications at the DOT. Figure 2 shows sample tables imported and modified to the new RIL system. The relationship of tables is created using the primary key "rtinvID" which is an auto incremental numeric field managed by the RDBMS.

As part of the improvement, the way roads are inventoried has to be changed. Currently, the coding procedure for West Virginia Roads is;

Route ID _ _ - _ - _ _ _ - _ _ - _ _
1 2 3 4 5 6 7 8 9 10

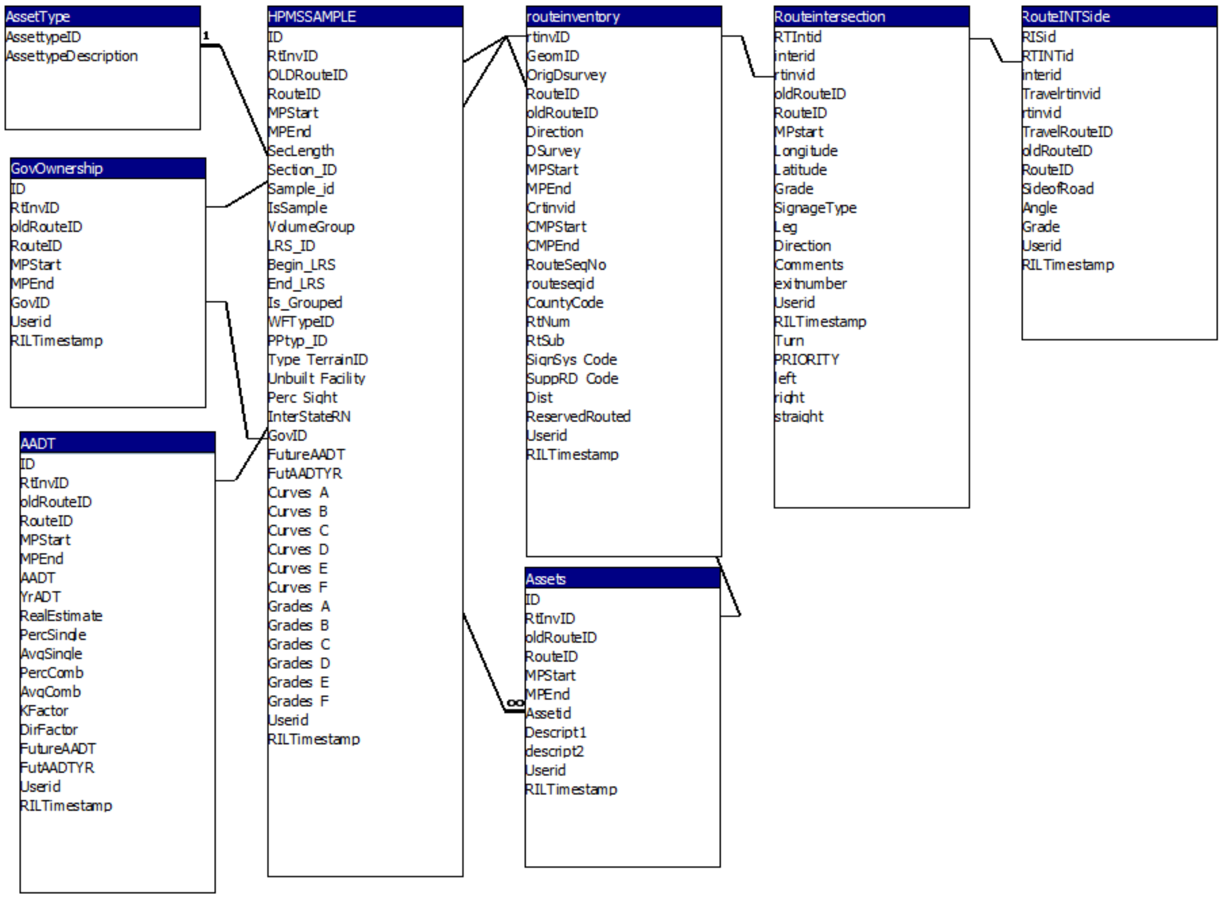
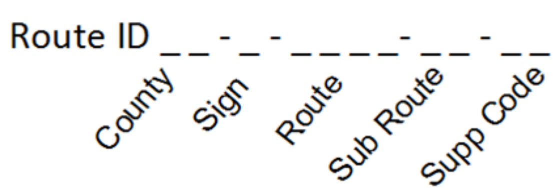


Figure 2. RDBMS RIL Tables

Where the suffix 1 and 2 represent the county and suffix 3 is for the sign system. Suffix 4, 5, and 6 would make up the route number and suffix 7 and 8 would be the sub route number. Suffix 9 and 10 would make up the supplemental description of the route. The new Route ID will have a four digit route number instead of three (West Virginia Department of Transportation. Planning & Research 2007).



There are ongoing discussions whether Route ID needs to be expanded further to accommodate other roadway characteristics such as the direction of travel and ramps. Any changes of the Route ID are very critical because many DOT applications and databases are relying on Route ID as the main identifier of roadways.

3. GIS Implementation at WVDOT

As mentioned before, the DOT reorganization effort established the GTI in order to continuously support GIS implementation throughout WVDOT departments and manage road network. The GTI has developed a strategy for an enterprise GIS and Linear Referencing that focuses on locating transportation assets and projects along transportation facilities. It was also necessary to comply with the 2010 HPMS mandate by the FHWA requiring submission of a geodatabase format with minimum GIS network requirements (West Virginia Department of Transportation. GTI 2009).

The WVDOT uses ESRI software as the main GIS implementation software but has Microstation CAD licenses for engineering and other works. Currently the GTI has a road network (GIS base map) that covers 90% of public roadways which include Interstates, US, State, County routes, Federal Aid Non-State (FANS), State Park and Forest Roads, and other roads. Missing coverage is mainly from FANS, State Park and Forest Roads, and other roads. The GIS unit is working diligently to fill this gap and is expected to have a complete coverage soon.

As a collaborative project, the WVDOT and RTI created the road network from Roadware GPS data (points & lines) and digitized from WVSAMB centerlines as well. Routes were manually created without segmentation. Opposite direction traversal was added to Interstate and US highways whether it is a divided highway or not. Beginning and ending distance measures of a segment (based on RIL and SLD) were entered to populate M-values for every vertex of a route, which allows dynamic segmentation. The entire road network has not been calibrated to reflect elevation. The DOT uses a dynamic segmentation technique to query a database, display/map data, and determine linear measure (only for reference purpose). RIL, SLD, and aerial imagery were used for additional quality control, alignment calibration, and attribute population. Overall scale of the GIS base map is 1:4800.

4. Linear Referencing and GIS

Linear referencing provides a set of methods and procedures for recording and retrieving locations along linear networks, and a typical LRS contains a transportation network and a location reference method (Miller and Shaw 2001). Emerging technologies and data collection methods have changed the way linear referencing is viewed and implemented. The NCHRP Report 359, "Adaptation of Geographic Information Systems for Transportation," provides an overview of the adaptation of GIS for the management and integration of the transportation information, and recommends that transportation agencies develop a conceptual organizing principle founded upon the notion of location as a data integrator (Vonderohe et al. 1993)

The implementation of linear referencing in GIS among transportation agencies has become standard practice and development of a complete and robust GIS-Transportation Linear Referencing Data Model was imperative. The data model can illustrate a digital representation of transportation systems and complex relationships among its components and use geographic location and relationships to manage transportation information.

Many efforts have produced a number of linear referencing data models that attempt to improve on the traditional tabular network database by applying a more sophisticated network data model that incorporates spatial elements (Krätzschmar 2001). However, the same problems commonly experienced with linear referencing have to be addressed (Federal Highway Administration and GIS/Trans. Ltd 1999). These are:

- the integration, translation, and transformation of data based on different linear and location referencing methods
- the effect of updates to the road networks on linear referenced data sets due to realignment, re-measurement, new construction, etc
- the limitation (accuracy) of one-dimensional measurements as applied to real-world

The model also must be able to support legacy systems (or at least transition), future enhancement, and database maintenance.

4.1 Enterprise LRS Data Model

4.1.1 NCHRP 20-27 (2) LRS Data Model

The National Cooperative Highway Research Program sponsored the NCHRP 20-27 (2) LRS data model in response to increasing needs to develop LRM and LRS data model by the transportation community. The data model was primarily based on the result of a workshop held in Milwaukee, Wisconsin, with the objective of developing a draft consensus conceptual data model for linear referencing system. Participants recognized that the development of a data model would meet all the needs of all application areas for transportation agencies was difficult and sought a generic model that met common needs and formed a core that could be extended in specific application areas. The model supports the following fundamental operations (Vonderohe et al. 1997):

1. **Locate**. Establishment of the location of an unknown point in the field by reference to objects in the "real world."
2. **Position**. Translation of a real-world location into a database location.
3. **Place**. Translation of a database location into a real-world location (the inverse of the "position" operation).
4. **Transform**. Conversion between various linear referencing methods, represented by database locations; between various cartographic representations; and between methods and cartographic representations.

The model supports higher-level operations such as those associated with GIS (for example, overlay, connectivity, and proximity) as well as those associated with network analysis (for example, pathfinding, routing, location, and allocation) by supporting these operations.

Figure 3 depicts a conceptual overview of the data model. The model includes three primary components: 1) linear referencing system; 2) business data; and 3) cartographic representation. The linear referencing system comprises linear referencing methods, networks, and datum. The data model uses a single linear datum that supports multiple cartographic representations at any scale and multiple network models for various application areas. The datum provides the fundamental referencing space for transformations between different linear referencing methods, multiple network models, and cartographic representations at various scales. The linear datum which represents the complete set of roadways is comprised of anchor points and anchor sections. Anchor points represent well known, uniquely identifiable real world locations, such as the intersections of two streets. Anchor sections connect two anchor points and represent the roadway segment. Business data refers to event data and is tied to traversals (or routes), which are built upon network links, through LRM.

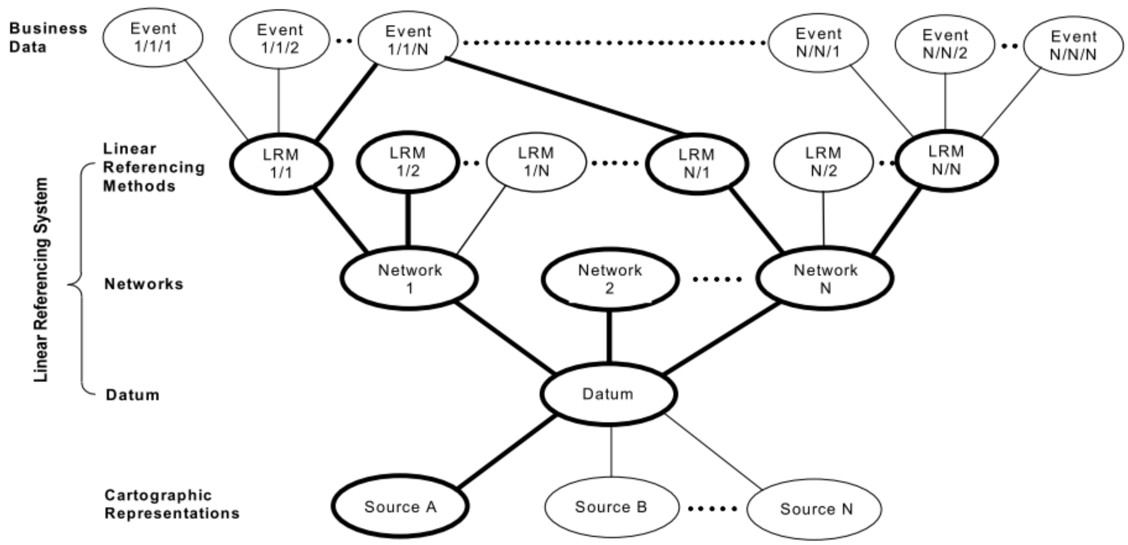


Figure 3. NCHRP 20-27 (2) LRS data model conceptual overview

A data model was developed in the format of an entity-relationship diagram, which describes the key elements of a linear LRS and the relationships between them. Figure 4 shows ER diagram of LRS data model.

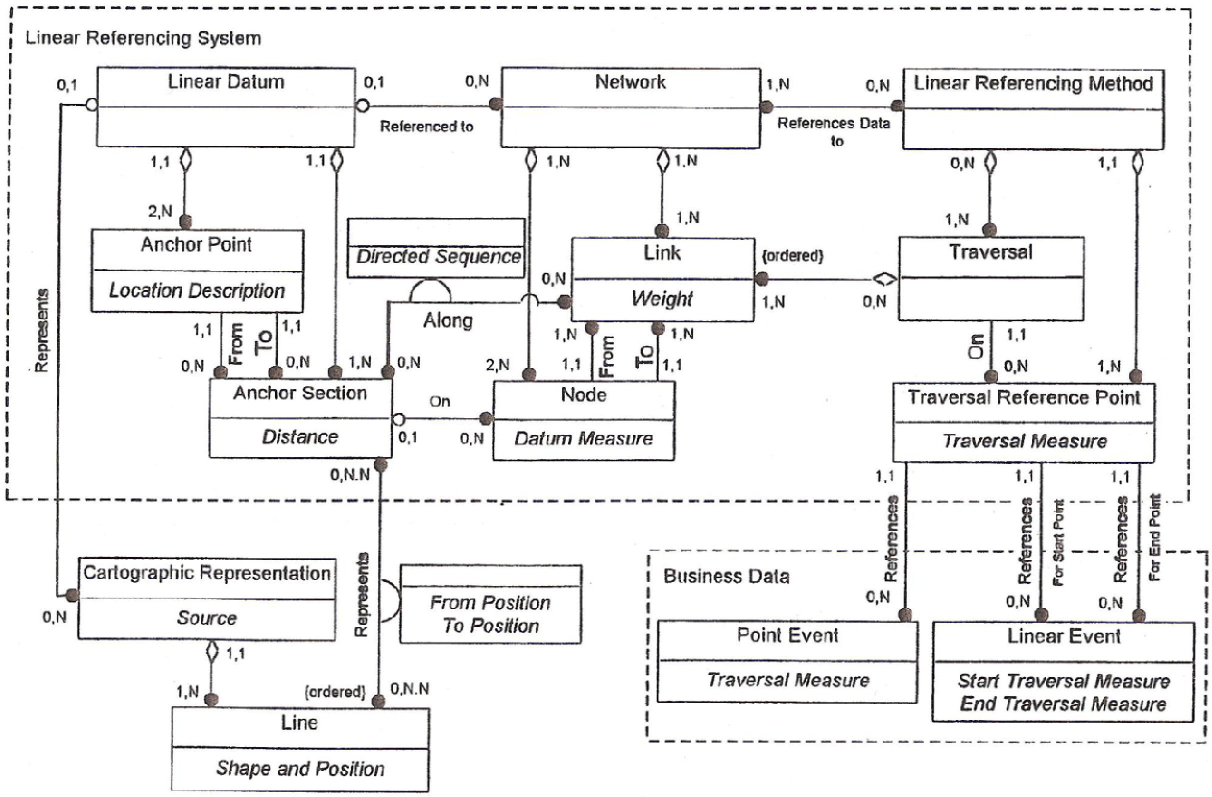


Figure 4. NCHRP 20-27 (2) LRS Data Model Entity-Relationship Diagram

4.1.2 The Dueker-Butler Model (GIS-T Enterprise Model)

Dueker and Butler developed a GIS-T enterprise data model that incorporates linear and non-linear location referencing systems. Similar to the NCHRP 20-27 (2) LRS data model, the Dueker-Butler model is independent of: (1) geographic datum; (2) the events that occur on the transportation system; (3) the geometry that represents the system; and (4) the link-node topology that makes up transportation systems. The model also supports areal transportation features (e.g., airports, railyards) as well as areal events (e.g., park-and-ride lot). Area events can be a non-transportation feature that affects transportation features (e.g., intersect). Figure 5 shows the conceptual data model in Entity-Relationship format.

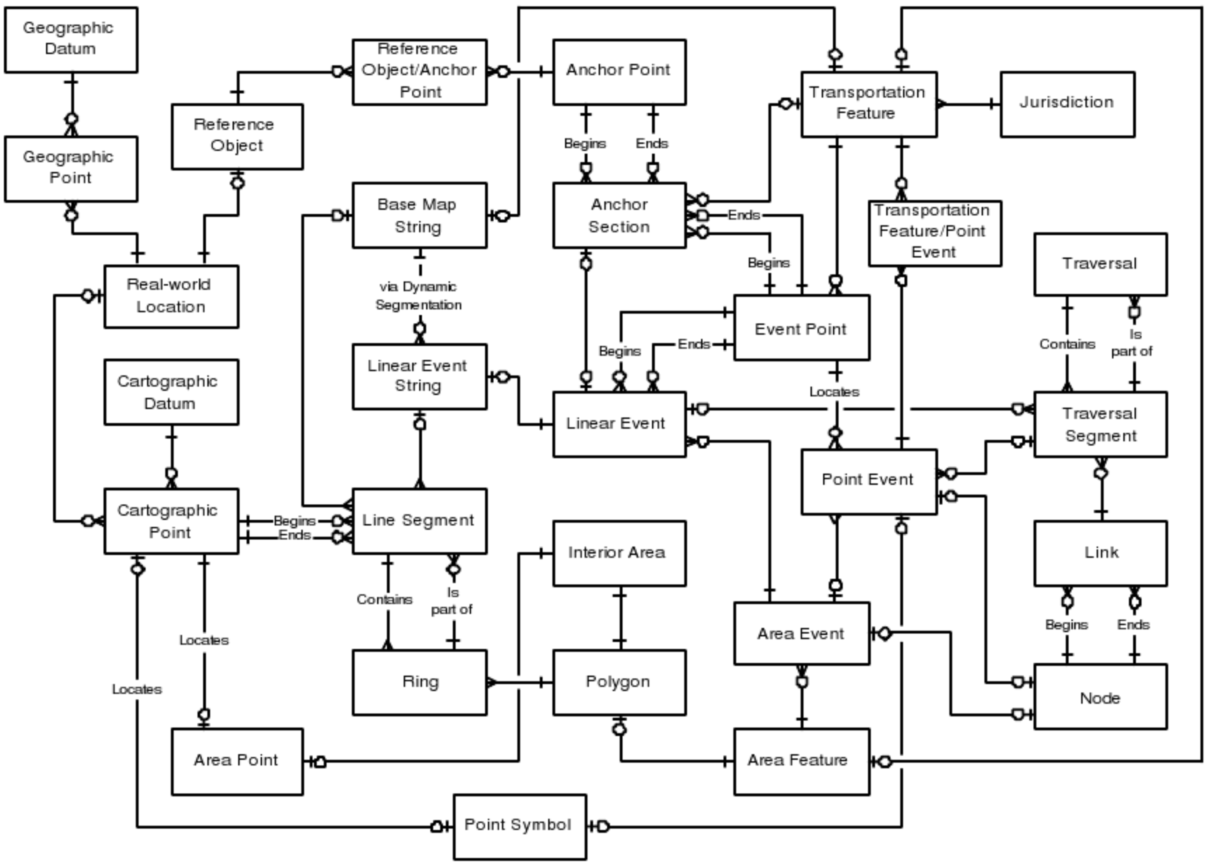


Figure 5. Dueker/Butler enterprise LRS data model

The most basic entities of the model are transportation feature, jurisdiction, and events. A transportation feature is an identifiable element of the transportation system and can be either a point, a line, or an area. Jurisdiction is a political or other context for designating transportation features. An event is an attribute (e.g., functional class, speed limit, pavement type), occurrence (e.g., traffic crashes, projects), or physical component (e.g., guardrails, signs, bridges) of a transportation feature (Dueker and Butler 1997).

4.1.3 UNETRANS

With funding support from ESRI, University of California at Santa Barbara developed the Unified Network for Transportation (UNETRANS) data model in consultation with a consortium of users from transportation communities (Butler 2008; Curtin et al. 2003; Krätzschmar 2001). The consortium focused on the needs of organizations that manage road and rail network and intended to: simplify enterprise project implementation, encourage data sharing with consistent data structure, provide a common starting point for application developers (Curtin et al. 2003). The objective of the UNETRANS project was to develop essential objects needed for the most common transportation applications (Krätzschmar 2001). Figure 6 shows an analysis diagram, a layout of all data objects (features and tables) that comprise the model.

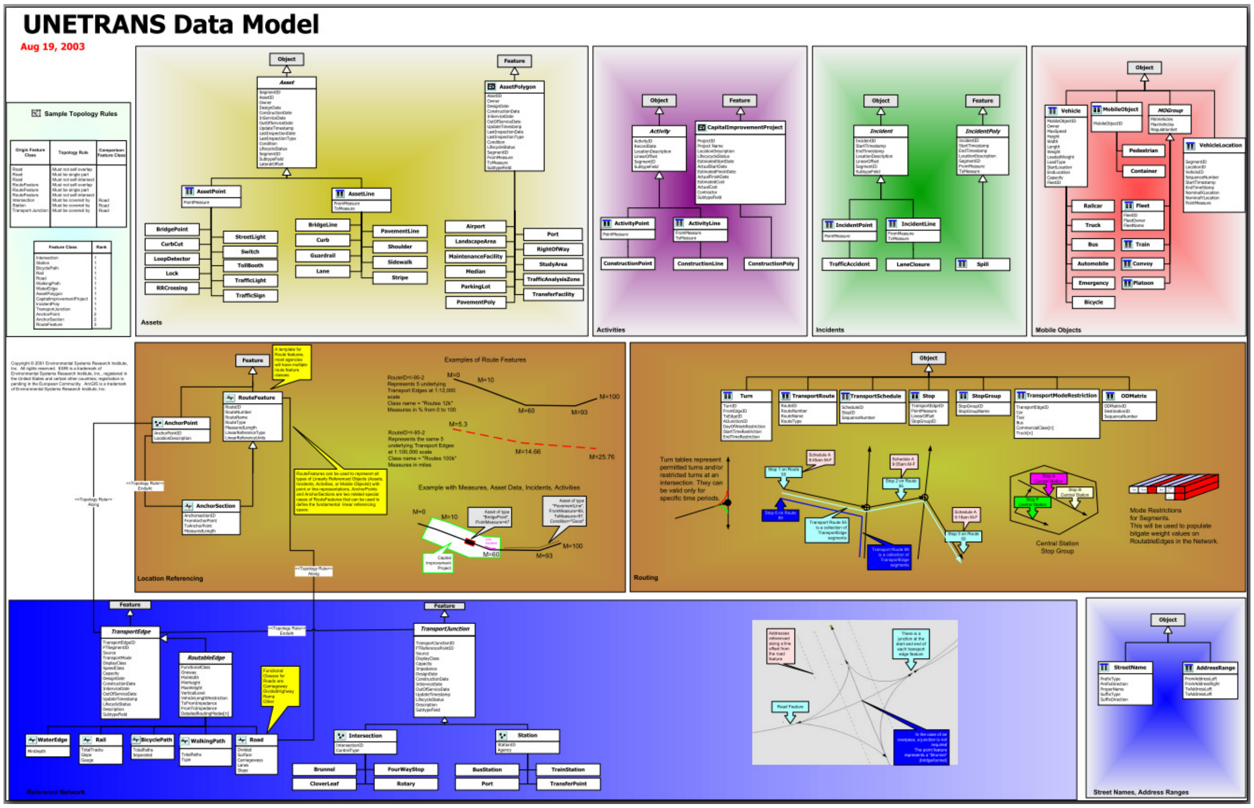


Figure 6. UNETRANS Analysis Diagram

Relationships are specified with connections between objects specified with a name, attributes, and behaviors. The UNETRANS model uses the ArcGIS geometric network as the underlying structure and every feature class or table inherits properties from one of the core ArcGIS object classes (Feature, Object, ComplexEdgeFeature, SimpleJunctionFeature) (Butler 2008; Curtin et al. 2003).

The UNETRANS model is subdivided into six packages (or logical groups) of related features and object classes, and a package of objects may be related by function or type (Curtin et al. 2003). Figure 7 shows an overview of these packages:

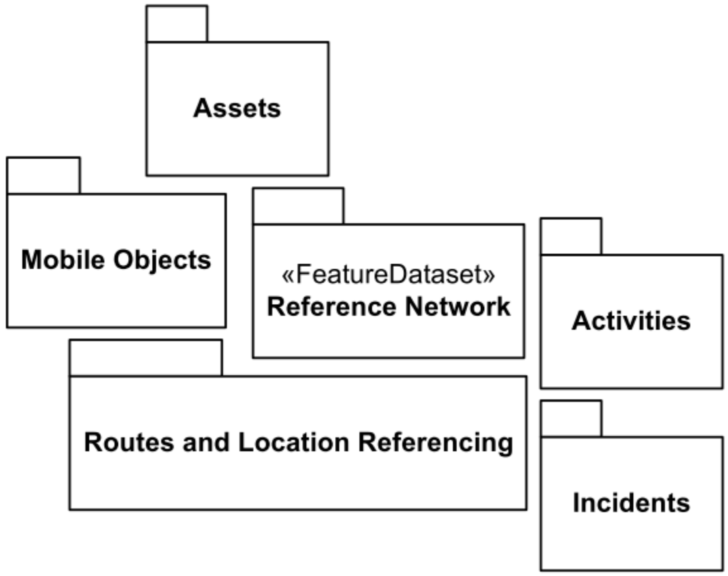


Figure 7. UNETRANS Packages

- Reference Network - A representation of linear facilities in transportation system (e.g., road, railroad tracks, bike paths, navigable waterways) and topological network defines the connectivity and adjacency of links.
- Routing and Location Referencing - feature and object classes to support turns, routes, mode restrictions, and other essential aspects of transportation network operations as well as procedures to reference objects to the transportation network.
- Assets - Representation of physical features that are not part of the network but are related to the network.
- Activities - Representation of planned actions that are related to the underlying network but are not elements of the network itself.
- Incidents - Representation of termed occurrences (e.g., traffic accidents, citations, spills) that are referenced to the network
- Mobile Objects – Representation of objects (e.g., pedestrians, airplanes, automobiles, bicycles) that can be transported across the network.

The UNETRANS model was never completed, but it introduced a design aspect combining the linear datum, geometry, and network connectivity into a single geometric network (Butler 2008).

4.1.4 Improved UNETRANS

Butler (2008) stated that the evolution of ArcGIS technology and experience with UNETRANS led to the improvement and enhancement of the original model that benefit all transport industry sectors. He proposed to regroup the original class packages into fewer packages structured by the application area. The original six packages with relationship classes are aggregated to four packages: Inventory, Network, Events, and Users (Mobile Objects). Figure 8 shows these regrouped packages. The Inventory package includes support for all types of transportation facilities including their characteristics and elements. The Network package utilizes new transportation-specific network model and replaces the geometric network. The Event package combines the previous Activities and Incident packages into a package representing things that occur on and to transport facilities. The Mobile Object package is an expanded version of the original package involving users of the transport system.

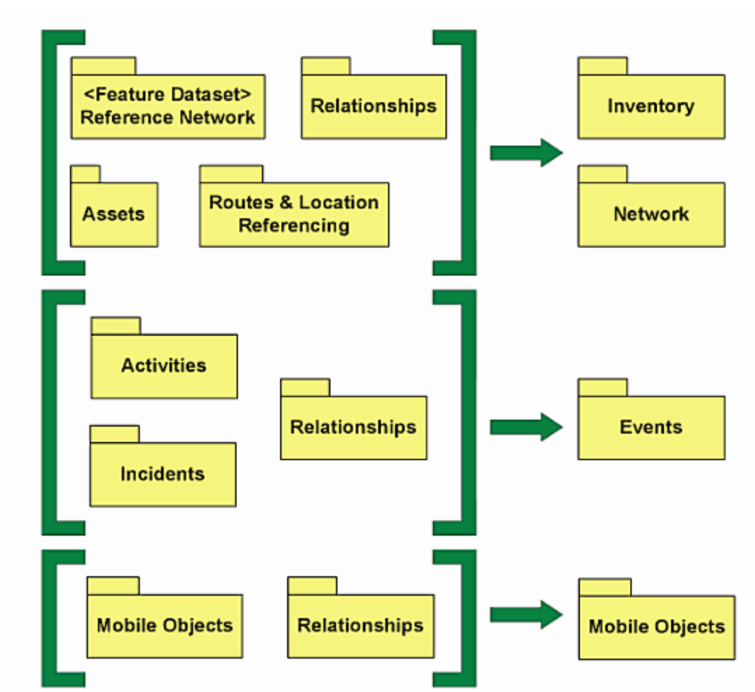


Figure 8. Revised Class Packages

The Entity class template, an abstract superlcass stereotype, is for developing all tables and feature classes to provide temporal support and editing process management by adding a set of standard fields to all user-defined geodatabase classes. The model promotes separation of the position data from the other entity attributes, and makes it possible to accommodate multiple datums for both linear referencing and geographic position. The figure 9 shows the Revised UNETRANS Inventory package, and its primary object classes which support facilities, their descriptive aspects and component elements, LRM position, and geographic coordinates. The new model adopted recent geodatabase design methods, separating route events into element (facility components, physical presence), aspect (facility attributes, descriptive facility characteristic), and things that happen (real events).

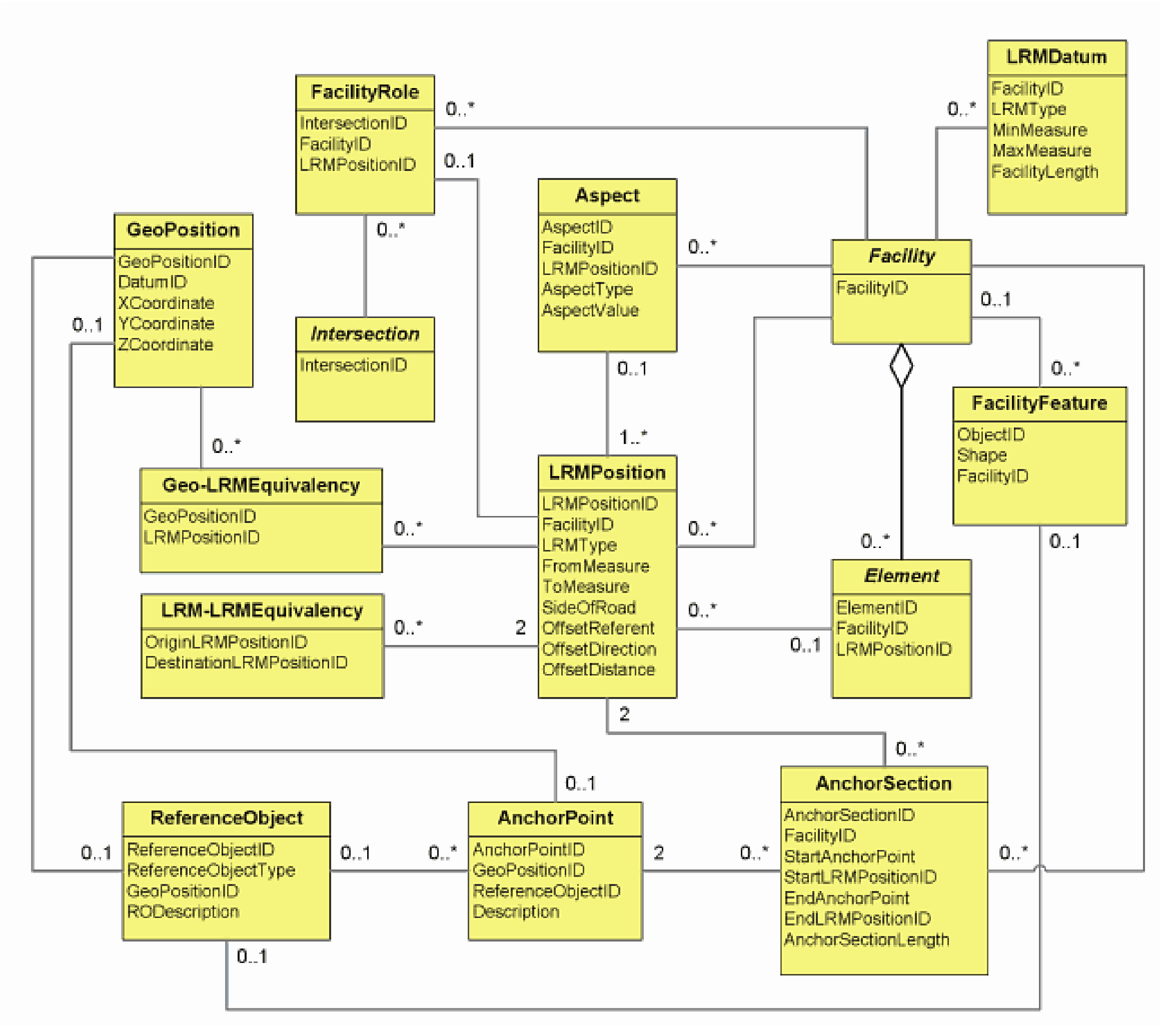


Figure 9. Improved UNETRANS Inventory Logical Model

4.2 Linear Referencing Implementation Issues

It is very important to consider the business rules and processes included in the model because data models cannot be separated from the business it serves. Depending on the transportation agency's business requirements, a model can be implemented in many different ways. From several meetings and interviews with GTI staffs, some linear referencing issues were identified. A slightly modified FHWA and GIS/Trans. Ltd (1999) questionnaire was used for interviews to review linear referencing and GIS practices in the GTI. The questionnaire and results can be found in the appendix C. However, the official document of linear referencing management manual is not currently available (lost or misplaced over time) to GTI staffs and it is absolutely crucial to establish the linear referencing rules/policies and procedures. LRS documents (SHL and Mississippi Dept. of Transportation 1996; Wisconsin Dept. of Transportation 1997; Vogt, South Dakota. Dept. of Transportation. Office of Research, and Re Spec Inc 1997) are available from other State DOTs and can be used as references. Some of the identified issues are:

- Coding traversal (route) identifier
- Use of separate traversals for each travel direction
- Special cases for defining traversals (divided highways, ramps, overlapping traversals, realignment, etc.)
- Location accuracy
- Linear referencing for local roads
- Determining location and distance (data collection methods): field and office practices
- LRS maintenance and quality control
- Management of historical data
- Multimodal integration

5. Preliminary/Pilot LRS Data Model for WVDOT

The following model is based on the Improved UNETRANS LRS data model. It is not the intension of this report to design a detailed and fully functional linear referencing system data model for WVDOT RIL, but to research the feasibility of implementing a suitable data model. It is highly recommended that additional work is needed to develop a full scale data model.

5.1 Road Inventory Log Logical Model

Butler (2008) offered a general logical data model for a state DOT facility inventory and figure 10 shows a highway inventory logical data model. This model is based on figure 9 and adopts the “everything is an event” view commonly implemented in state DOTs. The model can be modified and used to build a new RIL data model. The Event class on the model represents elements, aspects, and occurrences as events that happen on a roadway at a point event or linear event. Other classes represent elements (e.g., tunnel, culvert, bridge, sign assembly, pavement segment, intersection) located on a roadway using Event as an associative entity to connect the elements to LRM and geographic positions.

5.2 Route Segmentation

As discussed previously, the WVDOT has used a route-based LRM, and routes extend from state line to state line. Routes are typically composed of multiple segments. Initially each segment may represent the extent of a highway within a given county or district (sometimes state), but realignment and other changes will increase the number of segments. The Improved UNETRANS model supplies the standard class templates with domains for a route segment and is shown in figure 11. As discussed previously, implementing the Entity template (e.g., RecordDate, RecordStatus, EntityStatus, FromDate, ToDate) on these tables with domains (EntityCodes and RecordCodes) enables attribute level edit management and history recovery.

The template route table has RouteID (identifier of route, e.g., four digit route number), Name (route name, e.g., US 60), Abbreviation (route abbreviation for labeling), and RouteType (different highways or sign system). The segment table has CountyID, SegmentID, RoadwayID, and RCLink. CountyID is a three-digit FIPS code for the county. RoadwayID is a computer-generated simple candidate primary key and is used as a foreign key for relating to event classes and to link to geometric representations (e.g., centerline feature class). RCLink is a character string composed of RouteID, CountyID, and SegmentID and is a public key to relate roadway characteristic events to routes. These can be replaced and modified to use WVDOT codes for the RIL file. Figure 11 also shows how the Segment table is related to the Centerline feature class. The new UNETRANS model supports separation of the position data from the other attributes in order to accommodate multiple datums for both LRM and geographic positions. The Segment template in the figure uses a single LRM with included from- and to- measure values. Using the LRMPosition table instead of measure values in the Segment table can support multiple LRM types and is shown in figure 12. The relationship cardinality between a segment and a centerline is one-to-one, and one centerline should exist for each segment. However multiple versions of a segment and a centerline can exist, but there is only one active status of each. This is possible because of Entity edit and temporal management.

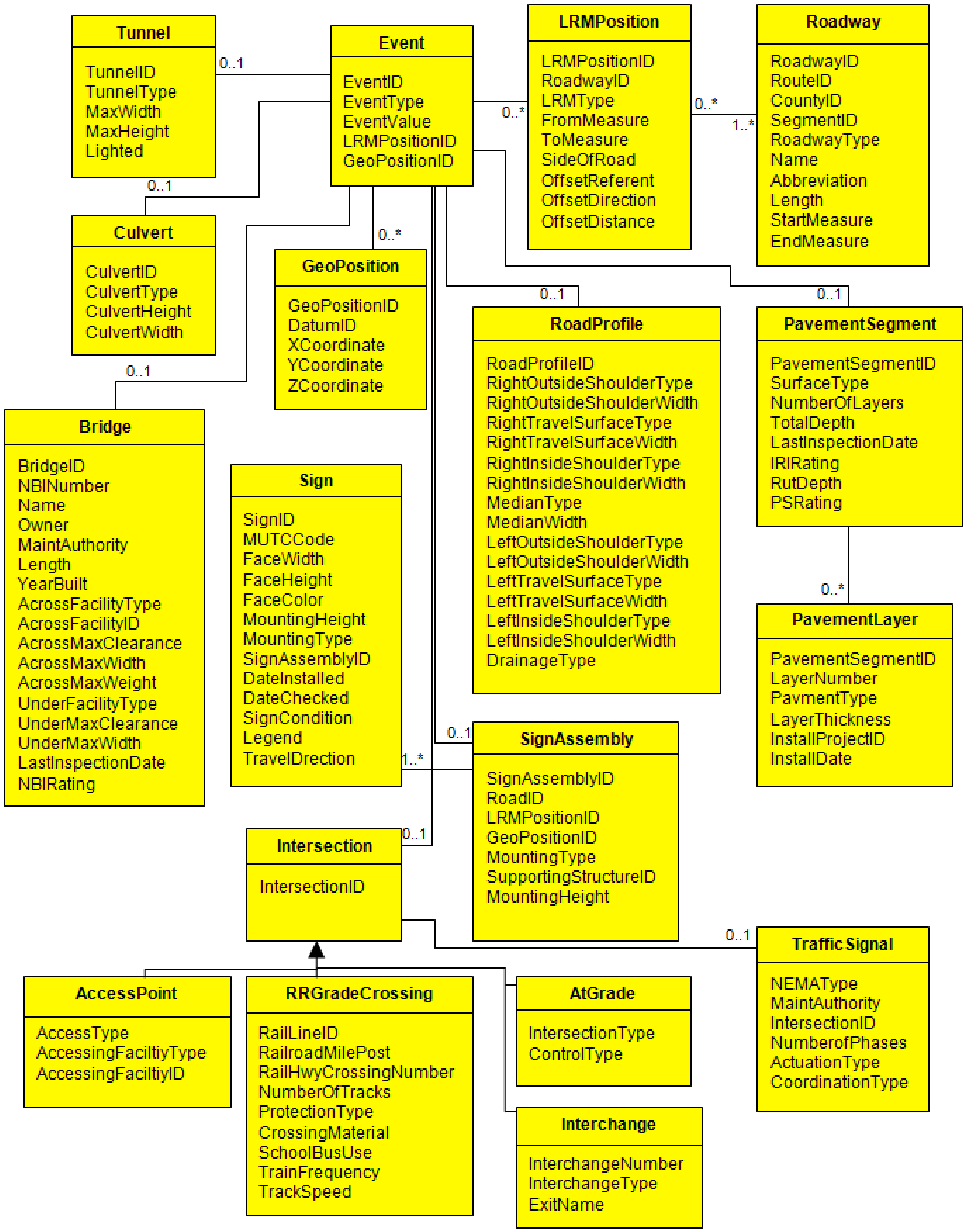


Figure 10. Highway Inventory Conceptual Data Model

Table **Route** — Route table

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	Description
OBJECTID	Object ID							
RouteID	Long integer	Yes			0			Identifier of route
RecordDate	Date	Yes			0	0	8	Data record was created
RecordStatus	Short integer	Yes	1	RecordCodes	0			Status of the record
EntityStatus	Short integer	Yes	7	EntityCodes	0			Status of the route
FromData	Date	Yes			0	0	8	Starting data of validity
ToDate	Date	Yes			0	0	8	Ending date of validity
Name	String	Yes					12	Name of route
Abbreviation	String	Yes					12	Abbreviated name of route
RouteType	String	Yes					2	Type of route
RouteLength	Double	Yes			0	0		Length of route, in miles

Table **Segment** — Route segment table

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	Description
OBJECTID	Object ID							
RouteID	Long integer	Yes			0			Identifier of route
CountyID	Long integer	Yes			0			Identifier of county
SegmentID	Long integer	Yes			0			Identifier of route segment
RoadwayID	Long integer	No			0			Identifier of route roadway
RCLink	String	Yes					15	Route segment public key
RecordDate	Date	Yes			0	0	8	Data record was created
RecordStatus	Short integer	Yes	1	RecordCodes	0			Status of the record
EntityStatus	Short integer	Yes	7	EntityCodes	0			Status of segment
FromData	Date	Yes			0	0	8	Starting date of validity
ToDate	Date	Yes			0	0	8	Ending date of validity
SegmentLength	Double	Yes			0	0		Length of segment, in miles
FromMeasure	Double	Yes			0	0		Starting LRM measure
ToMeasure	Double	Yes			0	0		Ending LRM measure

Simple feature class **Centerline** — Route Segment Centerline Features

Geometry *Polyline*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	Description
OBJECTID	Object ID							
SHAPE	Geometry	Yes						
RoadwayID	Long integer	Yes			0			Identifier of roadway
RecordDate	Date	Yes			0	0	8	Data record was created
RecordStatus	Short integer	Yes	1	RecordCodes	0			Status of the record
EntityStatus	Short integer	Yes	7	EntityCodes	0			Status of the centerline
FromDate	Date	Yes			0	0	8	Starting data of validity
ToDate	Date	Yes			0	0	8	Ending date of validity
SHAPE_Length	Double	Yes			0	0		

Coded value domain **EntityCodes**

Description *Entity Status*
Field type *Code*
Split policy *Short integer*
Merge *Default value*

Code	Description
1	Proposed
2	Under review
3	In design
4	Under construction
5	Substantial completion
6	Open to traffic
7	Accepted, in service
11	Damanged
12	Under repair
21	Jurisdiction transferred
31	Closed to traffic
32	Removed from service
33	Abandoned
34	Surplused
35	Stored
86	Demolished

Coded value domain **RecordCodes**

Description *Record status code*
Field type *Short integer*
Split policy *Default value*
Merge policy *Default value*

Code	Description
0	Work in progress
1	Proposed
2	Withdrawn
3	Rejected
4	Accepted
5	Active
6	Replaced
7	Retired

Coded value domain **RtType**

Description *Type of Route*
Field type *String*
Split policy *Default value*
Merge policy *Default value*

Code	Description
STATE_ROAD	State Road
CNTY_ROAD	County Road
CITY_STREET	City Street
FOREST_RD	Forest Road
SCENIC	Scenic Byway
COLL_DIST	Collector/Distributor
RAMP	Ramp
PRIVATE	Private
ACCESS	Access Road
TOLL	Toll
OTHER	Other

Figure 11. Route Segmentation

5.3 Events

Adopting the “everything is an event” view, figure 13 shows the geodatabase design of Event package plus Inventory package. In this design, the location data is moved from the Segment table to the LRMPosition table in order to support multiple LRM types (e.g., route-mile and street addressing). The Event table also uses a LRMPosition table plus a GeoPosition table to provide location reference instead of its location attributes. When the event represents a transportation facility element (in this case an interchange) an additional table (EventType) provides more descriptive information. The event type of “Intersection” indicates that EventValue field in the EventType table stores the identifier (IntersectionID) of the interchange which is a foreign key pointer to the Interchange table. The ElementClass field also points to the Interchange table that contains that matching foreign key value. The Intersection feature class and table stores routable information (e.g., direction of travel, turning movement, etc) that would be needed to create a navigable road network.

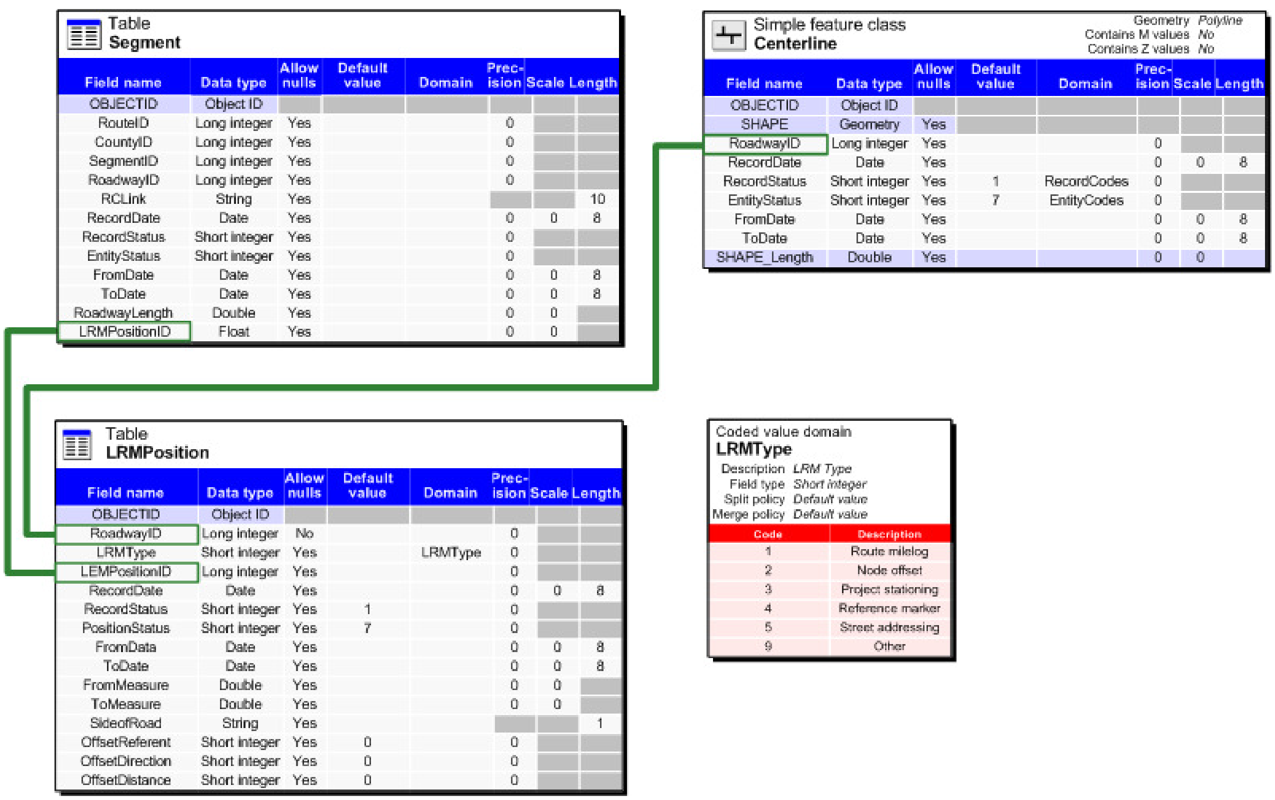


Table
Segment

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
RouteID	Long integer	Yes			0		
CountyID	Long integer	Yes			0		
SegmentID	Long integer	Yes			0		
RoadwayID	Long integer	Yes			0		
RCLink	String	Yes					10
RecordDate	Date	Yes			0	0	8
RecordStatus	Short integer	Yes			0		
EntityStatus	Short integer	Yes			0		
FromDate	Date	Yes			0	0	8
ToDate	Date	Yes			0	0	8
RoadwayLength	Double	Yes			0	0	
LRMPositionID	Float	Yes			0	0	

Simple feature class
Centerline

Geometry *Polyline*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
SHAPE	Geometry	Yes					
RoadwayID	Long integer	Yes			0		
RecordDate	Date	Yes			0	0	8
RecordStatus	Short integer	Yes	1	RecordCodes	0		
EntityStatus	Short integer	Yes	7	EntityCodes	0		
FromDate	Date	Yes			0	0	8
ToDate	Date	Yes			0	0	8
SHAPE_Length	Double	Yes			0	0	

Table
LRMPosition

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
RoadwayID	Long integer	No			0		
LRMType	Short integer	Yes		LRMType	0		
LEMPositionID	Long integer	Yes			0		
RecordDate	Date	Yes			0	0	8
RecordStatus	Short integer	Yes	1		0		
PositionStatus	Short integer	Yes	7		0		
FromData	Date	Yes			0	0	8
ToDate	Date	Yes			0	0	8
FromMeasure	Double	Yes			0	0	
ToMeasure	Double	Yes			0	0	
SideofRoad	String	Yes					1
OffsetReferent	Short integer	Yes	0		0		
OffsetDirection	Short integer	Yes	0		0		
OffsetDistance	Short integer	Yes	0		0		

Coded value domain
LRMType

Description *LRM Type*
Field type *Short integer*
Split policy *Default value*
Merge policy *Default value*

Code	Description
1	Route milelog
2	Node offset
3	Project stationing
4	Reference marker
5	Street addressing
9	Other

Figure 12. Alternate Segment Table Design

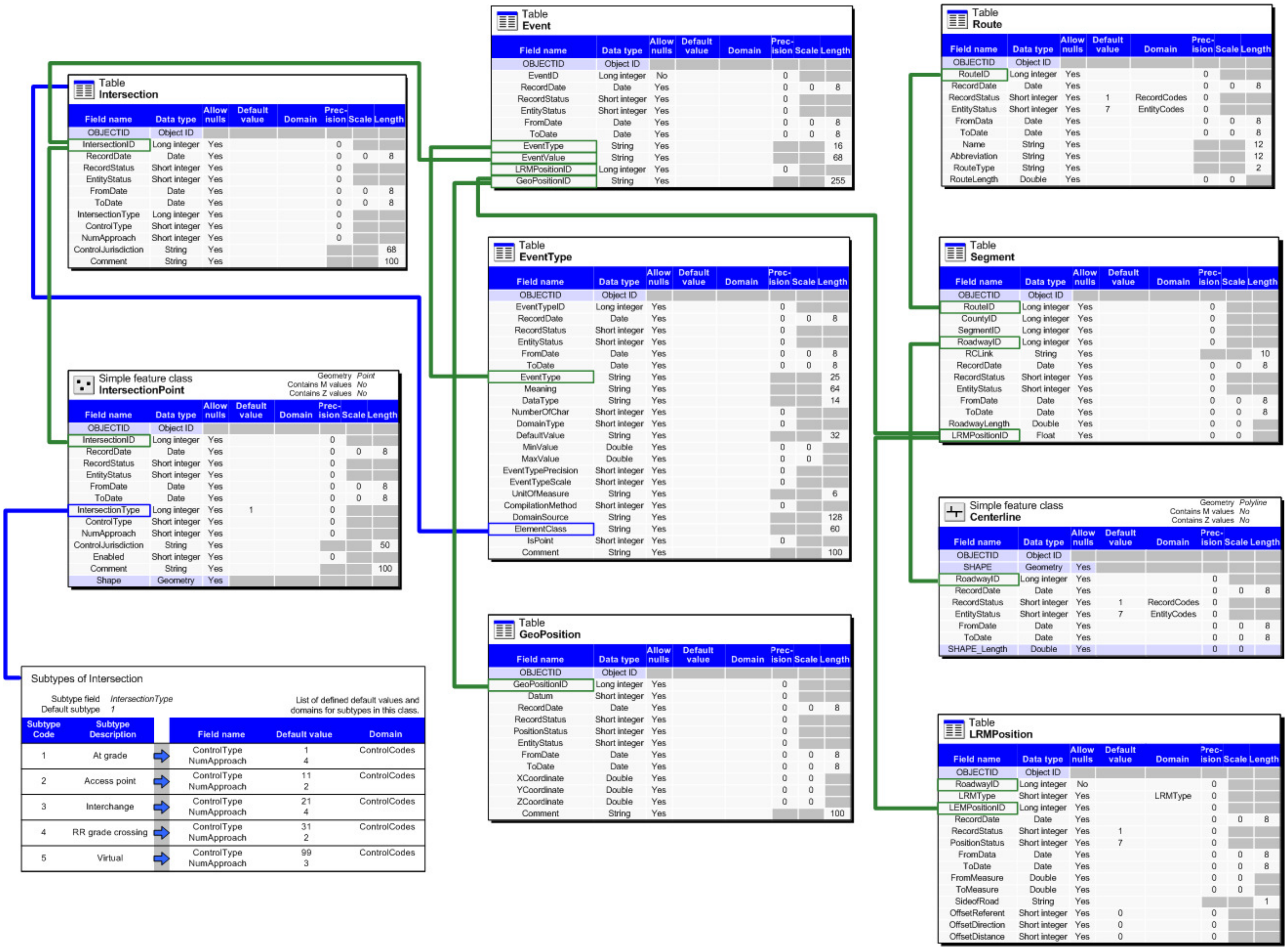


Figure 13. Event and Inventory Package geodatabase design

5.4 Navigable Network

The improved UNETRANS replaces the geometric network with the transportation specific network dataset and continues to support pathfinding (routing/traversing) applications. Network datasets are composed of two basic (edges and junctions) and one optional (turns) network elements (Environmental Systems Research Institute 1999). Edges connect junctions where flows travel over. Junctions connect edges and where flows can move from one edge to another edge. Turns store turning movements. In addition, elements have attributes that supplement flows along the network.

Elements are generated and connectivity is established from the source features when the network dataset is created. The new network dataset can be created from a shape file or feature classes within a feature dataset. The only required data source is a feature class that provides edge features. If a junction source is not provided, the process will create junction features where lines terminate and where two line cross.

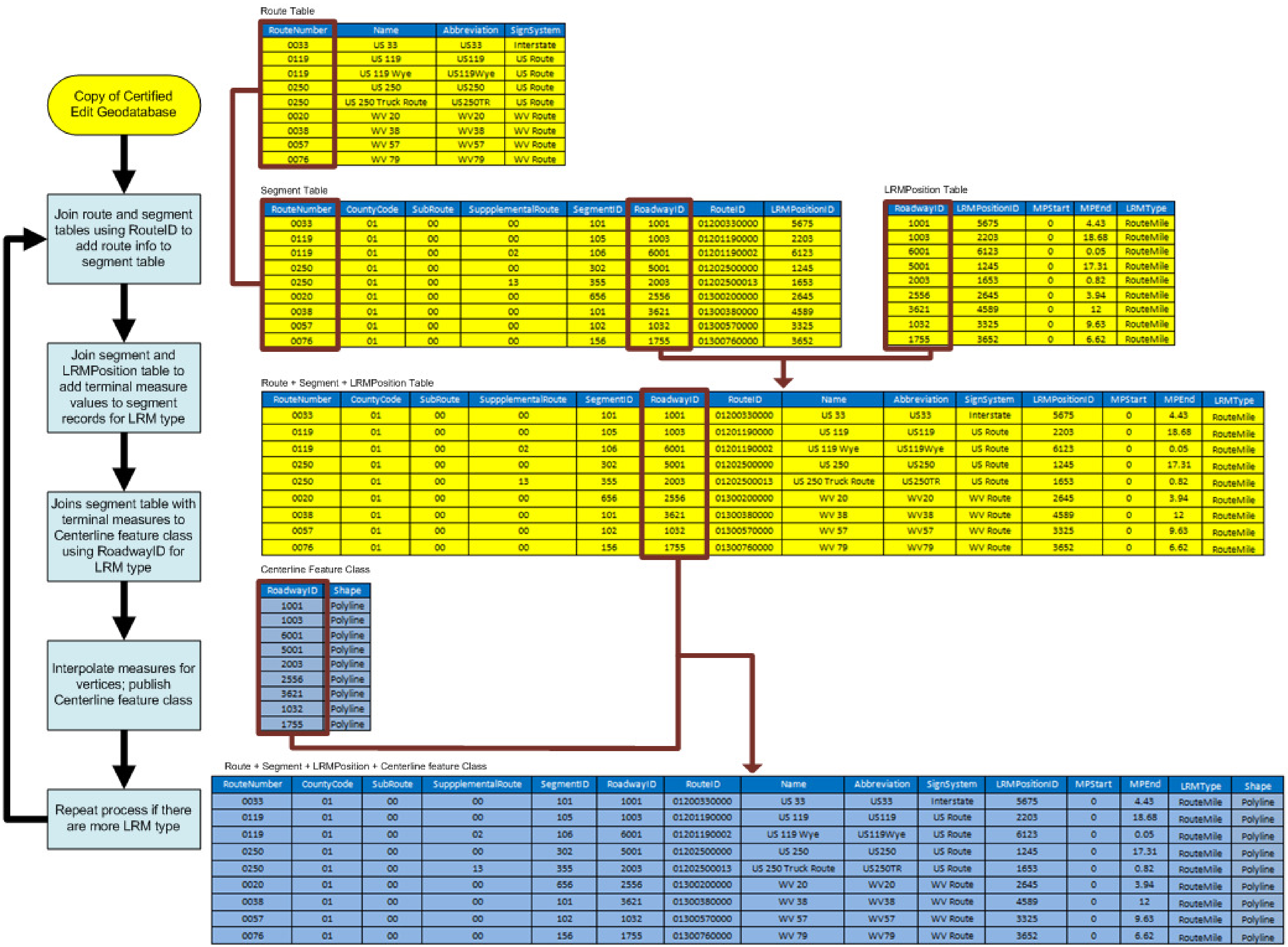
WVDOT and SAMB data do not include attributes on turn restrictions, one-way roads or any other travel impedances that can be used for effective routing. Building and maintaining statewide attributes required to support routing would be very challenging and time consuming. Commercial routing attributes are available for purchase but the typical license agreement is very restrictive or prohibitive of data sharing. There is also data conflation issue between commercial data and DOT data.

6. Publishing Data

Butler (2008) recommends using two separate geodatabases for editing and publishing. An effective editing geodatabase is designed to support editing routines and is highly normalized. Such a geodatabase is not suitable for data analysis and applications require denormalized and derived data. Also significant performance improvement can be achieved by separating an editing database from typical user data access and analysis. Denormalized tables and features classes in the published geodatabase are acquired from data extraction and combinations from multiple tables and feature classes in the edit geodatabase.

Figure 14 illustrates the short process required to publish a centerline feature class for dynamic segmentation along with tables and features class examples. Route, Segment, and

LRMPosition tables are joined using foreign keys (RouteNumber and RoadwayID in this example) adding route information and LRM locations to the Segment table. Then, join the Segment table with added information and the Centerline feature class. This step provides centerline features with route identifier and measurement values which are required to create the route feature classes. Using the Create Route function in ArcGIS Linear Referencing Tools, the output Centerline feature class will have M-values. Optionally, calibration points such as anchor points, if available, can be used to increase accuracy of the route. Similar to the Centerline feature class process, the process of publishing a denormalized Event table is shown in figure 15. The Event, LRMPosition and GeoPosition tables are joined to create the output Event table with LRM and Geographic locations data. Then extract and combine each event type by group and combination. Different Edit geodatabase designs can have different publishing processes.



Route Table

RouteNumber	Name	Abbreviation	SignSystem
0033	US 33	US33	Interstate
0119	US 119	US119	US Route
0119	US 119 Wye	US119Wye	US Route
0250	US 250	US250	US Route
0250	US 250 Truck Route	US250TR	US Route
0020	WV 20	WV20	WV Route
0038	WV 38	WV38	WV Route
0057	WV 57	WV57	WV Route
0076	WV 79	WV79	WV Route

Segment Table

RouteNumber	CountyCode	SubRoute	SuppplementalRoute	SegmentID	RoadwayID	RouteID	LRMPositionID
0033	01	00	00	101	1001	01200330000	5675
0119	01	00	00	105	1003	01201190000	2203
0119	01	00	02	106	6001	01201190002	6123
0250	01	00	00	302	5001	01202500000	1245
0250	01	00	13	355	2003	01202500013	1653
0020	01	00	00	656	2556	01300200000	2645
0038	01	00	00	101	3621	01300380000	4589
0057	01	00	00	102	1032	01300570000	3325
0076	01	00	00	156	1755	01300760000	3652

LRMPosition Table

RoadwayID	LRMPositionID	MPStart	MPEnd	LRMType
1001	5675	0	4.43	RouteMile
1003	2203	0	18.68	RouteMile
6001	6123	0	0.05	RouteMile
5001	1245	0	17.31	RouteMile
2003	1653	0	0.82	RouteMile
2556	2645	0	3.94	RouteMile
3621	4589	0	12	RouteMile
1032	3325	0	9.63	RouteMile
1755	3652	0	6.62	RouteMile

Route + Segment + LRMPosition Table

RouteNumber	CountyCode	SubRoute	SuppplementalRoute	SegmentID	RoadwayID	RouteID	Name	Abbreviation	SignSystem	LRMPositionID	MPStart	MPEnd	LRMType
0033	01	00	00	101	1001	01200330000	US 33	US33	Interstate	5675	0	4.43	RouteMile
0119	01	00	00	105	1003	01201190000	US 119	US119	US Route	2203	0	18.68	RouteMile
0119	01	00	02	106	6001	01201190002	US 119 Wye	US119Wye	US Route	6123	0	0.05	RouteMile
0250	01	00	00	302	5001	01202500000	US 250	US250	US Route	1245	0	17.31	RouteMile
0250	01	00	13	355	2003	01202500013	US 250 Truck Route	US250TR	US Route	1653	0	0.82	RouteMile
0020	01	00	00	656	2556	01300200000	WV 20	WV20	WV Route	2645	0	3.94	RouteMile
0038	01	00	00	101	3621	01300380000	WV 38	WV38	WV Route	4589	0	12	RouteMile
0057	01	00	00	102	1032	01300570000	WV 57	WV57	WV Route	3325	0	9.63	RouteMile
0076	01	00	00	156	1755	01300760000	WV 79	WV79	WV Route	3652	0	6.62	RouteMile

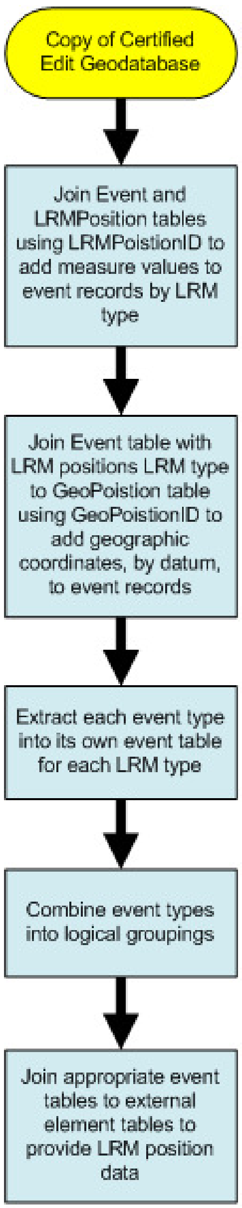
Centerline Feature Class

RoadwayID	Shape
1001	Polyline
1003	Polyline
6001	Polyline
5001	Polyline
2003	Polyline
2556	Polyline
3621	Polyline
1032	Polyline
1755	Polyline

Route + Segment + LRMPosition + Centerline feature Class

RouteNumber	CountyCode	SubRoute	SuppplementalRoute	SegmentID	RoadwayID	RouteID	Name	Abbreviation	SignSystem	LRMPositionID	MPStart	MPEnd	LRMType	Shape
0033	01	00	00	101	1001	01200330000	US 33	US33	Interstate	5675	0	4.43	RouteMile	Polyline
0119	01	00	00	105	1003	01201190000	US 119	US119	US Route	2203	0	18.68	RouteMile	Polyline
0119	01	00	02	106	6001	01201190002	US 119 Wye	US119Wye	US Route	6123	0	0.05	RouteMile	Polyline
0250	01	00	00	302	5001	01202500000	US 250	US250	US Route	1245	0	17.31	RouteMile	Polyline
0250	01	00	13	355	2003	01202500013	US 250 Truck Route	US250TR	US Route	1653	0	0.82	RouteMile	Polyline
0020	01	00	00	656	2556	01300200000	WV 20	WV20	WV Route	2645	0	3.94	RouteMile	Polyline
0038	01	00	00	101	3621	01300380000	WV 38	WV38	WV Route	4589	0	12	RouteMile	Polyline
0057	01	00	00	102	1032	01300570000	WV 57	WV57	WV Route	3325	0	9.63	RouteMile	Polyline
0076	01	00	00	156	1755	01300760000	WV 79	WV79	WV Route	3652	0	6.62	RouteMile	Polyline

Figure 14. Publishing Centerline Feature Class



Event Table

EventID	EventType	EventValue	LRMPositionID	GeoPositionID
4236	Guide Rail	3042	1035	526
4237	Guide Rail	3043	1036	527
4238	Guide Rail	3044	1037	528
4239	End Treatment	236	1038	529
5000	Guide Rail	3045	1039	530
5001	Signs	21223	1040	531
5002	Signs	21224	1041	532
3023	Bridges	10012	2056	236
2995	Guide Rail	2556	2057	237
2589	Guide Rail	2557	2058	238
2369	Bridges	10013	2059	239

LRMPosition Table

RoadywayID	LRMType	LRMPosition	FromMeasure	ToMeasure
503	RouteMile	1035	58.757	
503	RouteMile	1036	58.761	
503	RouteMile	1037	58.701	
503	RouteMile	1038	58.7	
503	RouteMile	1039	58.7	
503	RouteMile	1040	58.618	
503	RouteMile	1041	58.619	
489	RouteMile	2056	31.653	31.674
489	RouteMile	2057	31.653	
489	RouteMile	2058	31.65	
489	RouteMile	2059	27.556	28.125

Event + LRMPosition Table

EventID	EventType	EventValue	LRMPositionID	GeoPositionID	RoadwayID	LRMType	FromMeasure	ToMeasure
4236	Guide Rail	3042	1035	526	503	RouteMile	58.757	
4237	Guide Rail	3043	1036	527	503	RouteMile	58.761	
4238	Guide Rail	3044	1037	528	503	RouteMile	58.701	
4239	End Treatment	236	1038	529	503	RouteMile	58.7	
5000	Guide Rail	3045	1039	530	503	RouteMile	58.7	
5001	Signs	21223	1040	531	503	RouteMile	58.618	
5002	Signs	21224	1041	532	503	RouteMile	58.619	
3023	Bridges	10012	2056	236	489	RouteMile	31.653	31.674
2995	Guide Rail	2556	2057	237	489	RouteMile	31.653	
2589	Guide Rail	2557	2058	238	489	RouteMile	31.65	
2369	Bridges	10013	2059	239	489	RouteMile	27.556	28.125

GeoPosition Table

GeoPositionID	GPSLongS	GPSLongE	GPSLatS	GPSLatE	GPS_ELEV	Datum
526	-81.633050	-81.633050	38.359910	38.359910	589	NAD83
527	-81.632870	-81.632870	38.359970	38.359970	592.3	NAD84
528	-81.633930	-81.633930	38.360280	38.360280	583.4	NAD85
529	-81.633930	-81.633930	38.360280	38.360280	582.7	NAD86
530	-81.633930	-81.633930	38.360280	38.360280	582.7	NAD87
531	-81.635270	-81.635270	38.360440	38.360440	611.4	NAD88
532	-81.635250	-81.635250	38.360500	38.360500	609.3	NAD89
236	-82.054760	-82.054760	38.425600	38.425600	704.9	NAD90
237	-82.055080	-82.055080	38.425420	38.425420	705.3	NAD91
238	-82.055180	-82.055180	38.425490	38.425490	703.2	NAD92
239	-82.122270	-82.122270	38.439390	38.439390	619.1	NAD93

Event + LRMPosition + GeoPosition Table

EventID	EventType	EventValue	LRMPositionID	GeoPositionID	RoadwayID	LRMType	FromMeasure	ToMeasure	GPSLongS	GPSLongE	GPSLatS	GPSLatE	GPS_ELEV	Datum
4236	Guide Rail	3042	1035	526	503	RouteMile	58.757		-81.633050	-81.633050	38.359910	38.359910	589	NAD83
4237	Guide Rail	3043	1036	527	503	RouteMile	58.761		-81.632870	-81.632870	38.359970	38.359970	592.3	NAD84
4238	Guide Rail	3044	1037	528	503	RouteMile	58.701		-81.633930	-81.633930	38.360280	38.360280	583.4	NAD85
4239	End Treatment	236	1038	529	503	RouteMile	58.7		-81.633930	-81.633930	38.360280	38.360280	582.7	NAD86
5000	Guide Rail	3045	1039	530	503	RouteMile	58.7		-81.633930	-81.633930	38.360280	38.360280	582.7	NAD87
5001	Signs	21223	1040	531	503	RouteMile	58.618		-81.635270	-81.635270	38.360440	38.360440	611.4	NAD88
5002	Signs	21224	1041	532	503	RouteMile	58.619		-81.635250	-81.635250	38.360500	38.360500	609.3	NAD89
3023	Bridges	10012	2056	236	489	RouteMile	31.653	31.674	-82.054760	-82.054760	38.425600	38.425600	704.9	NAD90
2995	Guide Rail	2556	2057	237	489	RouteMile	31.653		-82.055080	-82.055080	38.425420	38.425420	705.3	NAD91
2589	Guide Rail	2557	2058	238	489	RouteMile	31.65		-82.055180	-82.055180	38.425490	38.425490	703.2	NAD92
2369	Bridges	10013	2059	239	489	RouteMile	27.556	28.125	-82.122270	-82.122270	38.439390	38.439390	619.1	NAD93

Figure 15. Publishing Event Table

7. Conclusion

Integration of WVDOT road centerline and SAMB dataset is feasible to create and maintain a single, statewide road centerline dataset that can meet most of the requirements of the WVDOT. In creating a statewide centerline data set, it is important to review existing data as well as identify any DOT requirements and develop a LRS and GIS data model. The revised/improved UNETRANS data model can be successfully implemented accommodating WVDOT RIL system requirements. The data model will minimize any impact on existing WVDOT business processes and improve/enhance them. Using the advantage of Edit and Publish geodatabase design practices, the DOT can continuously develop and perfect the data model and migrate from the old system in stages. At the same time, the DOT can provide data to users and applications without interrupting their services.

Creating and maintaining a statewide dataset that includes the attributes (e.g., one way roads, turn restrictions, etc.) required to support full automated routing (traversing) would be challenging and costly. These attributes do not exist in publicly available data but can be acquired from commercial vendors. However, integrating SAMB road centerlines will add connectivity, segmentation, and address ranges to a statewide centerline dataset which are requirements of routing. These will provide other benefits such as distance analysis and geocoding. The DOT should approach the routing requirement as a long-term project and develop an action plan.

Appendix A: Glossary

The definitions in this glossary are derived from the following sources.

[1] Federal Highway Administration, and GIS/Trans. Ltd. 1999. *Federal Highway Administration Linear Referencing Practitioners Guidebook*. [S.l.]: GIS/Trans Ltd.
[2] Highway Research Board, and National Academy of Engineering. 1974. *Highway Location Reference Methods*, *National Cooperative Highway Research Program (NCHRP) Synthesis of Highway Practice 21*. Washington, D.C.: Highway Research Board, National Academy of Sciences.
[3] United State Geological Survey. 1999. *Spatial Data Transfer Standard (SDTS)*. Reston, Va.: U.S. Dept. of the Interior, U.S. Geological Survey.
[4] Vonderohe, A. P., C. L. Chou, F. Sun, and T. M. Adams. 1997. A generic data model for linear referencing systems. In *Research Results Digest 218. National Cooperative Highway Research Program. Transportation Research Board*.
[5] Wikipedia contributors, Wikipedia, The Free Encyclopedia, http://en.wikipedia.org/ (accessed May 11, 2010).
[6] Wood, Stearns J., and Data West Research Agency. 2000. *A practitioner's guide to GIS terminology : a glossary of geographic information system terms*. University Place, WA: Data West Research Agency.

Anchor Point: A zero-dimensional location that can be uniquely identified in the real world in such a way that its position can be determined and recovered in the field. Each anchor point has a “location description” attribute that provides the information necessary for determining and recovering the anchor point’s position in the field. Forms of location descriptions can vary and can be quantitative or descriptive or both, (e.g., the intersection of the centerlines of Oak Street and Maple Street; and 1.2 miles south of the Post Office on the centerline of Route 9). Anchor points can be understood as one-dimensional control points, in that they serve the same purpose as geodetic control points in two and three dimensions. That is, they are the fundamental objects to which all other objects are directly or indirectly tied [3].

Anchor Section: A continuous, directed, nonbranching linear feature, connecting two anchor points, whose real-world length (in distance metrics), can be determined in the field. Anchor sections are directed by specifying a “from” anchor point and a “to” anchor point. Anchor sections have a “distance” attribute, which is the length of the anchor section measured on the ground. Values are expressed in units of linear distance measure (e.g., kilometers). Anchor sections provide the fundamental referencing space. The collection of anchor sections in a given linear referencing system is analogous to the ellipsoid surface in a geodetic datum or the map projection surface in a two-dimensional Cartesian referencing system [3].

Dynamic Segmentation: A GIS function for modeling linear features in highway applications such as accident analysis and pavement management. The process has the ability to compute locations of events on linear features at run time (or dynamically) in linear measure (e.g. milepost). Event features, the segmentation points, are not stored in the geometry of the coverage but are derived as needed. Route-system features and event handling commands provide the dynamic segmentation capability within GIS systems to dynamically locate events on linear features that are obtained from attribute tables of events for which distance measures are available. Both point and linear events can be located on routes; lane closure is an example of a linear event and the accident location is an example of a point event [6].

Entity-relationship diagram: In software engineering, an entity-relationship model (ERM) is an abstract and conceptual representation of data. Entity-relationship modeling is a database modeling method, used to produce a type of conceptual schema or semantic data model of a system, often a relational database, and its requirements in a top-down fashion. Diagrams created by this process are called entity-relationship diagrams, ER diagrams, or ERDs [5].

Event: A feature, characteristic or phenomenon that occurs along a roadway (or traversal) and is described by attributes stored in a database, including its location specified by a linear referencing method [1].

Linear Datum: The complete set of anchor sections and anchor points, constituting a mutually exclusive, totally exhaustive, ordered set of linear locations. The linear datum relates the database representation to the real world and provides the domain for transformations among linear referencing methods and among cartographic representations. There is a single linear datum. It is included in this data model because of the centrality of its concept to the overall model, not because there would necessarily be a number of instances that would have to be tracked in a database. Various versions of the linear datum might exist over time as changes in transportation facilities occur. No attributes are assigned to the linear datum [4].

Linear Event: A 1-dimensional event with location specified by a two linear measures along a traversal. A linear event must reference one ‘start’ and one ‘end’ reference point along the same traversal [1].

Linear Referencing Method: A location referencing method in with a location is specified as occurring on a uniquely identified linear feature (i.e., a traversal), at a set distance and direction from another point with a known linear measure (often the beginning of the traversal)[1].

Linear Referencing System: A location referencing system comprised of one of more linear referencing methods [1].

Link: A 1-dimensional object that is a topological connection between two nodes [3]. In common parlance, the term ‘link’ often refers as well to the linear feature that connects two nodes in a GIS centerline layer. However, a clear distinction is made for data modeling, where a ‘link’ is simply a topological connection, and a ‘line’ has shape and position and can be used for cartographic representation [1].

Location Referencing Method: The technique used to identify a specific point or segment of a roadway, either in the field or in the office [2].

Location Referencing System: Total set of procedures for determining and retaining a record of specific points along a roadway. The system includes the location referencing method(s) together with the procedures for storing, maintaining, and retrieving location information about points and segments on the roadways [2].

Node: A zero-dimensional object that is a topological junction between two or more links, or an end point of a link [3][4].

Point Event: A zero-dimensional event with location specified by a single linear measures along a traversal. A point event must reference one and only one traversal reference point [1].

Route: An ambiguous term which is often used to mean (a) a numbered or named highway (or roadway) as signed in the field, (b) a traversal with associated linear measures, or (c) both of these [1].

Segment: An ambiguous term referring to any portion of a roadway [1].

Traversal: An ordered and directed, but not necessarily connected, set of whole links. Coding conventions are required for establishing traversal directionality (in contrast to link directionality) and for specifying nonconnected traversals. No attributes are assigned to traversals [3].

Appendix B: Bibliography

Butler, Allison J. 2008. *Designing geodatabases for transportation*. 1st ed. Redlands, Calif.: ESRI Press.

Curtin, Kevin , Valerian Noronha, Mike Goodchild, and Steve Grise. 2003. ArcGIS Transportation Data Model (UNETRANS). In *UNETRANS Data Model Reference*.

Dueker, K. J. , and J. A. Butler. 1997. GIS-T Enterprise Data Model with Suggested Implementation Choices. Portland OR: Center for Urban and Public Affair, Portland State University.

Easa, Said, Yupo Chan, and American Society of Civil Engineers. Geographic Information Systems Committee. 2000. *Urban planning and development applications of GIS*. Reston, Va.: American Society of Civil Engineers.

Environmental Systems Research Institute. *ArcGIS desktop 9.3 help*. ESRI 1999. Available from http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=welcome.

Federal Highway Administration, and GIS/Trans. Ltd. 1999. *Federal Highway Administration Linear Referencing Practitioners Guidebook*. [S.l.]: GIS/Trans Ltd.

Highway Research Board, and National Academy of Engineering. 1974. *Highway Location Reference Methods*, *National Cooperative Highway Research Program (NCHRP) Synthesis of Highway Practice 21*. Washington, D.C.: Highway Research Board, National Academy of Sciences.

Krätzschmar, Marc. 2010. *Implementing the UNETRANS Data Model* 20012010]. Available from http://proceedings.esri.com/library/userconf/proc01/professional/papers/pap975/p975.htm.

Litteral, Sean. 2007. WVDOT Strategic GIS Implementation Plan. edited by West Virginia Department of Transportation. Geospatial Transportation Information.

Miller, Harvey J, and Shih-Lung Shaw. 2001. *Geographic Information Systems for Transportation: Principles and Applications*. New York, New York: Oxford University Press.

SHL, and Mississippi Dept. of Transportation. 1996. *Linear Refereencing System (LRS) Design and requirements*: Mississippi Dept. of Transportation.

Vogt, Tim J., South Dakota. Dept. of Transportation. Office of Research, and Re Spec Inc. 1997. *A Location referencing system to support data integration*. Rapid City, SD: South Dakota Dept. of Transportation, Office of Research.

Vonderohe, A P, L Travis, R L Smith, and V Tsai. 1993. Adaptation of geographic information systems for transportation. In *NCHRP Report 359, Transportation Research Board, National Research Council*: Press.

Vonderohe, A. P., C. L. Chou, F. Sun, and T. M. Adams. 1997. A generic data model for linear referencing systems. In *Research Results Digest 218. National Cooperative Highway Research Program. Transportation Research Board*.

West Virginia Department of Transportation. GTI. *About Highway Data Services* 2009. Available from http://gis.wvdot.com/gti/HighwayData.aspx.

West Virginia Department of Transportation. Planning & Research. 2007. Codes for Road Inventory File.

Wisconsin Dept. of Transportation. 1997. *Location control management manual*: Wisconsin Dept. of Transportation.

Appendix C: Linear Referencing System Questionnaire

LINEAR REFERENCING SYSTEM QUESTIONNAIRE

1. Organizational Information
    1.1. What office is responsible for development and maintenance of the agency's linear referencing systems? Describe its responsibilities.
    WVDOH has been using same Linear Referencing Method (LRM), which is a base-offset (named route/milepoint), since it took over roads from Counties in 1930s and hasn't changed how they specify locations along roadways. Mainframe application, Road Inventory Log (RIL), was developed to manage LRS since 1970 and DOH is developing a new RIL to migrate old system. RIL will serves as the enterprise transportation database. Geospatial Transportation Information (GTI) under Program Planning and Administration Division is responsible for RIL. The Highway Data System (HDS) unit under GTI processes addition, change or abandonment requests from the Districts and updates the roadway inventory records as Commissioner Orders are issued. Improvements are also updated to the Roadway Inventory File as received either from the Districts in the form of PJ-101, PJ-103 or by way of field notes generated by the regular field crew inventories. Other roadway history records dating back to 1933 including maps, scroll records, microfilmed documentation, correspondence files and official Commissioner Orders are also maintained in the work area. A Local Name Listing is updated as needed in coordination with the Districts and their respective County 911 organizations that have authority over the local name determination. The unit is also responsible to perform the functions necessary to support quality data needed to deliver the annual Public Certified Mileage Report and the Highway Performance Monitoring System (HPMS) submittal as per FHWA requirements and guidelines. The HPMS submittal is an expanded representation of the Certified Mileage and the data are used extensively by FHWA in the analysis of highway system condition, performance, and investment needs that make up the biennial Condition and Performance Reports to Congress. GIS unit, another GTI unit, is responsible for maintaining software and hardware of RIL.
    1.2. What office is responsible for coordinating GIS activities? Describe its responsibilities.
    GTI section
2. Overview of Current Use of Linear Referencing
    2.1. Can you name and briefly describe each of the linear referencing systems currently in use in your agency?
    Note: it's important to get the "name" by which each LRS will be referenced Detailed descriptions come in the next section.
    No official name for LRS (or RIL).
    2.2. We'll go over each of the LRSs in detail, but what are the major issues you face, as a department, with regard to linear referencing?
    For example: managing updates to the LRS and historical data, integration of data using different LRSs, integration with GPS and other data types, implementation in GIS, development of referencing systems for local roads. etc.
    No major issue was addressed by attendees.
    2.3. What formal process, if any, was used for development of your linear referencing system(s), e.g., Information Engineering?
    No formal process.
    2.4. Describe any current initiatives you have for revising / expanding your linear (and location) referencing.

No formal process

2.5. Do you have any standards or other documentation on your agency's linear (or location) referencing strategy and systems? • Request copies of any available documentation.

No official documentation.

3. Detailed Description of Each LRS

3.1. General Over View

3.1.1. How is this LRS referred to (its ''name'')?

Road Inventory Log.

3.1.2. What type of LRS is this (route/milepoint, link/node, control section, etc.).

Route/Milepoint

3.1.3. Briefly describe how the LRS is managed (e.g., computer application, hardware/software, etc.).

A mainframe CICS application is used to manage LRS control files and key event database, flatfile system. New RIL in MSSQL RDBMS will replace current system as soon as on-going RIL improvement project is completed.

3.1.4. What documentation describes this LRS (obtain copies)?

No

3.1.5. What documentation exists for end-users, on how to determine and record locations, standard database fields, etc.?

Codes for Road Inventory File and HPMS manual from FHWA

3.1.6. How long has this LRS been in use?

Since 1970s

3.1.7. Has it undergone any major revisions? If so, explain.

No.

3.1.8. Whose responsibility is it to maintain and update the LRS, and to assure correct use of the LRS?

HDS unit. End of year, when the annual Public Certified Mileage, the HPMS, and the biennial Condition and Performance Reports are due, HDS unit also does cross quality check.

3.2. Use of this LRS

3.2.1. Who in this agency uses this LRS (e.g., what management systems), and what information is referenced to this LRS:

- ☒ General roadway characteristics system
- ☒ Traffic management (counts, volumes, etc.)
- ☒ Congestion management
- ☒ Accidents
- ☒ Bridges
- ☒ Pavement management
- ☒ Highway / work program development
- ☒ Project monitoring system
- ☒ Engineering / design
- ☒ HPMS
- ☐ Other:
- ☒ Right-of-way
- ☒ Videolog
- ☒ Permit routing
- ☒ Maintenance
- ☐ Local road inventory
- ☒ Rail (crossings, etc.)
- ☐ Air / aviation
- ☐ Public transportation
- ☒ Construction management
- ☒ Sign inventory

3.2.2. What end-user applications (GIS or other) make use of this LRS (work program development, etc.)?

All of GIS web and desktop applications, HPMS applications, Project tracking application, PRS & PRS master (construction/engineering/right-of-way applications), etc

3.2.3. To what degree is this LRS used and/or maintained and updated by DOT district offices?
Division and district initiate LRS change process and also responsible for field validation of any LRS changes.

3.3. Route definition, coding, resolution

3.3.1. How are routes defined? What roadway sections make up a route, and how are start and end points-determined?
By state law, sequential, commissioner order, design specs, ADT

3.3.2. To which roadways does this LRS apply (state system, county, other public roads, etc.)? Note: specific cases like ramps and service roads are dealt with below.
Any roadways (approximately 37,000 miles) State owns.

3.3.3. How are the routes IDs coded? Note: be specific concerning the meaning of individual characters and codes, the use of leading zeros, justification within the field, etc. Any documentation?
New System
Route ID _ _ - _ - _ _ _ _- _ _ - _ _
1 2 3 4 5 6 7 8 9 10 11
Where the suffix 1 and 2 represent the county and suffix 3 is for the sign system. Suffix 4, 5, 6, and 7 would make up the route number/use leading zero and suffix 8 and 9 would be the sub route number. Suffix 10 and 11 would make up the supplemental description of the route. When field is N/A zero is used.
Old system in mainframe
Route number is 3 digits instead of 4 digits

3.4. Linear Referencing System control

LRS control files (or tables, or diagrams) define the key components which control the LRS, and the relationships between them. LRS control elements may include routes, links, control points, mileage equations or other components. Data tables (or event tables) are not part of the LRS control.

3.4.1. What documentation describes the LRS control files (or tables, diagrams, etc.)?
SLD and commissioner order

~~3.4.2. Describe the control files used to manage the LRS (or reference the documentation).~~

3.4.3. Are mileage equations used? If so, describe their use and function.
No.

3.4.4. Describe any other tables that comprise the LRS database, and the database structure.
Mainframe application –
RIL -

3.4.5. What are the strengths and weaknesses of the LRS control database?
Weakness: Historical record keeping once a year back to 1996. flat file

3.5. Field practices / data collection

3.5.1. Are mileposts or reference posts (i.e., signs) used in the field? ☒Yes ☐No If so:
~~a) When were they established?~~
b) Have they been maintained, and are there any maintenance issues?
Interstate and some US & State routes have mileposts
c) Are they considered to be accurate?
Every 1 mile with 0.1 mile accuracy

3.5.2. How are 'correct' route lengths determined in the field (e.g., use of DMIs)?
Use of DMI for at least 10 years

3.5.3. What "centerline" is used to determine road length (e.g., right lane)?

Design mile is based on the center of the road. In the RIL, road length is based on a measured mile and every three to five years they remeasure.

3.5.4. Where exactly are the start and end points of routes (e.g., within an intersection)?
State & county boundary and Intersections.

3.5.5. How are the measures (the "locations") of point and linear events determined:

a) in the field (e.g., mileposts or reference posts)?
Off-set from known point

b) in the office (e.g., Straight Line Diagrams, 'route log' or 'log mile' listings, or computer applications)?
SLD, field note, and commissioner order

3.5.6. If Straight Line Diagrams are used: Yes

a) do they have route IDs on them (e.g., as used in the LRS control database)?
Yes, but it is different from RIL or mainframe. SLD route Id consists of street name, route, sub route, county, and district.

b) do they have milepoints on them? Yes

3.5.7. What problems or issues are there in the field (or office) for those using the LRS for their data collection?
Inconsistent use of same route name in field note and other records

3.5.8. What are your standards (or practices) for linear measurement accuracy (e.g., accuracy tolerance in urban/rural areas, accuracy for different feature types, etc.)?
There are standards and will request a copy.

3.5.9. If a route is re-measured and found to differ from the old length, is there a tolerance below which the official length is left unchanged? N/A

3.6. GIS implementation

3.6.1. What GIS software is currently used? ESRI

3.6.2. What process was used to "implement" this LRS using GIS?
DynSeg and Event tables via Route-mile

3.6.3. Have all roads handled by the LRS been implemented in GIS? Yes.

3.6.4. Describe the GIS base map (centerline file) used:

a) Original source of centerlines:
Interstate, US, State - GPS points & lines from Roadware
County Routes, FANS, HARP, State Park and Forest Roads – SAMB digitized road centerline based on aerial Imagery, head-up digitizing using SLD info and aerial imagery.

b) Scale: 1:4800

c) Development process:

d) Accuracy/quality:

e) Other:

3.6.5. Quality control of the GIS base map:

a) What quality control has been done on the LRS implementation in the GIS base map?
GIS unit use RIL, SLD, aerial imagery and commissioner order to control quality.

b) Have mismatches been identified between field-measured lengths and GIS lengths?
N/A, DOH only implement field-measured lengths on GIS system. Sometimes GIS length is used for field measure verification/comparison purpose only.

~~c) Are there discrepancies between the LRS and the coding in the GIS base map (e.g., differences in section lengths, problems with interchange alignments, etc.)?~~

3.6.6. GIS base map update procedures:

a) What update procedures are used for the GIS base map?

GIS unit updates/changes GIS base map, when HDS unit receives any change/update request via commissioner order, field note, or district request. Any submitted requests are required supporting documents indicate/illustrate/describe a location change (currently paper maps but electronic file such as CAD and GIS file will be required)

b) Is the GIS base map kept synchronized with the LRS (e.g., if the linear measures for a route are updated in a relational database)? If so, what procedures are used?
No, GTI is working on backlogs but will be available to synchronize with the LRS once when backlogs are clear. There are no formal procedures yet.

3.6.7. If local roads (some or all) are included, describe: Not included yet.

a) Source of the local roads centerlines: Possible source is SAMB road centerlines
b) How local road centerlines were integrated: segment & relate
c) How local roads (and their routes) are updated and maintained:
E911 process but not all counties are capable of updating and maintaining local roads due to resources constrain
d) Other:

3.6.8. To what degree have the measures in the GIS been calibrated? Not calibrating yet.

3.6.9. How accurate (or inaccurate) are the locations of features as displayed in the GIS? Is this a problem?
Accuracy is reasonable from 1:4800 to 1: 24000.

3.6.10. How is linear referencing currently being used in the GIS:

- ☒ Data display/mapping
- ☒ Database query (e.g., select a location or road section on the map and get a report)
- ☒ Determination of linear measures (e.g., to specify crash locations)
- ☐ Automated data input (e.g., including graphic specification of locations)
- ☐ Other custom applications (construction project information, work program, etc.)
- ☐ Quality control of data Integration and analysis of different event tables (e.g., identify accidents associated with specific pavement conditions)
- ☐ To convert between different LRSs (Note: LRS conversion does not require GIS, but a GIS application is often used)
- ☐ Other:

3.6.11. What (other) issues or problems have there been with the GIS implementation?
No or insufficient data, data format conversion, emerging technologies.

3.6.12. What have been the (other) major benefits and successes of the GIS implementation?
Hussein's Slide

3.7. Special roadway cases

How does your LRS (and GIS base map) handle each of the following special cases:

3.7.1. Divided highways

a) How are attribute locations specified along the separate travel ways (e.g., an accident which occurs in the north-bound lane)? Only in GIS system
b) If divided highways are not specially handled, are there problems due to the separate travel ways having somewhat different lengths/measures? RIL has only one length
c) If divided highways are specially handled in the LRS, what constitutes a 'divided highway'? (E.g., only highways with full access control? Highways with a certain type of median?)
In RIL and LRS, all Interstate highways and any 4 lane of greater roadways with median are a divided highway. However, there is no dual record for each direction in RIL.

Pavement type and width and grade width are only attributes info in RIL for each direction

In SLD, if there is significant disparity between each travel directions, separate SLDs are require to depict additional info. In GIS basemap, Interstate and US highway have dual geometry.

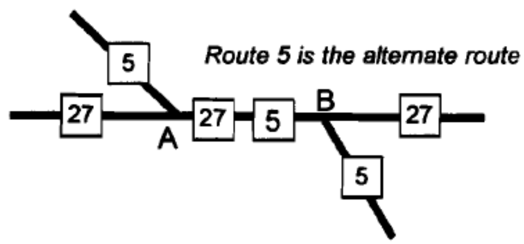
d) ~~Are routes defined for separate travel ways? If so, how are the measures determined, and are they correlated between the different travel directions?~~

3.7.2. Ramps

a) Are ramps included in the LRS? No.
b) Where do the measures for a ramp begin (e.g., at the gore point)?
Hasn't collect the measures for ramp yet but the system will use a measure where ramp start at the gore point.
c) Are acceleration/deceleration lanes considered to be part of a ramp? Yes

3.7.3. Approaches (at intersections, including ramp intersections). Especially, how is a 'Y' intersection handled? Is a separate route defined for one of the legs?

3.7.4. Alternate or overlapping routes



Route 5 is the alternate route 88

a) For the case illustrated above, does the LRS use coincident routes (measures increase for both routes along the common section), or is there a gap for the alternate route?
No
b) Are multiple road/route name aliases supported for alternate routes?
No, but the new system (RIL) supports multiple road/route name aliases.
c) If a 'primary' route is designated, how is it selected?
Typically higher functional class and lower number route are designated as the primary route but there are some exceptions for example I64 and I77 on WV Turnpike.
d) Are attributes (events) along the common section associated with only the primary route, or can they be associated with either route?
All attributes (events) are only associated with primary route. However, the new system (SQL RIL) will have any to link with the secondary route
e) Suppose there is a gap for the alternate route. For example, suppose the measures for route 5 stop at 2.5 miles at point A, then continue from 2.5 miles at point B. In this case, the location 'milepoint 2.5 on route 5' would be ambiguous, existing at 2 places (points A and B). Is this the case for this LRS? __ Yes _x_ No If so:
   1) Has this posed any problems for you (e.g., is it possible for an accident at point A to be ambiguously located at '2.5 miles along route 5)?
   2) If there are such gaps, do these potentially cause problems for analysis, such as for identifying high accident locations? For example, could a high accident location along route 5 span both legs, thus including two separate intersections?

3.7.5.If your routes are defined by county (or other jurisdiction), what happens when a route exits and reenters a county? Are there ambiguous measures (as there can be for a route with a spatial gap)? County routs are defined by county boundary but there are exceptions. There is no gap for a route. The measures continuously increase even if a route exit and reenter a county.

3.7.6. One-way pairs (i.e., where a road divides into 2 one-way sections of different length)
No case.

a) If a separate route is defined for one leg of a one-way pair, what criteria determine if the leg is to become a separate route?
b) Are there any route ID coding conventions?

3.7.7. If local roads are included, are there any special accuracy or maintenance considerations?
Local roads are not included unless they are part of state roads.

3.7.8. Layered or tiered roads (e.g., a 2-level bridge). NO

3.7.9. Service roads (which parallel a limited access highway, provide a buffer the limited access and local roadway). Not in WV.

3.7.10. Individual lanes (including HOV lanes).
Currently stored as attributes of logical centerline.

3.7.11. Associated facilities (truck runoff ramps, rest areas, emergency V-turns, etc.).
Not in RIL nor mainframe app.

~~3.7.12. Rotaries: how is the situation illustrated at right addressed, where a portion of a rotary doesn't belong to any of the intersecting routes?~~

3.7.13. Cul-de-sacs: is a standard direction (clockwise or counterclockwise) used for determining the direction of increasing measures?
No standard direction yet.

3.7.14. Proposed highways: if measures are assigned, how are these integrated with the base map?
Separated file. Unofficial supplement code is assigned.

3.7.15. Locations of offset features (i.e., perpendicular offset from a route).
Perpendicular offset from a route.

3.8. Attribute storage schemes

3.8.1. Is there a major, centralized ''roadway characteristics" database? If so, what is it called?
Mainframe app and RIL

3.8.2. Are event tables 'linearly normalized', 'linearly denormalized', or a hybrid?
Currently mainframe app is completely denormalized but the new system (RIL) will be normalized.

3.8.3. Are any QA/QC procedures used to:
RIL enhancement project will have QA/QC procedures

~~a) Verify that a linear event table covers the entire network? For example, every section of roadway falls under a single jurisdiction; is there a routine to assure the 'jurisdiction' event table covers all roadways in the system?~~
~~b) Verify that all event route IDs and milepoints are valid?~~
~~c) Verify point events are not coded at ambiguous milepoints (i.e., at discontinuous routes that have continuous measures?~~
~~d) Other?~~

~~3.8.4. Are there any barriers to database query or analysis associated with the database structure?~~

3.9. Updates to the LRS and management of historical data

3.9.1. Briefly, what process is used to update the LRS (not the GIS data), due to reconstruction, new construction, abandonments, re-measurements, etc.?

When construction is done, doc is submitted to GTI. Field crew is sent to verify the work. Then HDS enters the info.

3.9.2. Is there a system for tracking updates to the LRS over time? How are updates recorded?
Mainframe, it is possible to track when record was changed but not what record was changed. New system will have any to track these changes.

3.9.3. Is there a system for notifying end users of updates to the LRS, so their event tables can be updated?
No.

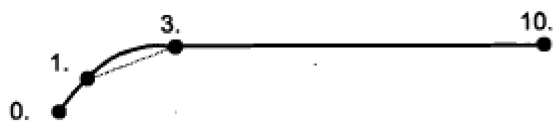
3.9.4. Are routes and/or events time stamped? ☐ Yes ☒ No If so, describe what the time stamps refer to (data entry data, effective/expiration dates, etc.), and how they are used.

3.9.5. Are historical alignments (and/or routes) stored:
   a) in the LRS? No
   b) In the GIS data? No

3.9.6. Are there procedures for comparing the records of an event table to assure that events are 'synchronized' with the current LRS (i.e., to identify any records that reference routes or portions of routes which have been updated)? N/A

3.9.7. Are there procedures for keeping updates to the GIS network synchronized with updates to the LRS? In proposed work flow, GIS will be part of syn process.

3.9.8. Consider a specific example, a realignment with reduction in route length. Suppose that a reconstruction project between milepoints 1.0 and 3.0 of a 10.0-mile route eliminates 0.1 miles from the route.



   a) How are the route IDs modified? No.
   b) How are the measures (and/or routes) updated along the full length of the original route (e.g., does the original section from 0.2 to 10.0 miles now measure from 0.1 to 9.9 miles)? With commissioners order the measure updated.
   c) Are field markers updated (with new measures)?
   If the change of length is greater than 0.5 mile.
   d) For on-line event tables (in the centralized "roadway characteristics" database), are the measures for events referenced to the updated route updated accordingly? If so, is the process automated or manual?
   Yes. done manually
   e) How are updates handled for event tables other than in the centralized database (i.e., used by different divisions)?
   Speed limit – traffic dept, assets – traffic, pavement & bridge – maintenance, Tunnel – district office

3.9.9. Procedures used for other types of updates. Using the questions posed above under 4.9.8 as a model, how are each of the following cases updated in the LRS, with regards to the route IDs, measures, field markers, storage of historical data, etc.
   a) ~~Roadway realignment with increase in length (any difference from the update process for a reduction in length, as in 4.9.8?):~~
   b) Change to the route identifier (e.g., if highway jurisdiction changes from state to county):
   County route can be changed

~~c) Correction to route measures without any change to the roadway alignment (e.g., due to remeasurement in the field):~~
~~d) Addition of a new roadway (and route):~~
~~e) Addition of a new portion to an existing route, and the end or beginning of the route:~~
~~f) Deletion of an entire roadway/route:~~
g) Deletion of a portion of a route, from the beginning, middle or end of the route:
Rename route name where a change happens
~~h) Creation of a new node (e.g., due to addition of a new road), in the middle of a route, with a newly-determined measure:~~

~~3.9.10. What needs do you see for managing historical data, which are not currently being met?~~

4. HPMS Submission
   4.1. Have you developed a separate or modified LRS to meet HPMS submission requirements? If so, please elaborate.
   No.
5. Data Integration
   5.1. Data transfer between information systems
      5.1.1. Consider a roadway characteristic such as Average Annual Daily Traffic (AADT), which is typically used by many information systems. When new AADTs are determined, how are the new values transferred to other information systems (e.g., traffic modeling, bridges, railroad crossings, etc.)?
      Each dept acquires from RIL
   ~~5.2. Integration of different LRSs~~
      ~~5.2.1. To what degree are your multiple LRSs integrated?~~
         ~~a) Are you able to translate measures from one LRS to another? For which LRSs?~~
         ~~b) Are you able to map features using different LRSs?~~
         ~~c) Are you able to perform queries with custom applications, drawing from data sets using different LRSs?~~
         ~~d) Are you able to perform ad hoc queries, from data sets using different LRSs?~~
      ~~5.2.2. What major problems and/or successes have you had integrating data located by different LRSs?~~
   5.3. Integration with GPS and other geographically referenced data
      5.3.1. Are you integrating GPS data with linearly referenced data? If so, please elaborate.
      Some point features have GPS data.
      5.3.2. Does your GIS base map have link attributes? If so, what are the attributes, and how are these integrated with linearly referenced data? NO
      5.3.3. Are you integrating linearly referenced data with any point or polygon data (e.g., for any specific projects)?
      Yes.
6. Use of Related Technologies
   6.1. Describe any GPS activities related to linear referencing, such as:
      6.1.1. Refinement of the LRS measures? Yes
      6.1.2. Refinement of the GIS base map? Yes
      6.1.3. Resolution of discrepancies between the LRS and GIS base map?
      6.1.4. Data collection? Yes

~~7. Relationship to Other Modes of Transportation~~

7.1. Are you considering the use of linear referencing to support other modes of transportation, such as for supporting analysis and modeling of transit information?