DDOT Street Spatial Database Development Project
- A Use Case for the ERSI UNETRANS Data Model

Minhua Wang, Ali Fatah, Markos Yeterawork
Government of The District of Columbia
District Department of Transportation
Emmanuel Onwukwe
GeoImaging Consulting Inc.
Tony Pietropola
GeoDecisions, A Division of Gannett Fleming Inc.

Abstract

DDOT's street database system is moving into an enterprise system architecture, namely the Transportation Enterprise Asset Management System (TEAMS), in which GIS is a key component. The roles that GIS play in TEAMS are not only as the software platform for mapping but also as the data integrator, the common denominator, for enterprise data integration. DDOT GIS division staff evaluated ESRI's UNETRANS data model. The new street spatial database model used UNETRANS as the foundation and took roadway segment and intersect point as the basic geometry elements for the data model, constructed a four-tier data structure to cover street roadway network and assets, and applied ESRI's geodatabase topology technology to create shared geometry, thus simplifying spatial data maintenance. This presentation will demonstrate the completed project including street spatial data model, topology setting, custom rule setting for spatial data maintenance, and the complete DDOT street spatial database.

Introduction

District Department of Transportation (DDOT) Spatial Database System Division currently maintains street GIS database for the District in ESRI’s shape file format. The street GIS database includes five different street road types: street centerline, alley, drive, ramp and service road, respectively, in five different shape files. These street GIS data files serve for a variety of applications across the District, including GIS mapping, GIS data warehouse, snow routing, AVL system, emergency responses and trash collection routing, etc.

DDOT’s street database system is moving into the enterprise system architecture, namely the Transportation Enterprise Asset Management System (TEAMS), in which GIS is a key component. The roles that GIS plays in TEAMS are not only as software platform for mapping and spatial analysis, but also as data integrator, the common denominator - location, for enterprise data integration. The biggest challenge for DDOT’s GIS to meet such enterprise requirements is to develop an enterprise data model for the street spatial data.

As a central repository for the enterprise wide transportation data management, the street spatial database must meet the needs of both GIS operations, such as ArcGIS platform, relational database management, and transportation business operations such as Linear Referencing Systems for location referencing, and business analysis and business reporting.

This paper addresses not only the conceptualization of the Street Spatial Data Model, but also the practical implementation of the model and the construction of the street spatial database.

Challenges of DDOT Street Spatial Data Model

In the past decade, in particular, in the last five years, there has been a great deal of attention in the US and elsewhere paid to the management of transportation data and the creation of more useful information from vast amounts of raw data. Part of this effort has focused on the creation of *transportation spatial data models*. Among these, three models have been investigated and form the basis for the design methodology of the DDOT's Street Spatial Data Model:

1. *The new FGDC "GIS One-Stop" Model Advisory Team (MAT) transportation data model*. A new model, similar in outline to the NSDI, but incorporating some features of NCHRP, UNETRANS and GDF.

2. *NCHRP 20-27(2):* A transportation model created with a focus on integrating data with multiple cartographies and meeting state DOT needs.

3. *ESRI's UNETRANS:* A "template" developed along with other domain models for using and extending ArcGIS software, again with a DOT focus.

The common aspects of these models includes:

1. Emphasize conceptual model design
2. Based on Linear Referencing System (LRS) concepts
3. Defined basic entity and relation in a transportation network, for example, *Anchor Point* and *Anchor Section* in NCHRP model, *TranSeg* and *TranPoint* in "GeoSpatial One Stop" model, and *TransportEdge* and *TransportJunction* in UNETRANS model.
4. Focus on DOT business, particularly for highway network
5. Promote data standard and data sharing

These provide very good foundation for designing the DDOT's Street Spatial Database. However, DDOT is facing new challenges for the new model design: the unique urban environment (not much highway), multiple linear referencing methods, multiple application support and practical architecture for data maintenance and data integration. A typical example is that the definitions of basic entity and relation in transportation network varies based on the operational needs (or applications) for transportation network, for example, for street maintenance, a segment is defined by street block (from intersection to intersection), but for trash pickup routing, a segment is defined by any routable roadway segment (e.g., from a driveway intersection to an alley intersection). None of existing models can handle multiple definitions of basic entity and relation. The biggest challenge is to design a practical data model to support data maintenance and data integration. Most existing models do not address practical issues such as data maintenance. In particular, when multiple definitions of basic entity exist in the model, data maintenance becomes an issue, that is how to avoid duplicated editing for the geometry shared by multiple feature classes. In addition, most transportation data are collected through non-GIS environment, which means the location information can be any format of description, how the model will integrate these data into the street spatial database.

By evaluating the available nationwide transportation data models, DDOT selected ESRI's UNETRANS model as a starting point. The UNETRANS model framework is closer to DDOT's needs because ArcGIS and ArcSDE are the platforms for DDOT's GIS, but the uniqueness of DDOT's business and operational needs have made us to design the model from the scratch but under the UNETRANS framework. Through the next several sections, you will find that DDOT Street Spatial Data Model has many similarity as the UNETRANS model, but the structure and entity definitions are very different from the UNETRANS model.

Street Spatial Database Model Requirements

The requirements for the new street spatial data model can be summarized in three major areas:

Enterprise IT Management Needs

- Support current Street Inventory System (SIS) model
- Support data linking with DDOT business data
- Provide core model for the TEAMS development project
- IT Architecture: work within DDOT IT Architecture including both hardware infrastructure and software standards.
- Exiting DBMS: Use Oracle 9i database with ArcSDE 8.3
- Existing Datasets: Preserve investments in legacy datasets and provide link or/and migration path to the new database
- Existing Custom Software Applications: Support or upgrade existing GIS applications and other business applications using GIS data.

GIS Operation Needs

- Implement enterprise spatial database management system such as Oracle and ArcSDE

- Based on ArcGIS platform
- Compliant with existing GIS standards
- Simplify spatial data maintenance and reduce duplicated efforts for geometry editing

Transportation Business Needs

- Support multiple Linear Referencing Systems
- Support multiple application needs for street centerlines and multi-level centerline models
- Compliant with nationwide transportation data models such as UNETRANS
- Support DDOT business applications such as street inventory system, traffic monitoring system, project management system, etc.

Among these requirements, Support multiple Linear Referencing Systems, Support multiple application needs and Support spatial data maintenance are most critical requirements.

Street Spatial Database Project

Based on the requirements, DDOT initiated the Street Spatial Database Development project. The objectives of the project include:

- To promote enterprise system approach
- To improve GIS operations using state-of-the-art GIS, RDBMS, Internet and system development technologies
- To establish a model for transportation GIS in large metropolitan area

The project is divided into five phases: 1) High Level Design (Conceptual Design); 2) Prototype Testing; 3) Detailed Design; 4) System testing and Data migrating; and 5) system implementation.

The High Level Design phase of the project determines major components and their relationships within the database system. Specifically for the Street Spatial Database, the High Level Design phase identifies major data elements for constructing street network, defines key fields for linking street network with other applications and other data elements, and generates Entity-Relation diagram to model the major data entities and relations for the street spatial database. The high level design will take advantage of new ArcGIS functionality for topology (ArcGIS 8.3) to support the requirements for data maintenance and data distribution.

The objective of the Prototyping is to conduct proof of concept for the high level design. For example, the high level design may make certain assumptions for adopting new ArcGIS functionality, such as Topology. However, these assumptions need to be tested based on pre-defined Use Cases. The prototype testing is to prove the new database will support existing applications, such as the Routing application, and to simplify on-going data maintenance by implementing triggers and stored procedures to synchronize attribute changes between tables through relationships.

The detailed design will review the results of prototype testing, and provide detailed database design, based on high-level design, for the street spatial database. The detailed design will focus on data elements from existing Street Inventory System (SIS) and other business data system (such as Tree Management System) and essential for the street spatial database. Most importantly, the detailed design will define reference keys that will be used to link to other data elements and other applications in the future. The output of the detailed design should be in ESRI geodatabase format or ready to import to ESRI geodatabase.

The System Testing and Data Migrating phase will load existing street GIS data into the new Street Spatial Database schema. The data loading process should use the procedures or scripts developed during the detailed design. The data loading process may also involve building network feature class, defining topology rules, and populating reference key fields.

The implementation phase is an On-Going data maintenance and support. After a period of testing, the Street Spatial Database should be fully functional, it will provide support for daily street data maintenance, support for distributing street centerline files and routing reference network, and support for daily GIS mapping.

The following sections will highlight some of the key components in the projects.

Conceptual Design of Street Spatial Database Model

Based on the requirement definitions, the fundamental design cornerstones have been defined as follows:

1. Adoption of Linear Referencing model as the common location referencing method, with accommodation of other location referencing methods such as planar coordinates method (e.g., Lat/Long).
2. Support of both data creation and data maintenance, such as supporting multiple reference (network) features and use of new topology functionality in ArcGIS to handle shared geometry between reference features.
3. Use of best practice concepts in Transportation data modeling as starting point, such as NSDI/MAT transportation data model, NCHRP 20-27, UNETRANS, etc.
4. Support of multiple applications for various usages of spatial data, such as supporting both feature-events and object-events

As a result of these considerations, the high level design of the new street spatial database has highlighted the following key aspects:

1. Use of combination of measurement-based linear referencing method (LRM) and address range referencing method as a basis for linear referencing. As a result, all referencing features will have LRS keys such as reference ID (SIS_ID),

from_measure and to_measure, and standard address range information; all events will have similar LRS keys depending on the feature type (point event will only have point measure, while linear event will have from_measure and to_measure);

2. Use of three-tier reference feature structure to support various applications requiring usage of street spatial, but limiting geometry updates at only one tier, called Base Reference Feature, by applying new topology technology in ArcGIS 8.3;
3. Use of dual-event data structure to accommodate both feature-based events and LRS based events;

The model is demonstrated in Diagram 1. The model can be summarized as:

1. Four-tier data components: base reference feature, application reference feature, LRS reference feature and LRS events.
2. Multiple reference networks with shared geometry: the base reference feature is the basis for geometry updates; application reference features will be updates through the topology rules between base reference features and application reference features.
3. Parallel event data structure to capture both feature-based events and object-based events: it accommodates both feature-based events, which have geometry, and object-based events, whose locations are based on linear referencing information.
4. UML-based format to meet ArcGIS geodatabase requirements: to be imported into ArcGIS through Microsoft repository.
5. Best practice concepts to be compatible with the existing Transportation Models in both government-specific (e.g., FGDC's NSDI model) and software-specific (e.g., ESRI's UNETRANS model): the model adopts the best practice concepts in Transportation data models from both government-specific (e.g., FGDC's NSDI model) and software-specific (e.g., ESRI's UNETRANS model), to be able to share data with the federal government agencies (e.g., FHWA) and other government agencies that use ESRI software products

Central to the concept of the model is the Base Reference (Network) feature. The foundation for the Base Reference Feature is the StreetTransSeg and StreetTranspoint, which are equivalent to NSDI/MAT's TranSeg and TranPoint. Since DC is in a Urban area, the definition for StreetTransSeg is *any routable roadway segment*; the formation of Base Reference (Network) feature can be a merge of existing five street centerline layers: street centerlines, alley centerlines, ramp centerlines, driveway centerlines and service centerlines, after geometric conflations between the layers.

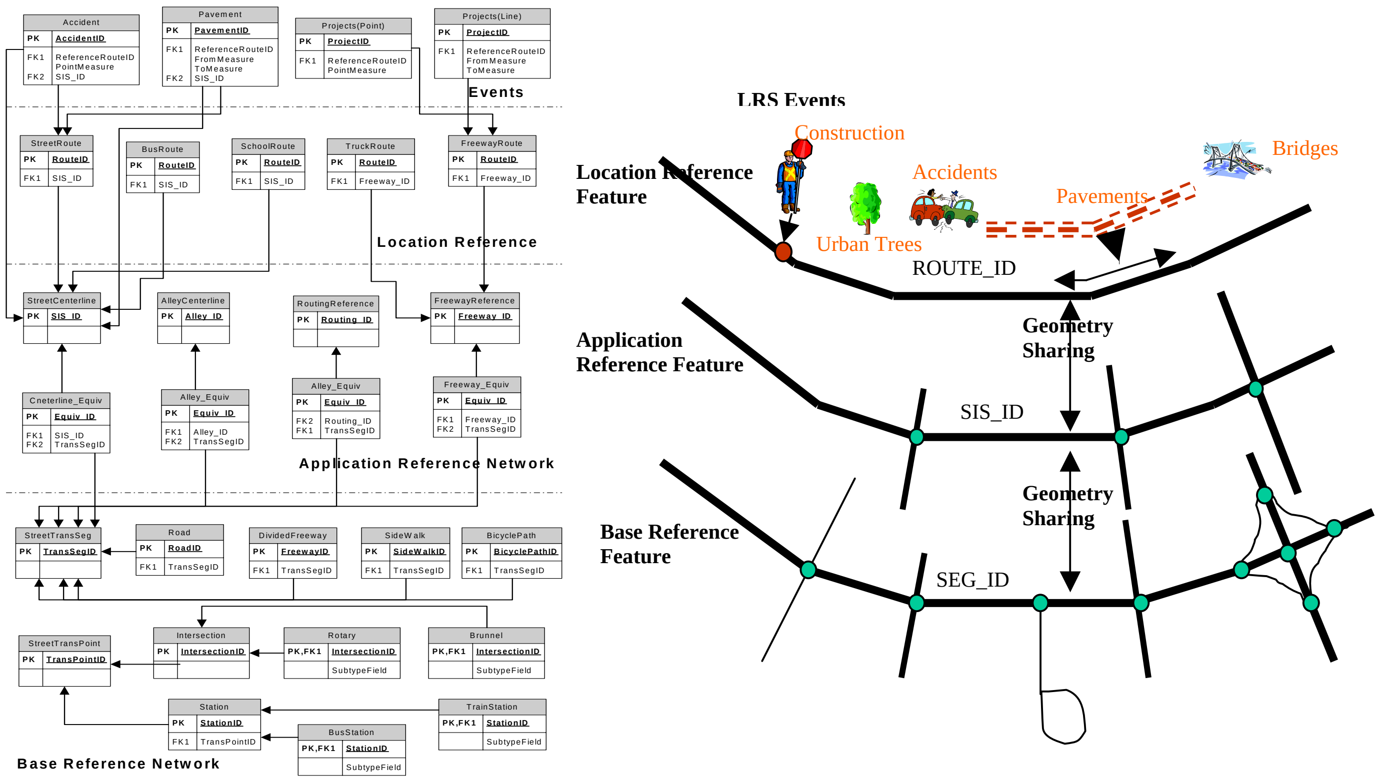

Diagram 1: DDOT Street Spatial Database Model

Use Cases for Street Spatial Database Maintenance

At core of the Street Spatial Database Model is the need to maintain spatial data at one layer - edit geometries of all roadway centerlines at one place. The Base Reference network (BRN) layer is where all roadway segments exist and be maintained. The base geometry is consisted of five independent road types that are sub typed. These road types include Street, Service Road, Ramp, Alley and Driveway. One of the challenges in this project is how to maintain the geometry without duplicated editing under this multi-tier data model. Our approach is to define use cases and from the use cases to find solutions.

Spatial data maintenance includes adding new roadway segment, deleting roadway segment, reshaping roadway segment and modifying roadway attributes. Because of the design of the multi-tier feature data model, it is critical to maintain data integrity while editing spatial data at one single place. The new ArcGIS (8.3 and above) provides a new technology, called “GeoDatabase Topology”, to handle geometry sharing between feature classes. This new technology provides a useful tool for geometry reshaping, but not help adding new or deleting old geometry. In order to deal with the data maintenance issues, we defined several use cases; one of these is Adding New Roadway segment (see diagram 2). The use cases help to define the solutions. Because the Topology cannot handle Add New and Delete Old, we developed a custom tool within ArcMap which utilizes the existing Editor tool but expand it to automatically update geometry changes to other geometry-shared feature classes while editing the base reference features.

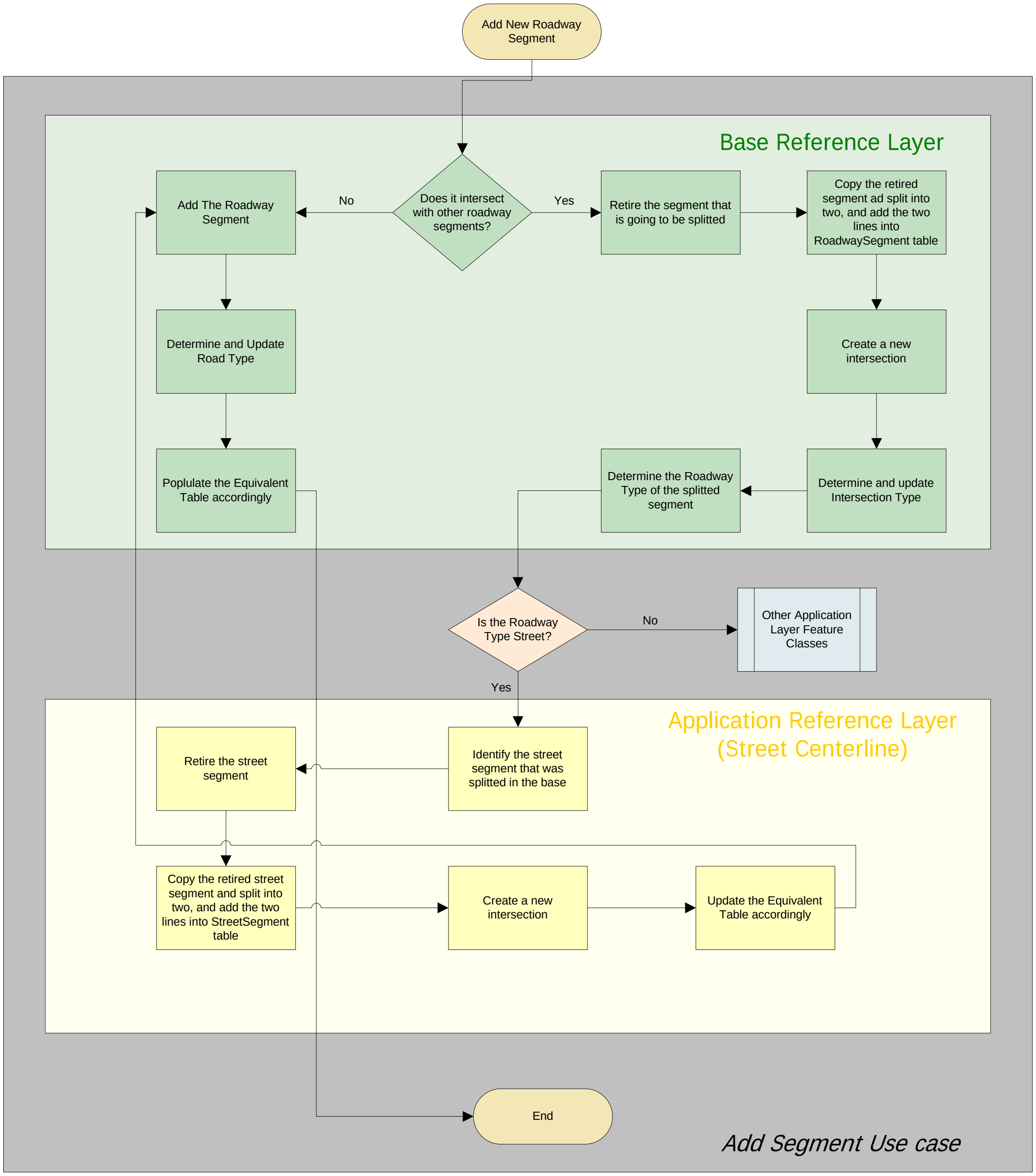

Diagram 2: Use Case: Add New Roadway Segment

Data Migration

After data model has been gone through proof of concept testing, data migration has become another challenge. As mentioned before, the current DDOT street GIS data are stored in five separate files: street centerlines, service road centerlines, ramp centerlines, alley centerlines and driveway centerlines. These file-based data need to be migrated to the new data model. The migration includes the following steps: 1) data merge; 2) LRS key building; and 3) data conflation. Some custom codes have been developed to handle data merge, geometry editing (splitting and snapping), geometry conflation between source files, etc. New unique identifier conventions for street segments and intersections have been developed, and required LRS keys have been populated.

Conclusion

The design of DDOT Street Spatial Database Model addresses two fundamental transportation database issues: data storage and data maintenance. The model also defines four components of the street data model: the framework of data model, the basic element of roadway segment, multi-tier structure of reference features and dual event model (feature based and object based). The project demonstrates that enterprise transportation database benefits both GIS operations and agency's business operations. DDOT's Street Spatial Database also provides a practical example of the implementation of the UNETRANS model and other enterprise spatial transportation model.

Author Information

Primary Contact:

Minhua Wang
Chief Architect
District Department of Transportation
Government of District of Columbia
2000 14th St., NW
Washington DC, 20009
(202) 671-2122
minhua.wang@dc.gov