1.0 Executive Summary

The NJDOT is at an opportune time to make significant changes to its GIS in order to meet the transportation information needs of the 21st century. The change from one GIS system to another allows the opportunity to review and/or improve the database architecture, geographic source data, existing procedures, and data model. To better leverage the significant investment that NJDOT has made in the GIS, Baker recommends implementing a simplified data model as detailed in this report. Furthermore, Baker recommends implementing the following strategies for the GIS:

Incorporate Multiple Centerlines for Divided Roadways

Multiple centerlines allow for more precise positioning of attributes such as MMS features or accidents along the secondary direction of a roadway. With multiple centerlines, the secondary direction of a route is treated as an individual route with a separate SRI number. This is the same route numbering/mapping policy that is implemented successfully in Virginia and New Hampshire, two other states where Baker provides transportation services.

Develop and Maintain an EZ-Query Table of Common Attributes

Casual or untrained database GIS users would benefit greatly from a combined table of commonly queried database attributes. Such an "EZ-Query" table could be pre-segmented to produce homogeneous records with ten or more common attributes. Those common attributes would be the ones that are most often queried in the database. The table could be recreated on a nightly basis by an automated process.

Leverage Third-Party Attribute Data

Many non-NJDOT public agencies as well as private companies have been compiling a wealth of information about New Jersey roads. It would be prudent to investigate the incorporation of this third-party data in the Department's GIS. Much data that is now collected by methods such as GPS based inventory, orthophoto digitizing, or video feature extraction, may be already available from other agencies or private companies. It may be cost effective to purchase the data rather than to re-collect it internally.

Study the Incorporation of Street Address Data

There are several areas of the Department that would benefit from having street address information linked to the GIS and SLD systems. The Crash Records Section could utilize street address information to verify and consistently locate vehicle crashes that were originally described using a street address. The Department's Right-of-Way and Access Permits bureaus could utilize address information to better identify properties impacted by construction projects or are requesting driveway access to state highways. Address information is readily available from sources such as the TIGER files from the United States Census Bureau or from most of the commercially available mapping products. An in-depth review of these sources should be performed to quantify the costs and benefits of obtaining, verifying, and implementing address information.

Create and Maintain Network Topology

The development and proper maintenance of network topology could provide substantial cost savings and increase the utility of the GIS to the Department. Redundant efforts to maintain disparate roadway network data sets could be eliminated or reduced by implementing network topology. Furthermore, new applications such as over-weight truck and/or snowplow routing could be developed to better utilize NJDOT staff time and provide additional services to Department customers. Planning functions such as traffic modeling could use the same base network as the GIS. Applications such as incident management information could be developed to alert the motoring public to alternate routes in the event of an accident or other road closure.

Develop a Stronger Web Presence

Several states have comprehensive web sites that provide volumes of attribute data to the general public. This data is accessed via attractive GIS interfaces. A good example of a strong web presence is the Illinois DOT web site. The same model of data delivery could be implemented at NJDOT. Powerful tools like ArcIMS should be utilized to publish data such as traffic counts, accident statistics, roadway information, construction zones, and detour routing for access via a map-based interface.

2.0 Introduction

The New Jersey Department of Transportation (NJDOT) is currently researching the effort and implications of changing their Geographic Information System (GIS) from the current Intergraph Modular GIS Environment (MGE) system to the ArcGIS system from Environmental Systems Research Institute (ESRI). To that end, representatives from ESRI have proposed a simplified version of the ArcGIS Transportation Data Model (which is derived from the UNETRANS data model) for NJDOT.

As system administrator for the Straight Line Diagram (SLD) System, Michael Baker Jr., Inc. (Baker) has a strong interest in the result of the research effort. The mapping and databases developed to support the SLD application are closely tied with the Department's GIS. Furthermore, Baker is responsible for maintaining the SLD/GIS road network as tasks of several contracts with NJDOT. Any changes to the NJDOT GIS would have a profound impact on the business rules and procedures developed for the SLD system and current project efforts at Baker.

As a sub-task of the Enhanced Straight Line Diagram contract with the Bureau of Transportation Data Development (BTDD), NJDOT requested that Baker analyze the ESRI Transportation Data Model, estimate the impacts of implementing the model on the SLD application, and make recommendations for implementation aspects of the model at NJDOT. This report is the result of the requested analysis effort and contains recommendations for implementing a modified version of the data model.

This report will also examine the current state of GIS at NJDOT and potential future GIS applications.

3.0 GIS at NJDOT

The NJDOT has been using a GIS for at least the last two decades. This section summarizes the operations of the GIS effort in the Department.

3.1 Organization

The Bureau of Information Management and Technology Planning (BIMTP) under the Division of Information Technology currently maintain the GIS. Gary Zayas is the Bureau Manager and Ron Stewart is the Division Director.

3.2 Mission

BIMTP is responsible for supporting/maintaining the database, software, and equipment used for the GIS. BIMTP supports the entire Department by developing and publishing mapping products from the GIS files and database (including the state tourist map). BIMTP also provides technical support to users of the GIS database and map files.

3.3 GIS Focus

Efforts to date by the BIMTP have been focused on ensuring that mapping products developed from the GIS are cartographically accurate. Map files are updated by digitizing from aerial photography. The network of attributed routes to date include the following roadways:

- Interstate Highways
- US Numbered Routes
- State Numbered Highways
- Toll Authority Routes (GSP, ACE, NJTPK, PIP)
- County 500 Series Numbered Routes
- County Non-500 Series Numbered Routes (600, 700, etc.)
- Non-numbered National Highway System (NHS) Connectors

A secondary focus of the BIMTP has been to add new attributes from other Department sources to the GIS database for the attributed routes. Until 1996, the attributed network consisted entirely of those roadways under NJDOT jurisdiction. The other layers of the route hierarchy shown above have been slowly included in the attributed network, mainly through the efforts of the BTDD.

3.4 Software and Database

The GIS software currently used and supported by BIMTP is Intergraph's Modular GIS System (MGE) and GeoMedia. Other users in the Department have used products by MapInfo and ESRI. The GIS map files for MGE are in MicroStation (*.dgn) format. The GIS database files are in an Oracle 8i database administered by the Office of Information Technology (OIT).

3.5 BTDD Involvement

The Bureau of Transportation Data Development (BTDD) is responsible for development of the Interstate, US, and State highway route network in New Jersey. BTDD is also responsible for development and implementation of the Standard Route Identification (SRI) system of route naming. James R. Carl is the Bureau Manager.

3.6 BTDD Efforts

Currently, BTDD is implementing the SRI system for all local roads in the state. Part of this implementation process is the attributing of roadways in the Department's GIS. Efforts by the BTDD since 1996 have been focused towards attributing all of the New Jersey's public roadways in the GIS. A recently completed contract has added all of the Non-500 series county routes to the network. Current BTDD contracts are adding all ramps and local roads to the attributed road network. By the summer of 2004, all public roadways in New Jersey will be attributed in the GIS and have at least a minimum amount of roadway inventory information available. These efforts are detailed in Table 1, below:

Table 1 - Data Integration Progress

Route Type	Status
Interstate	Fully integrated since 1996
U.S. Routes	Fully integrated since 1996
NJ State Highways	Fully integrated since 1996
Toll Authority Routes	Fully integrated since 1996
500 Series County Routes	Fully integrated since 1998
Other County Routes	Integration completed in 2002
National Highway System Connectors	Fully integrated since 1996
Local Roads	Estimated completion in summer of 2004

The BTDD is also responsible for development, maintenance, and production of the Department's Straight Line Diagrams (SLD). The current SLD project manager, Donald Perry, has contracted with Baker to continue the SLD system development, maintenance, and administration under a three-year contract that expires in 2005. A task of the current SLD contract between BTDD and Baker is the maintenance of the GIS map files required for each SLD page. The SLD page maps have been created from the Department's GIS files that are maintained for each county as MicroStation CAD files.

Coordination of efforts between BTDD and BIMTP is essential for ensuring that the GIS and SLD databases and map files are consistent in terms of route and attribute information.

4.0 Existing NJDOT Data Model

NJDOT currently has a simplified GIS/SLD data model with a single road feature class and other attribute tables. Figure 1 shows a graphic representation of the Straight Line Diagram database data model. The data model for the GIS database is essentially similar.

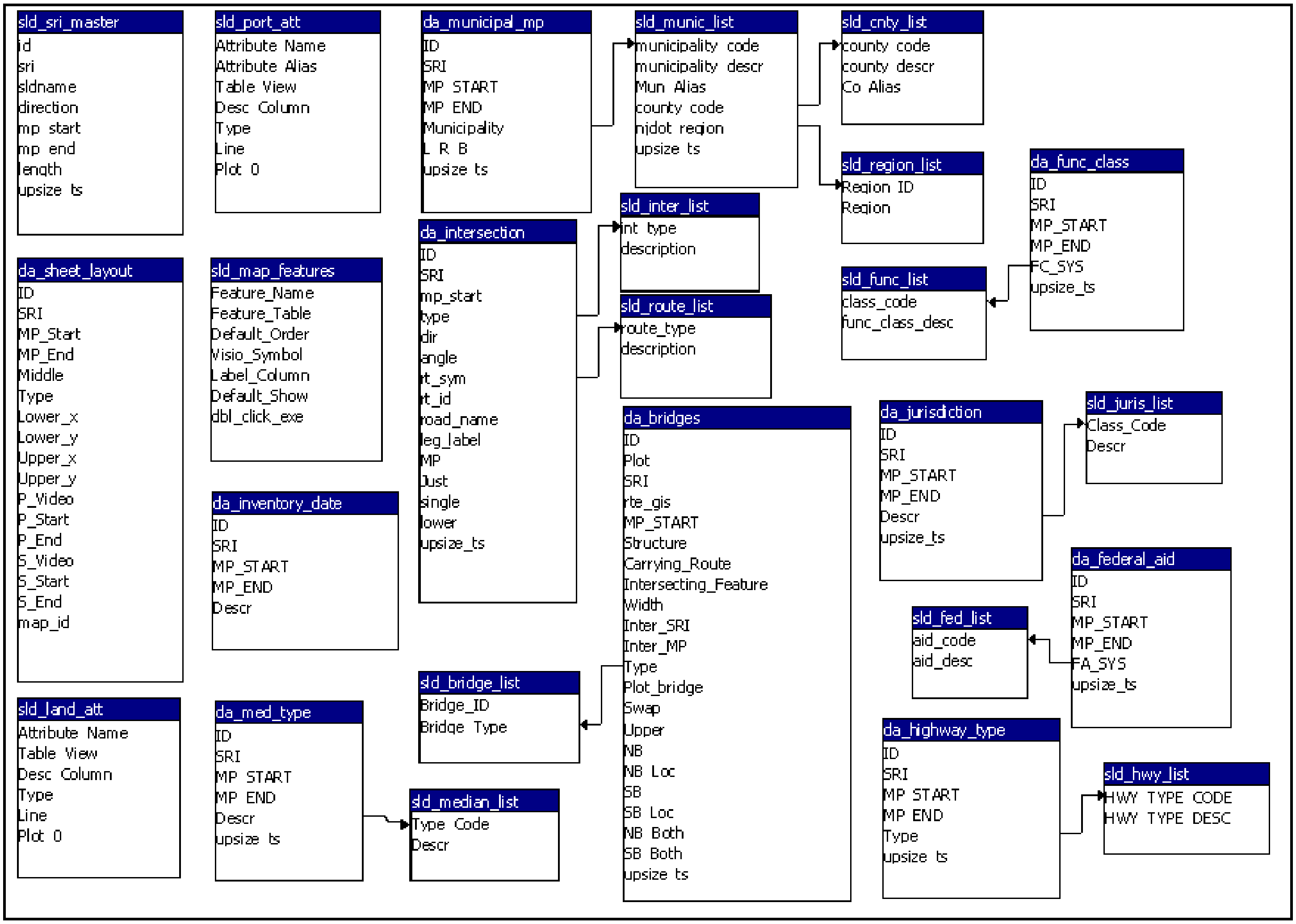


Figure 1 – Existing SLD Data Model

4.1 Master Route Table

A single feature class is used for all roads attributed in the SLD databases. Attributes in the feature class master route table are shown in Table 2, below:

Table 2 – Existing Master Route Attributes (sri_master)

Column	Type	Description
SRI	Text	The Standard Route Identifier for the route
SLD_Name	Text	Common Road Name (i.e.: I-95 or Middlesex County 615)
Direction	Text	Predominate Direction of the Road (i.e. South to North)
MP_Start	Numeric	Starting Milepost of the Route Section
MP_End	Numeric	Ending Milepost of the Route Section
Length	Numeric	Section Length of the Route, in miles

The feature class contains a single record for each route unless the route is broken as it runs coincident with a route that is higher in the route hierarchy. All other database tables are either event tables (both point and linear) that contain attributes, domain tables that include lookup values for event tables, or system tables used to control the operation of the SLD application.

4.2 Attribute Tables

The typical attribute (event) table contains either two or three mandatory columns, SRI, MP_Start, and MP_End. Point tables require only the SRI and MP_Start columns, while linear attribute tables also require the MP_End column. At least one additional column is necessary to contain the attribute value for the record. This column is usually named "Descr". However, the name is arbitrary and can be any legal column name that is not reserved. Dynamic segmentation is used to display attribute data from these tables in maps or on the SLD. Table 3, shown below, provides a list of some of the attributes available in the SLD database.

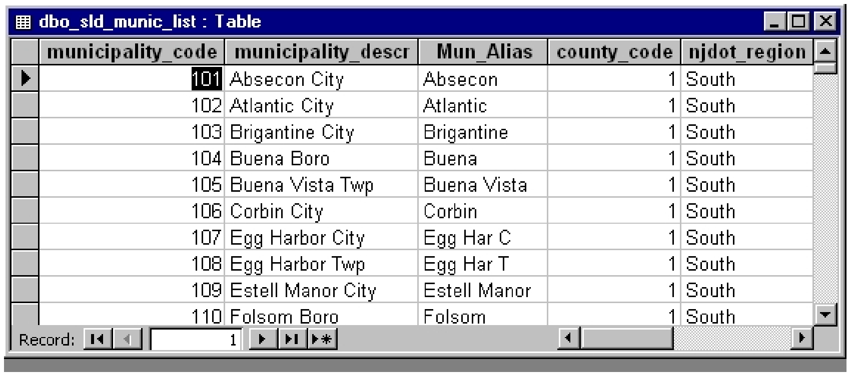
Table 3 – Some of the Attribute Tables in the SLD Database

Attribute Tables in the SLD Database	Attribute Tables in the SLD Database
Street Name	NB/EB Rutting Depth
Jurisdiction	NB/EB Distress Rating
Functional Class	NB/EB Skid Resistance
Federal Aid System	SB/WB Ride Quality
Control Section	SB/WB Rutting Depth
Speed Limit	SB/WB Distress Rating
Number of Lanes	SB/WB Skid Resistance
SB/WB Shoulder Width	HPMS Sample Section Name
SB/WB Pavement Width	Terrain
Median Type	Noise Barrier Material
Median Width	Noise Barrier Status
NB/EB Pavement Width	Noise Barrier Year Constructed
NB/EB Shoulder Width	AADT
Traffic Volume	Highway Type
Traffic Station ID	18 Kip ESAL-Heavy Truck-Flexible Pavement
Structure Number	18 Kip ESAL-Heavy Truck-Rigid Pavement
Contract Number & Date	18 Kip ESAL-Light Truck-Flexible Pavement
Enlarged Views	18 Kip ESAL-Light Truck-Rigid Pavement

Attribute Tables in the SLD Database	Attribute Tables in the SLD Database
NB/EB Ride Quality	Guiderail

4.3 Domain Tables

The SLD database makes use of several domain tables to validate attribute data in the event tables. The SLD Entity Relationship diagram shown in Figure 1 illustrates the relationships between the attribute and domain tables in the SLD database. An example of a domain table is the municipality list table shown in Figure 2.



municipality_code	municipality_descr	Mun_Alias	county_code	njdot_region
101	Absecon City	Absecon	1	South
102	Atlantic City	Atlantic	1	South
103	Brigantine City	Brigantine	1	South
104	Buena Boro	Buena	1	South
105	Buena Vista Twp	Buena Vista	1	South
106	Corbin City	Corbin	1	South
107	Egg Harbor City	Egg Har C	1	South
108	Egg Harbor Twp	Egg Har T	1	South
109	Estell Manor City	Estell Manor	1	South
110	Folsom Boro	Folsom	1	South

Figure 2 - Example of an SLD Domain Table

The GIS database is very similar to the SLD database. In general, the only relationships between tables are between attribute and domain tables.

4.4 Single Centerlines

The modeling of routes within the current NJDOT GIS is done with a single centerline representation for roads. This applies to all functional classifications of roads from Interstate highways down through local roads. Ramps are also represented with single centerlines.

4.5 Street Addressing

No street addressing exists within the current NJDOT GIS data model. NJDOT has had little need for addressing for traditional transportation operations and therefore street address information was never conflated from TIGER files or other sources.

4.6 Network Topology

Network topology is the relationship between spatial objects in the GIS. The relationships established in a GIS dictate the interaction between the objects. Network topology is necessary for advanced spatial analyses.

NJDOT does not utilize network topology in the GIS. There are no applications such as routing or traffic modeling that currently use the GIS database. The NJDOT planning division has been performing traffic modeling for years, but has used other GIS products such as MapInfo or TransCAD.

5.0 Transportation Data Model

This section will define a proposed data model for use by the NJDOT GIS and SLD systems. Each aspect of the model will be examined. The benefits and risks of implementing the proposed data model will be examined.

5.1 ArcGIS Transportation Data Model

The ArcGIS Transportation Data Model (code named UNETRANS) was developed by a group of ESRI transportation industry users, consultants, ESRI Business partners, and academics. The goal of the group was to define an "essential data model" for ArcGIS user organizations within the transportation industry, and in particular for roadway management organizations (e.g., DOT's), as well as for Railroads, Transit, Airport, and Waterway Authorities. Central areas for the group included road and rail network topology, linear referencing systems, dynamic event representation and asset location and management.

There are 3 components to the UNETRANS data model:

- A conceptual object model of transportation features, incorporating multiple modes of travel, and accommodating multiple scales of interpretation of the real world (e.g. modeling a large freeway interchange as a point at one scale, and a series of ramps and even lanes at a larger scale)
- UML code, which is easily transformed into an ESRI geodatabase. The average user can immediately begin to populate the geodatabase rather than to design it, and the inherent commonality between users facilitates exchange of data.
- Documentation in the form of a book on transportation GIS.

Figure 3 shows a graphical depiction of the UNETRANS data model.

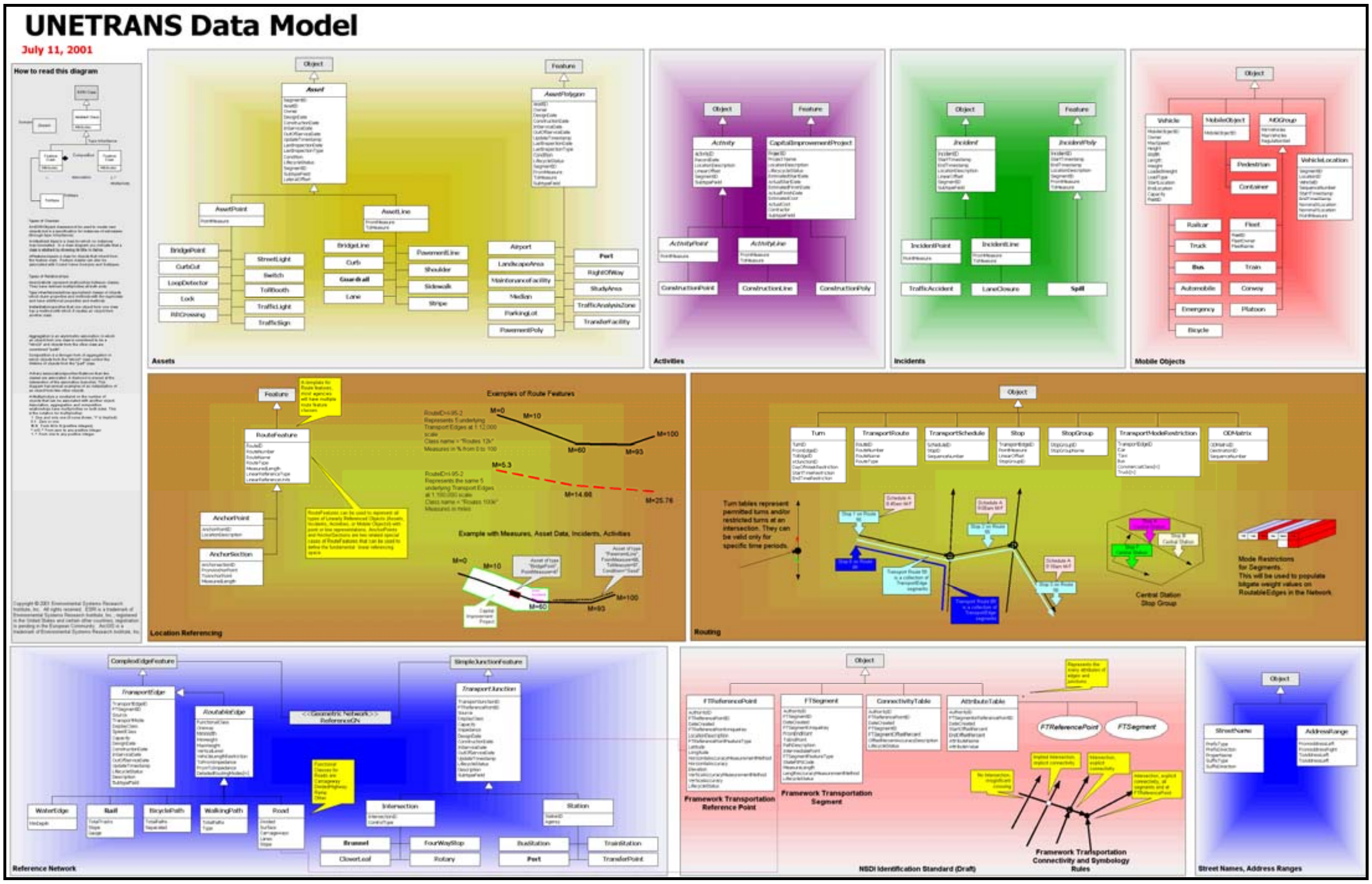


Figure 3 - UNETRANS Data Model

For more detailed information on the ArcGIS Transportation Data Model, please refer the UNETRANS website at http://www.ncgia.ucsb.edu/vital/unetrans/.

5.2 Key Features

The ArcGIS Transportation Data Model is very broad and covers all aspects and modes of transportation. The model can handle everything from a fixed roadway or railway network, to flexible routing such as bus operations, and to mobile objects such as cars passing through a toll plaza. The model contains nine different object packages or logical groupings of essential objects that can be incorporated into a customized data model for a GIS or discarded as unnecessary. Each package contains a set of object and feature classes and the relationships between those classes. Each object class consists of a descriptive name and a set of attributes that define the object. All UNETRANS object classes inherit properties from one of the basic object types that are provided in ArcGIS 8.1. The object packages in the ArcGIS Transportation Data Model are listed here and shown in Figure 4.

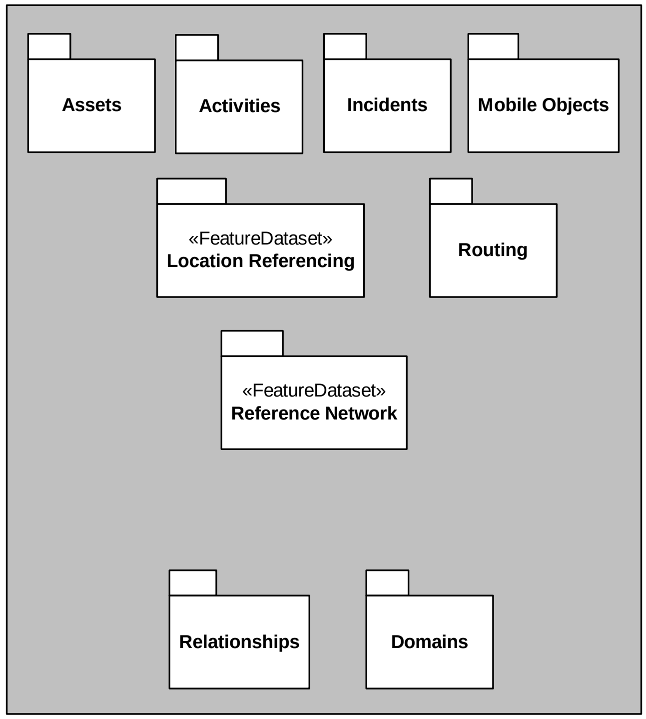


Figure 4 - Object Packages in the ArcGIS Transportation Data Model

5.2.1 Assets

Asset objects are transportation network features that are significant enough to represent a major capital investment from the Transportation agency. Examples of assets are bridges, roads, rest areas, signalized intersections, or roadway weather systems. Assets can be either point or linear features. Bridges and roadway weather systems are examples of point assets, while rest areas and roads are examples of linear assets.

The current SLD database contains asset object data, which was collected to support the Department's Maintenance Management System.

5.2.2 Activities

Activities are events such as construction projects that occur along a route. Activities are generally longer in duration than incidents but are not permanent. Activities can be either point events or linear events.

5.2.3 Domains

Domains are table objects that contain allowable sets of values for other event objects. An example of a domain would be the list of all municipalities in the State by municipal code number. Another example would be a table of all speed limit values from 5 MPH to 65 MPH.

5.2.4 Incidents

Incidents are short duration events that impact a roadway. Traffic accidents and sporting events are examples of incidents.

5.2.5 Location Referencing

Location referencing objects are those tables that are required to assign route and/or milepost information to a road network. The assigned route and milepost information for each route segment is used to calculate the spatial position of an object that is linearly referenced with route number and milepost information.

5.2.6 Mobile Objects

Mobile objects are features such as autos, bicycles, or buses that traverse the road network. Trains, ships and airplanes are also considered mobile objects if the data model has been extended to include rivers, railroads, and air routes. A mobile object can be a single object, such as an automobile, emergency vehicle, or railcar, or it can be a multipart object such as a convoy, train, or platoon of vehicles.

5.2.7 Reference Network

The basic transportation network can be represented as a GIS data model in many different ways. In fact, one of the challenges of a common transportation data model is that even within a single organization there are often multiple road datasets with different ways of measuring the location of objects along the roads. The methodology for locating objects along the transportation network is typically referred to as *linear referencing*. The reference network comprises the physical entities traversed by mobile objects. The physical objects can take the form of linear objects or point objects. Examples of linear objects are roads, rails, bicycle paths, walking paths, or waterways. Examples of point objects in the reference network include intersections, cloverleaves, brunnels (bridge/tunnel), bus stations, ports, train stations, or airports.

5.2.8 Relationships

The relationship objects dictate how the other data model objects interact with each other. Relationships describe behaviors and properties of objects. For example, a relationship called "RoadHasAddressRanges" would dictate the one-to-many relationship between records in the road table and the address range table. In other words, the relationship dictates that one road can contain one or more address ranges along its length.

5.2.9 Routing

The routing objects in the data model detail the penalties that are assessed upon mobile object attempting to traverse specific network objects. For example, a routing object may state that left turns are not allowed at an intersection during a specific time of day. Routing objects also contain schedule information for bus and rail mobile objects.

Many of the model objects are incorporated into the current NJDOT GIS and SLD systems in one form or another. For example, assets in the form of Maintenance Management System feature tables have been loaded to the SLD database via the recently completed MMS North data collection contract.

By design, the NJDOT GIS system uses location referencing objects in the form of routes and milepost data in the route master table and all attribute tables. Although NJDOT currently performs location referencing, the exact details of the location referencing objects of the data model are not identical to the current NJDOT design. Location referencing is performed by route and milepost in the attribute tables utilizing starting and ending milepost values.

5.3 Proposed NJDOT Data Model

Considering the current needs of the Department, the UNETRANS data model may be more complicated than is necessary at this time. The Department's GIS does not currently contain data about mobile objects, routing, incidents, or activities. A data model that is more complex than necessary increases the administration burden of keeping all of the feature classes up to date and increases the likelihood that high data quality cannot be maintained. The effort to keep the data model as simple as possible, yet maintain the capability to add functionality as needed is the keystone of this analysis. Figure 5 represents a proposed data model for the Department.

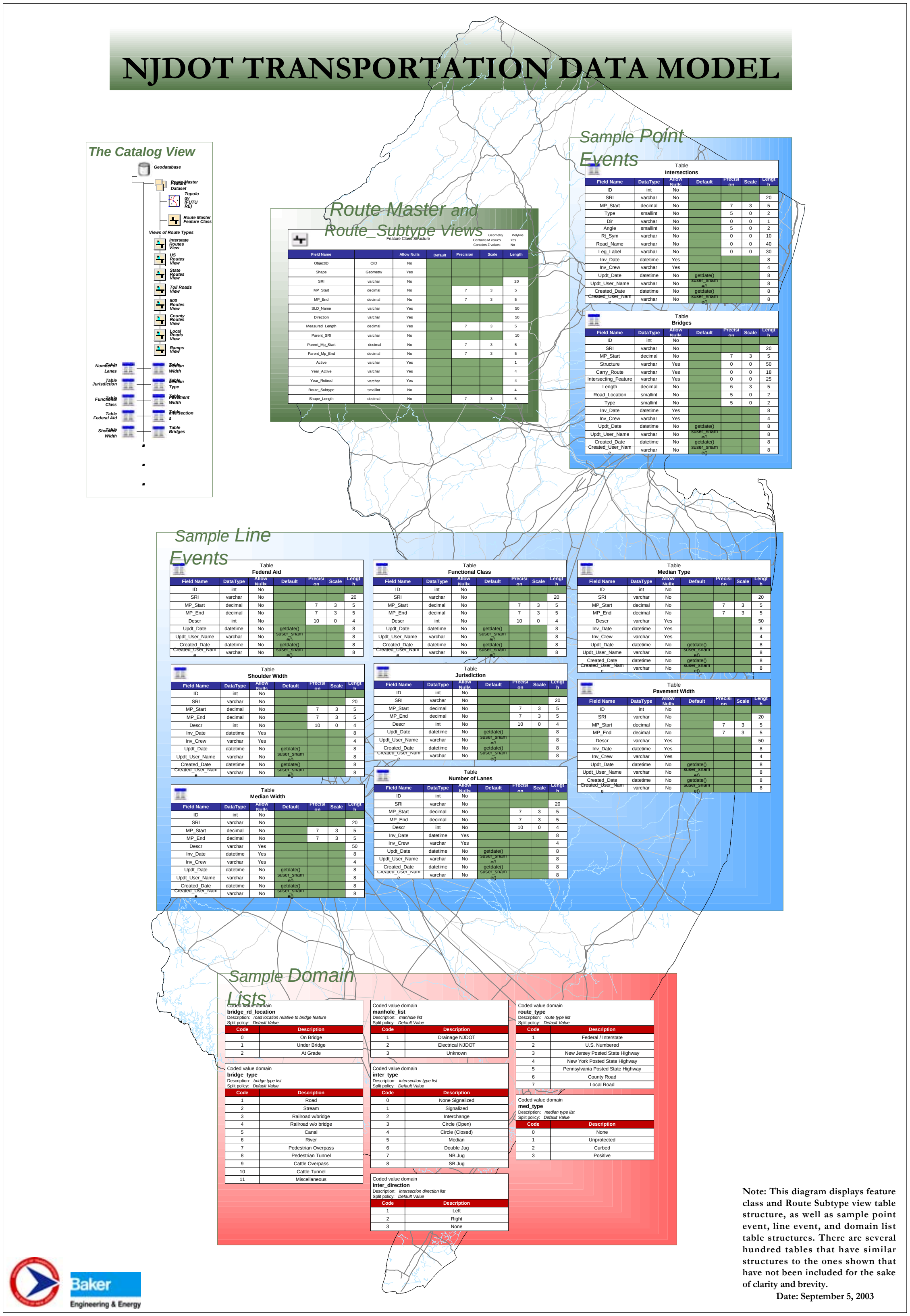


Figure 5 - Proposed Data Model

5.3.1 Components of the Model

The proposed NJDOT data model has several components or layers.

- Base layers contain background mapping information such as orthophotography, water features, and municipal lines. These layers can be from non-NJDOT data sources such as NJDEP or commercial maps.
- Routing layers contain the individual route feature classes that contain the data relative to the road network. These layers are discussed in detail in the next section.
- Cartographic layers contain other cartographic elements such as annotation requirements and or route shields. Separate cartographic layers give NJDOT the liberty to move symbols to make the mapping products more attractive.

5.3.2 Route Master Feature Class

Considering the unique attributes and requirements of different road classes ranging from Interstate Highways, to Local Roads, and to Ramps, and the need for ease of use, the data model includes a single, combined feature class for all route information. While the combined feature class will simplify some chores, there will likely be times when routes of only one type will be of interest. To facilitate use of, and speed queries upon route events in these situations, this proposal includes the creation of spatial views, one for each route type. The route network will include all of the following eight route types:

- Interstate Highways
- US Highways
- NJ Highways
- Toll Authority Routes
- 500 Series County Routes
- Other County Routes
- Local Roads
- Ramps

The actual structure of the feature class is shown in Figure 6. The subtype field has been added to keep track of the eight route types as listed above. Key features are identified after the figure in three distinct groupings, based on required attributes by route type.

Feature Class Structure

Geometry Polyline
Contains M values Yes
Contains Z values No

Field Name		Allow Nulls	Default	Precision	Scale	Length
ObjectID	OID	No				
Shape	Geometry	Yes				
SRI	varchar	No				17
MP_Start	decimal	No		7	3	5
MP_End	decimal	No		7	3	5
SLD_Name	varchar	Yes				50
Direction	varchar	Yes				50
Measured_Length	decimal	Yes		7	3	5
Parent_SRI	varchar	No				10
Parent_Mp_Start	decimal	No		7	3	5
Parent_Mp_End	decimal	No		7	3	5
Active	varchar	Yes				1
Year_Active	varchar	Yes				4
Year_Retired	varchar	Yes				4
Route_Subtype	smallint	No				4
Shape_Length	decimal	No		7	3	5

Figure 6 - Feature Class Structure

The first five route types (Interstate, US, NJ, Toll, and 500) contain the higher order highways in the state that are all basically similar in functional operations. These route types require identical attribute information. The key features for these higher order route types are detailed below.

- Multiple Centerlines – Multiple centerline graphic representation of divided roadways will be implemented. The feature class will contain separate segments for each carriageway of divided and dual-dual highways. Each carriageway of divided highways will have its own SRI number and be identified as a separate route. However, each carriageway will be associated with a parent segment that will be used for a single centerline representation of the roadway. This parent is the segment in the primary direction of travel of the route. Therefore, values for parent SRI and parent milepost ranges are carried in the table for each segment.
- Minimal Segmentation –The number of segments included in the feature class for each of the five higher order route types will be kept to a minimum. Segments will not be broken as the local road name of the route changes. Multiple segments for a route will only be added when the route is broken at coincident sections.
- SRI Numbers – The data model will continue to utilize the SRI route identifier format for all routes.

- Route Subtype – Within the Routes Master feature class, a separate subtype will be established for each of the eight route types. This will allow for validation of attributes, and eventually topology, depending upon the type of route a feature represents.
- Road Name – The common name for each route will continue to be carried in the feature table.
- MP Start and MP End – The measured starting and ending mileposts of the route segment will be explicitly stated as well as carried in the M values.
- Activation – A status field called "Active," as well as activation and retirement dates, "Year_Active" and "Year_Retired" respectively, will be maintained for each segment. This allows the capability to keep a graphic element that may no longer carry a public roadway.

County Route and Local Road route types contain the lower order roadways in the state that basically provide land access and collector functions. NHS connectors that are not on numbered routes are included in the feature class, and are treated as Local Roads. Key areas where County Route and Local Road route types differ from higher order route types are identified below.

- Single Centerlines – Single centerline graphic representation of local and county roadways will be implemented. With very few exceptions, these route types generally do not contain divided highways. Therefore, single centerline representation of the routes is sufficient. Because these routes have single centerlines, the parent SRI and parent milepost range will be the same as the SRI and milepost range for each record.
- Segmentation for Road Name Changes – The number of segments included for each County Route and Local Road in the feature class will still be kept to a minimum. However, segments will be broken as the local road name of the route changes. This policy is intended to simplify the query process for these routes. In most cases, queries are based on road name and not route number or SRI number. Therefore, breaking segments at road name changes is prudent.

The final distinct route type is ramps, which are treated similarly to other routes. Ramps each have their own route number and are considered as undivided highways. Unique features of the Ramp route type are identified below.

- Single Centerlines – All ramps are represented by a single centerline graphic. By definition, ramps are unidirectional and cannot be divided.
- Parent SRI and Milepost – Ramp identifiers were created from a variation of the standard SRI numbering scheme that incorporates the parent route and milepost location along the route associated with the ramp. The Ramp route type will carry values for parent SRI and parent milepost range to allow for querying of ramps by parent route.

5.3.3 Event Tables

All of the existing attribute tables in the database, as described in Section 4.2 of this report, will become event tables in the geodatabase. There are two types of event tables; point and linear. Point tables contain features that can be located at a single point along a roadway such as an intersection, traffic count, or accident. Linear tables contain features that extend for a measurable distance along a route such as the number of lanes, speed limit, or functional classification. All event tables will contain columns for SRI number and starting milepost. Linear event tables will include an additional column for the ending milepost of the feature. All event tables will include one or more additional columns that describe the attributes of the feature. Examples of these columns include the speed limit, accident severity, traffic count volume, or functional classification code.

5.4 Impacts of the Model

As with any change in the design of a computer system or database model, there will be impacts on existing systems, data, and processing resulting from the change. This section will attempt to quantify the impacts to the various users of the GIS.

5.4.1 Single vs. Multiple Centerline

The centerline of a roadway is the primary graphical depiction of the route for analysis and mapping purposes. There are many options for depicting centerlines of roadways. For example, a single centerline may be used to represent all travel lanes of a roadway. The single line model would apply to all levels of roads from the lowly slip ramp to large multi-carriageway divided highways such as heavily traveled Interstates. This is the model that NJDOT has used.

Alternatively, a roadway could be depicted with multiple centerlines. In this case, each carriageway of a divided highway would be represented by a graphical line. Multi-carriageway freeways such as the New Jersey Turnpike could have four centerlines, one for each of the local and express carriageways by direction. Each centerline would have its own linear referencing system established with milepost values that may vary from those of the other centerlines for the route. In addition, the direction of travel will be carried in the 10^{th} digit of the SRI. However, all carriageways would include the same parent SRI and milepost range. Figure 7 depicts a divided highway represented by multiple centerlines.

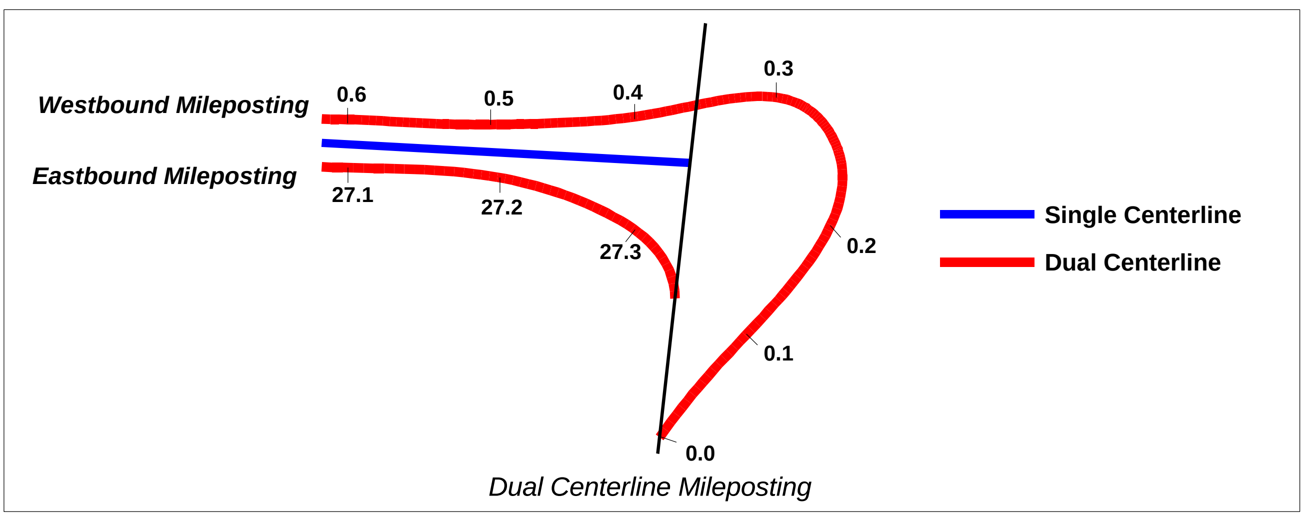


Figure 7 – Milepost Values with Dual Centerlines

Centerline Definition

For the purposes of the NJDOT data model, two types of highway centerlines are recognized and defined below. The road centerline location (RCL) of a highway is defined as the center of all through-lanes (driving lanes) of a roadway. Through lanes are the driving lanes typically used by through traffic. They do not include turn lanes, shoulders, or parking lanes.

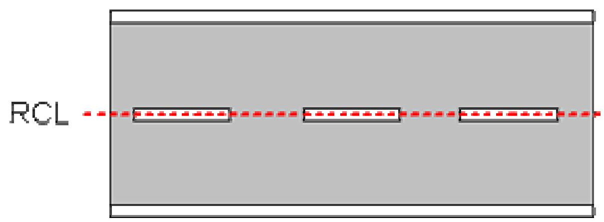
Divided Highway – A divided highway is defined to be a highway where the traffic lanes in the opposing directions of travel are separated from each other by a median strip intended to prevent traffic from crossing over from one lane to a lane in the opposing direction. The median strip may or may not include a constructed barrier such as a cabled or metal railing, concrete barrier wall, or landscaping for purposes of traffic control and safety. A determination to develop two centerlines instead of one centerline when short median strips are encountered will be in accordance with "common sense" consideration, with generally a minimum median strip length of 500 feet.

Non-Divided Highway – A non-divided highway is defined to be a highway where the traffic lanes in the opposing direction of travel are not physically separated with a boulevard or turn lane projection.

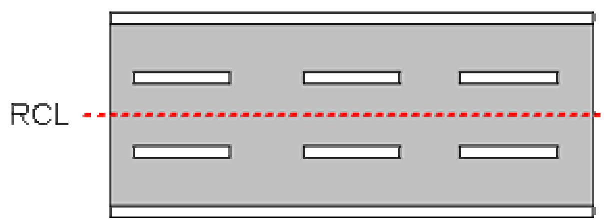
Examples of Multiple Centerline Definition for Different Roadway Types

The examples shown below apply whether a road carries traffic in one direction (one way streets, divided highways) or in both directions.

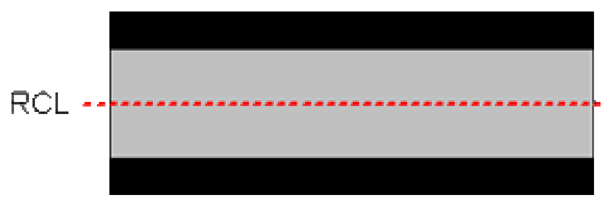
Even Number of Driving Lanes - RCL is defined by the visible lane markers in the center of the road.



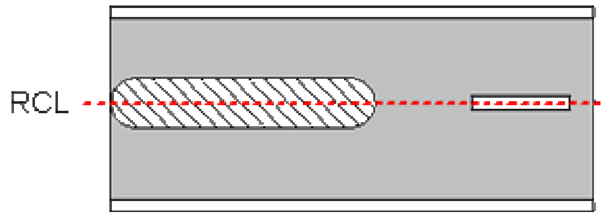
Odd Number of Driving Lanes - RCL is defined as the center of the middle lane.



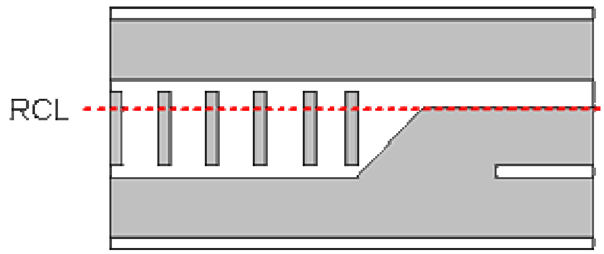
Unmarked & Unpaved Roads - RCL is defined as the center of the visible driving surface of the road.



Traffic Islands and Medians - RCL is defined as the center of the median or traffic island.



Uneven Turn Lanes - RCL is defined as the center of the median, traffic island, or area between the driving lanes.



Centerline Issues

Historically, the single centerline representation of roads has satisfactorily served the traditional GIS customers such as the Department's planning division. However, recent attempts to use GIS technology for applications such as the Maintenance Management System (MMS) have exposed weaknesses in the single centerline model.

For example, one requirement of data collection for the MMS is that data is collected and tagged with an SRI route number and milepost accurate to within the nearest 1/1000 of a mile (5.28 feet). Data collection procedures designed to collect maintenance feature data at that precision have problems with divided roadways. In many divided roadway cases, the primary (NB or EB) and the secondary (SB or WB) directions of travel (carriageways) differ in length (See Figure 7). The order of magnitude of the length difference is much greater than the required data collection precision. Therefore, a mileposting scheme running along the primary direction does not synchronize with the corresponding mileposting along the secondary direction. Historically, these length differences were handled by using "rubber band miles", in which mileposts along a secondary direction are stretched or shrunk to match up with mileposts along the primary direction. This often resulted in differences between mileposts that were either longer or shorter than 5,280 feet. However, when you are using mileposting to measure lengths of linear features such as guiderails, incorrect quantities will result. The length of a continuous guiderail between two milepost signs could be, for example, 5,500 feet or 4,500 feet depending on the difference in length between the two carriageways. Figure 8 depicts a divided highway with rubber band miles.

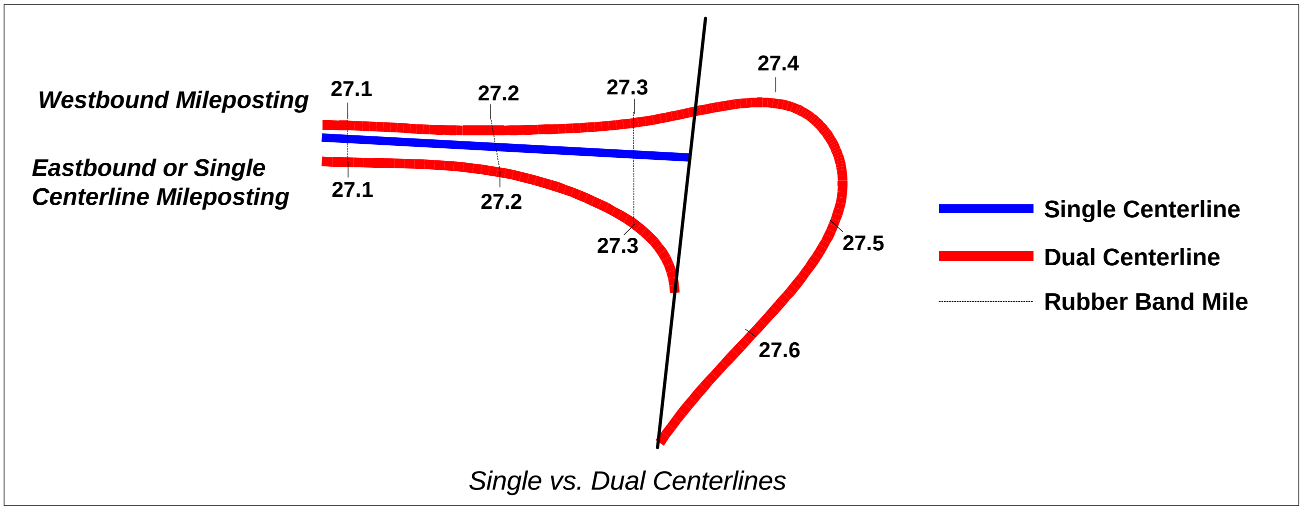


Figure 8 – Mileage Variations between Single and Dual Centerlines

5.4.2 Multiple Centerline Attribute Impacts

If divided highway were to be represented by dual centerlines (one centerline for each carriageway), the aforementioned rubber band mile problems would vanish. However, other problems may arise to make implementation of multiple centerlines difficult. This section of this report attempts to quantify the impacts of a multiple centerline model on the current attribute tables in the SLD database. The same analysis shown here applies to attribute tables in the GIS database.

Listed below in Table 4 are the impacts that multiple centerlines will have on the current SLD attribute tables given their current data structure. A **Major Impact** indicates that data may have to be recollected or repopulated from the source/owner. A **Minor Impact** indicates that routines will have to be developed to convert data into the proposed multiple centerline SRI values.

Table 4 – Impacts of Multiple Centerline Model on SLD tables

Table Name	Table Description	Impact	Comment
da_18Kip_Flow	Truck Flow	Minor	Conversion based on values being divided by the number of carriageways.
da_AADT_Flow	AADT Flow	Minor	Conversion based on values being divided by the number of carriageways.
da_bridge_sidewalk	MMS Bridge Sidewalk	Minor	Conversion required based on location field.
da_cont_date	Contract No. & Date	Major	Data may have to be recollected or reassessed.
da_cont_sec	Control Section	Major	Data may have to be recollected or reassessed.
da_curb	MMS Curb/Barrier/Wall	Minor	Conversion required based on location field.
da_delineator	MMS Delineator	Minor	Conversion required based on location field.
da_ditch	MMS Ditch/Channel	Minor	Conversion required based on location field.
da_federal_aid	Federal Aid	Minor	Conversion based on values being same for both carriageways.
da_fence	MMS Fence	Minor	Conversion required based on location field.
da_fiber_optic	MMS Fiber Optic	Minor	Conversion required based on location field.

da_func_class	Roadway Functional Class	Minor	Conversion based on values being same for both carriageways.
da_guiderail	MMS Guiderail	Minor	Conversion required based on location field.
da_highway_type	Highway Type	Major	May have to recollect data to get correct mile posting for secondary carriageway.
da_inventory_date	Standard SLD Inventory	Minor	Conversion based on values being same in both Primary and Secondary directions.
da_island_pave	MMS Island Pavement	Minor	Conversion required based on location field.
da_jurisdiction	Roadway Jurisdiction	Minor	Conversion based on values being same in both Primary and Secondary directions.
da_landscape_bed	MMS Landscape Bed Data	Minor	Conversion required based on location field.
da_lanes	Number of Lanes	Major	Must determine number of lanes for each new carriageway.
da_med_dual_type	Centerline Median Type	Minor	Conversion required based on table data.
da_med_dual_width	Centerline Median Width	Minor	Conversion required based on table data.
da_med_type	Median Type	Minor	Conversion required based on table data.
da_med_width	Median Width	Minor	Conversion required based on table data.
da_mowable_area	MMS Mowable Area Data	None	Not populated with data.
da_nbeb_l_pave	NB/EB Pavement (Inner)	Minor	Conversion required based on table data.
da_nbeb_l_shou_in	SB/WB Outside Shoulder (Inner)	Minor	Conversion required based on table data.
da_nbeb_l_shou_out	SB/WB Inside Shoulder (Inner)	Minor	Conversion required based on table data.
da_nbeb_pave	NB/EB Pavement Width	Minor	Conversion required based on table data.
da_nbeb_shou	NB/EB Outside Shoulder Width	Minor	Conversion required based on table data.
da_nbeb_shou_in	NB/EB Inside Shoulder Width	Minor	Conversion required based on table data.
da_noise_wall	MMS Noise Wall	Minor	Conversion required based on location field.
da_org_unit	MMS Organizational Unit	Major	Source data will have to be reassessed and may have to be repopulated.
da_pave	Pavement Performance Data	Major	Source data will have to be reassessed and may have to be repopulated.
da_pipe	Pipe	None	Not populated with data.
da_rpm	Plowable Reflective Pavement Markers	Minor	Conversion required based on location field.
da_sbwb_l_pave	SB/WB Pavement (Inner)	Minor	Conversion required based on table data.
da_sbwb_l_shou_in	SB/WB Outside Shoulder (Inner)	Minor	Conversion required based on table data.
da_sbwb_l_shou_out	SB/WB Inside Shoulder (Inner)	Minor	Conversion required based on table data.
da_sbwb_lanes	SB/WB Number of Lanes	Minor	Conversion required based on table data.
da_sbwb_med_type	Median Type (SB/WB)	Minor	Conversion required based on table data.
da_sbwb_med_width	Median Width (SB/WB)	Minor	Conversion required based on table data.
da_sbwb_pave	SB/WB Pavement Width	Minor	Conversion required based on table data.
da_sbwb_shou	SB/WB Outside Shoulder Width	Minor	Conversion required based on table data.
da_sbwb_shou_in	SB/WB Inside Shoulder Width	Minor	Conversion required based on table data.
da_shoulder_type	MMS Shoulder Type	Minor	Conversion required based on location field.
da_sidewalk	MMS Sidewalk	Minor	Conversion required based on location field.
da_special_light	MMS Special Light	Minor	Conversion required based on location field.
da_speed	Speed	Minor	Conversion required based on speed value being the same for each direction.
da_Street_Name	Street Name	Minor	Conversion required based on value being same for each direction.
da_tunnel	Tunnel	Minor	Re-populate data based on carriageway.
da_videolog	Videolog	Minor	Re-populate data based on carriageway.
da_views	Enlarged Views	Minor	Re-populate data based on carriageway.
da_yard	MMS Maintenance Facility Locations	Minor	Conversion required based on location field.

da_attenuator	MMS Attenuators	Minor	Conversion required based on location field.
sld_sri_master	Master SRI System Table	Major	Re-inventory secondary carriageways to get new lengths.
da_sheet_layout	SLD Page Layout Control Table	Major	Redesign data structure to account for reference back to primary carriageway.
da_municipal_mp	Municipal Line	Minor	Conversion required based on "left/right" field.
da_intersection	Intersections	Major	May have to recollect data to get correct mile posting for secondary carriageway.
da_route_flags	Route Flags	Major	Will have re-populate mile posting for secondary carriageways.
da_bridges	Bridges	Major	May have to recollect data to get correct mile posting for secondary carriageway.

5.4.3 Single Feature Class with Spatial Views

There are several possible options for configuring the spatial data within the geodatabase. Through performance testing and in consideration of ease of use, it was determined that a single feature class for all spatial data would give the best combination of ease and speed. The number of records in the entire database will make certain functions unwieldy, especially scrolling through lists and sorting tables. In order to make this model more flexible, this proposal includes the creation of eight spatial views based on the single feature class, one for each distinct route type. A spatial view is essentially a stored query within the database, that filters the records that will be read by the Arc software. By using spatial views, user requests to the database can be restricted specifically to the data of interest, without the need to process records from the entire database. If data is needed for all route types, the user should be aware that response time can be significant when compared to that of the spatial view. The preferred method for ease of use and response speed would be to use the individual views whenever practicable. Details of the performance testing (including a more thorough discussion of benefits/costs) are archived at Baker, and can be made available as needed.

5.4.4 Address Matching

Address matching is the process of creating geometric representations for descriptions of locations. As mentioned previously, NJDOT has not previously identified a need for street address matching using the GIS database. Therefore, no attempt was made to conflate street address attributes to centerlines in the GIS. However, the purpose of this analysis is to examine potential future uses for GIS and to make sure that the Department's significant investment is leveraged to the fullest extent possible.

Figure 9 is an example of address matching (also known as "Geocoding") in action. Suppose an applicant has applied for a highway access permit on U.S. Route 130 and DOT staff would like to determine specific road attributes such as the speed limit for that location. The software analyzes the components of the address as shown below and compares the results to start/end address values in the Routes Master table. A point is then placed on the U.S. Route 130 line segment, which shows the location of the access permit request.

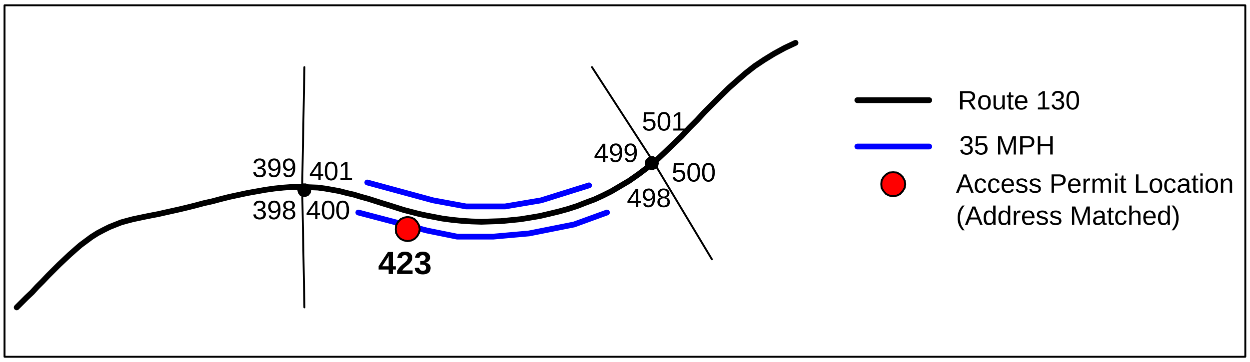


Figure 9 - Address Matching an Access Permit Location

By implementing address matching, milepost values would need to be correlated to start and end address ranges in an attribute table.

Potential uses for address matching at NJDOT include:

- Accident Tracking
- Highway Access Permit Tracking
- Right-of-Way Acquisition
- Construction Notification

5.4.5 Impacts to the SLD

There will be significant impacts to the automated SLD system as a result of implementation of the proposed data model. However, Baker is in the middle of a major overhaul of the SLD application code. Therefore, the opportunity exists to have the necessary data model changes included in the next generation of the automated SLD program with minimal negative impact on the application. The impacts to the SLD application are detailed in this section.

Graphic Depiction

With a multi-centerline data model, each carriageway is a separate route. However, SLD users will probably want to see both carriageways of a divided highway on the same SLD page in a manner similar to the current SLD. One proposed solution to display both carriageways of a divided roadway is shown in the form of a prototype SLD page in Figure 10. Note how the prototype page now contains two schematics, or “stick diagrams” and two attribute grids. Also note both carriageways are highlighted in the map area of the page.

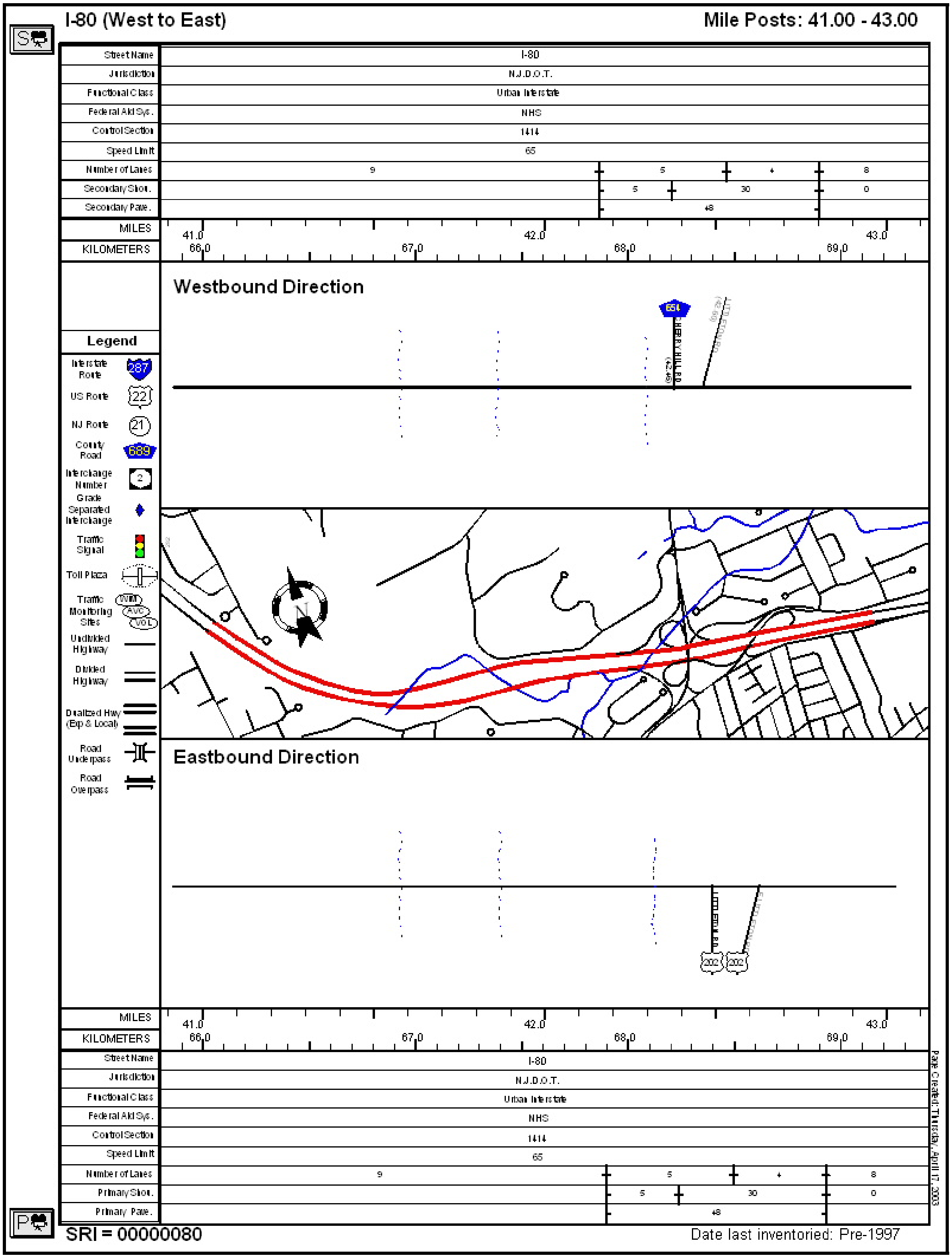


Figure 10 - Prototype SLD Page with Multi-Centerlines

Route Selection

The process of selecting routes to display in the SLD application will be impacted. With the addition of the local roads and ramps to the SLD network, the number of records in the current SLD master table has increased significantly and will probably exceed 100,000 records. Currently, the route list is displayed in a single combo box within the application. However, the responsiveness and sheer size of a combo box with 100,000 records will be unacceptable. The SLD application can be modified to use a tree view control, which would be matched to the eight route types. A significant performance increase could be realized with this technique.

5.4.6 Impacts on Data Development

Existing Systems

All of the Bureau of Transportation Data Development system databases will have to be examined to determine if modifications are required to accommodate multiple centerlines. These systems include Weight In Motion (WIM), Highway Performance Monitoring System (HPMS), and Traffic Monitoring System (TMS). Baker's database expertise can be utilized to determine any potential modifications and to implement necessary modifications. It is possible that data in these systems may have to be re-collected if a feasible conversion cannot be made.

Maintenance Requirements

The complexity of the proposed data model will increase the maintenance required on the various attribute and system tables. Modifications to existing validation, data management, and GIS routines will be necessary to accommodate the new data model. Some of the modifications will be minor. However, some could be extensive. These will have to be examined further on a case-by-case basis.

Software Purchases

In order to continue to administer and support the Department's GIS and SLD systems at the Baker Princeton office, Baker will need the appropriate software. For example, if NJDOT does indeed migrate to an ESRI-based solution for the GIS, Baker will need licenses for software such as ArcInfo, ArcSDE, and ArcIMS. This software will be needed in the very near future. Baker is requesting that NJDOT procure these licenses for Baker's use for the duration of these projects. At the end of the related projects, Baker will return the licenses to BTDD.

5.4.7 Impacts on BIMTP

Impacts on the BIMTP can be expected from a change in the transportation data model. Potential impacts include:

Department-wide software migration to the ESRI ArcGIS product line

As mentioned earlier, NJDOT utilizes various GIS and CAD software applications from multiple vendors to satisfy its current needs. These software packages are often incompatible with each other, and do not lend themselves to being used as a system-wide tool for NJDOT or for compatibility with those outside the department. Department-wide migration to ESRI ArcGIS would provide a common framework for all users, inside and outside the organization. The migration would require buy-in from all stakeholders at NJDOT for it to be effective. Administrators would need to master and implement multi-user database management using ArcSDE, as well as be able to support potential ArcIMS applications.

Training Needs

The need for training of both administrators and end-users in the use of new software would also require a department-wide commitment. Training would be crucial for the understanding of the impact of new concepts such as multiple centerlines, topology maintenance, and changes to the Straight Line Diagrams. Additional staff may need to be hired or reallocated to this task.

Internet-Enabled Mapping Development

One of the advantages of going with ESRI ArcGIS is the ability to provide end-user access to select data via Internet-Enabled Mapping using ArcIMS. This may require additional hardware and qualified staff to create and maintain this system.

5.4.8 Impacts on NJDOT

Adopting a new transportation data model will have some impacts on how NJDOT operates. Impacts may include:

- Providing a more robust network for other applications
- Reduction of software redundancies
- Significant learning curve
- Enhanced training needs
- Potential multiple centerline impacts requiring data re-collection to Pavement Management System, Project Reporting System, Traffic Operations, and the Highway Maintenance Management System
- Easier access to data via a web-enabled interface and custom applications
- Potential to implement truck routing and maintenance planning applications

5.4.9 Non-NJDOT Impacts

Revising the transportation data model used at NJDOT would affect outside users of NJDOT information, although to a lesser degree than users within the Department. Potential impacts of revising the model include:

- SLD Format Changes - SLD Users would need to adjust to a multiple centerline format. Although this is a relatively minor change, documentation would need to be provided, and the end user would need to learn to read the new format.
- Coordination with Outside Agencies/Sources - Opportunities exist to reduce redundancies of effort by coordinating more closely with outside agencies including:
    - Counties
    - Municipalities
    - NJDEP
    - E911 Providers
    - US Census Bureau MAF-Tiger 2010 Initiative
    - Commercial Vendors

6.0 Geographic Source Data Options

Several options exist for acquiring roadway centerline and feature attributes for the Department's GIS. The following is a summary of the advantages and disadvantages of each method.

6.1 Aerial Photography

Roadway centerlines are digitized in a GIS using digital orthophotos (aerial photographs in which displacements caused by the camera and the terrain have been removed). Aerial photographs are available for the entire state from the NJDOT/NJDEP joint effort. This is the approach that the NJDOT GIS has used to obtain centerlines.

Advantages:

- Easy to acquire centerline information quickly, without having to go out into the field
- Can have several people digitizing centerline information at the same time
- Requires standard GIS software (ArcGIS)
- Inexpensive

Disadvantages:

- Not as accurate as GPS
- Can only obtain a centerline, not attribute information (such as pavement type, width, turning lanes, guide rails, shoulders, etc.)

6.2 GPS

The line representing the center of the road is collected. This is done by placing a GPS antenna on the driver's side of a vehicle and driving at normal traffic speeds, maintaining a constant distance from the roadway centerline. A GPS point is collected at a specified interval (typically set at 1 point per second). An offset is applied to the data to account for the distance between the antenna location and the centerline of the road since it is impossible to drive over the true centerline (due to traffic).

Advantages:

- Accurate (typically to within 1 meter)
- Can acquire attribute information on roadway features at the same time as you are collecting centerline information. For example, information on pavement type, width, turning lanes, guide rails, shoulders, etc. could be collected in the field.
- Relatively inexpensive

Disadvantages:

- Requires a minimum of two people in the field to collect data (one person to drive, one to operate the GPS)

- Requires software to download and translate GPS files into GIS readable files. The information often needs to be "cleaned up" in the GIS to eliminate spikes in the GPS trail
- If the GPS signal is lost, or if there is user error in feature attribute collection, data must be recollected, requiring a secondary session in the field

6.3 Video Based Feature Extraction

Mobile mapping technology utilizes multiple cameras placed at varying angles on top of a vehicle which is driven down a route, providing high-resolution geo-referenced digital images showing the transportation infrastructure of the roadway. The images are viewed in stereoscopic pairs. Customized feature extraction software is then used to calculate the geographic coordinates for any pixel in the photo. To map the centerline, a user simply clicks on the centerline of the roadway in each successive photo. The software then calculates the geographic coordinates for the point. All points are then connected to form a centerline.

Advantages

- Accuracy of collected data location. Sub-meter accuracy is typical with this technology
- Can acquire attribute information on roadway features at the same time as you are collecting centerline information. For example, information on pavement type, width, turning lanes, guide rails, shoulders, etc. could be collected simultaneously
- If features are missed during collection, it is easy and quick to go back to the photographs file and extract the features. There is no need to go out into the field again
- Speed of data extraction. After field photo collection, several people can be extracting features simultaneously from the same photo set

Disadvantages

- Requires specialized software and vehicles. Not many companies are equipped to do this at the present time

6.4 Third-Party Datasets

Third-party datasets can be purchased from commercial vendors such as Navtech and GDT, county agencies, or obtained from the United States Census Bureau (TIGER line files). Third-party datasets generally include road centerlines and various attribute data for each road segment. Examples of road attribute data that is already contained in third-party solutions include: functional road classifications, ramps, speed classifications, bridge and tunnel locations, turn restrictions, physical and painted lane dividers, toll indication, and address ranges.

Prices for the commercial datasets range from $12,000 to $14,000 for 1-5 end users, with quarterly updates costing anywhere from $1,200 to $17,000 per update. Raw TIGER line data is free for download from the Census Bureau's website, or for a nominal fee on CD-ROM.

<u>Advantages of Using Third-Party Data:</u>

- Potential cost savings related to obtaining ready-made centerlines and attribute data.
- Ability to perform address matching/geocoding.

<u>Disadvantages of Using Third-Party Data:</u>

- All third-party datasets would require extensive QA/QC in order to verify the accuracy and suitability of the data, especially the TIGER Line data.
- Additional data would still need to be obtained via traditional methods (GPS), making the cost of third-party data less attractive.
- Third-party datasets are generally focused on routing applications, not transportation systems feature inventories and maintenance.
- Strict licensing restrictions exist on use of derivative data. Use would require entering into a data-sharing agreement with the third-party entity.

7.0 Network Topology

Using network topology offers many advantages to an organization that plans to make use of advanced features. For example, both routing and traffic modeling could be maintained from the same feature datasets used by the Straight Line Diagrams (SLD) and MMS, once topology is established. Advantages include:

7.1 Advantages of Using and Maintaining Network Topology

- Advanced routing, traffic modeling, and address matching possibilities.
- Consolidation of datasets and GIS software needs throughout NJDOT.
- Relationships and rules can be applied to and between feature datasets. This allows for complex analysis of the relationships between data, and also controls how and what data can be added to datasets. For example, rules could be set up to ensure that crossing lines break at intersections.
- Compatibility with outside agencies including NJDEP, county planning boards, etc.
- Automated detection of undershoots and dangles = cleaner data.

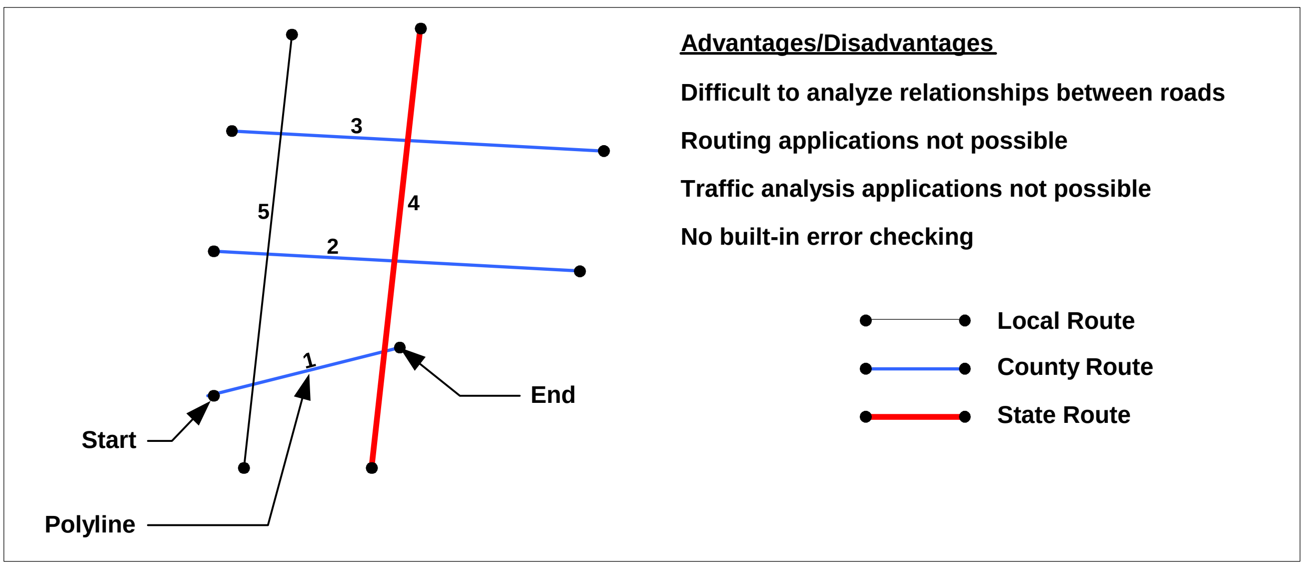


Figure 11 - Data without Roadway Topology

7.2 Disadvantages of Using and Maintaining Network Topology

- Creating and maintaining network topology is more difficult and time-consuming.
- Network topology may significantly increase server load and network traffic. It would also increase regeneration time.

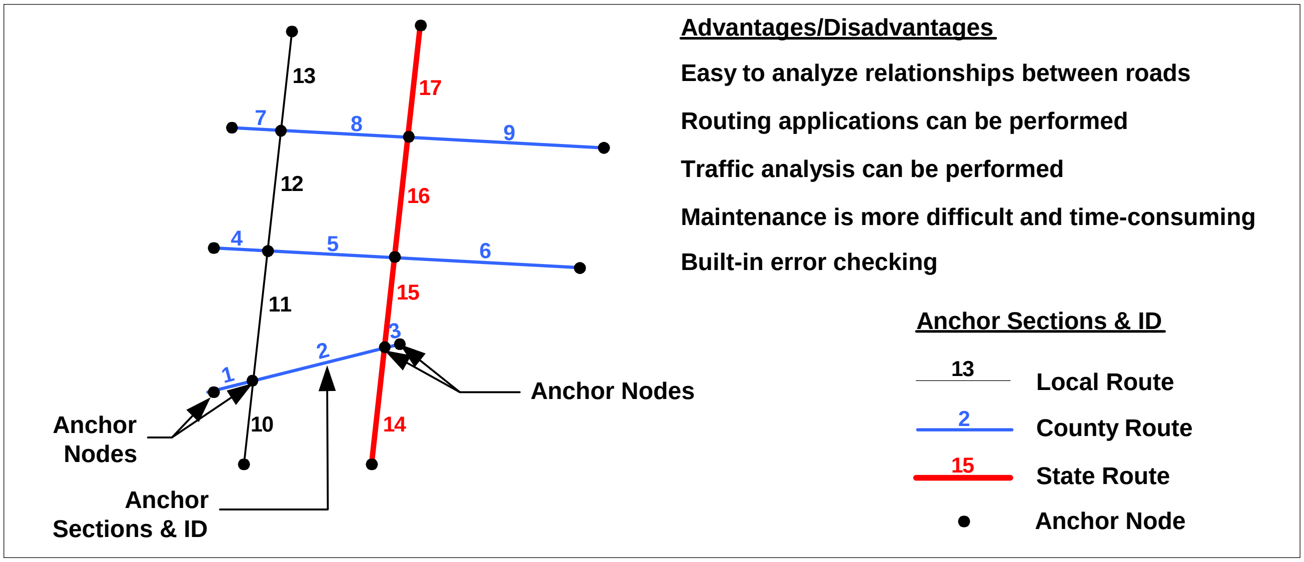


Figure 12 - Network Topology of Roadways

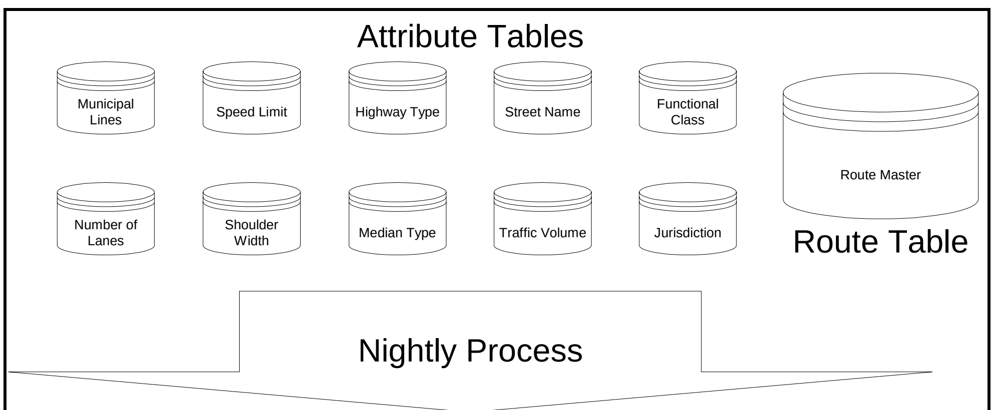
8.0 EZ-Query Table

The GIS data model relies heavily on the process of dynamic segmentation to query attributes across different tables. The use of dynamic segmentation allows the structure of each attribute table to be as simple as possible. This in turn decreases database query times on the individual tables and eases database maintenance.

The main disadvantage of storing attributes in separate tables is that it is difficult to query across multiple attribute tables without using a dynamic segmentation tool such as in ArcView. Users that may wish to query data but have limited query training or tools will either not be able to execute a multi-attribute query, or the query will return unexpected (i.e. wrong) results.

Casual or untrained database GIS users would benefit greatly from a combined table of commonly queried database attributes. Such an "EZ-Query" table could be pre-segmented to produce homogeneous records with ten or more common attributes as shown in Figure 12. Those common attributes would be the ones that are most often queried in the database. The table could be recreated on a nightly basis by an automated process.

The EZ-Table structure would allow quick queries via a web-based or client-server application that prompts the user through development of the query. The SLD application uses a similar process in the Master Route List Filter screen as shown in Figure 13. Results of the queries could be displayed on a web-served GIS map, exported to Excel or Access, or printed in a report. Mathematical functions such as sum, maximum, minimum, or averages could be performed on the results.



SRI	MP Start	MP End	Municipal Code	Speed Limit	Highway Type	Street Name	Functional Class	Number of Lanes	Shoulder Width	Median Type	Traffic Volume	Jurisdiction
00000033	0.000	0.015	1111	35	1	Greenwood Ave	02	2	0	0	23,500	State
00000033	0.015	0.230	1111	35	1	Greenwood Ave	02	2	4	0	24,600	State
00000033	0.230	1.300	1111	25	1	Greenwood Ave	02	2	4	0	30,000	State
00000033	1.300	10.067	1103	25	1	Greenwood Ave	02	3	8	1	18,000	County
00000058	0.000	1.300	1910	50	2	Jones St.	13	2	12	1	56,700	State
00000058	1.300	1.850	1910	50	2	Jones St.	13	2	12	1	60,200	State
00000058	1.850	3.090	1911	50	2	Main St.	14	4	12	1	65,300	State

EZ-Query Table

Figure 13 - EZ-Query Table Creation Process

The EZ-Query table would be regenerated on a regular basis using automated procedures from the existing relational attribute tables as part of the SLD or GIS system administration. Prototypes of procedures to populate an EZ-Query table are under development at Baker.

A separate GIS feature class that corresponds to the EZ-Query table would be available to users for graphic queries.

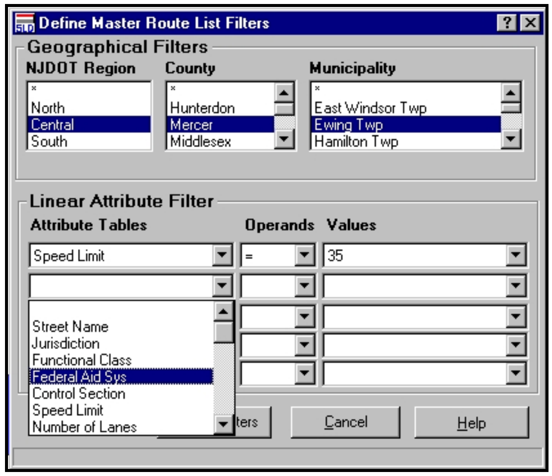


Figure 14 - SLD Filter Screen

9.0 Web Enabled GIS Data

Several states have comprehensive web sites that provide volumes of attribute data available to the general public. This data is accessed via attractive GIS interfaces. A good example of a strong web presence is the Illinois DOT web site. The same model of data delivery could be implemented at NJDOT. Powerful tools like ArcIMS should be utilized to publish data such as traffic counts, accident statistics, roadway information, construction zones, and detour routing for access via a map-based interface.

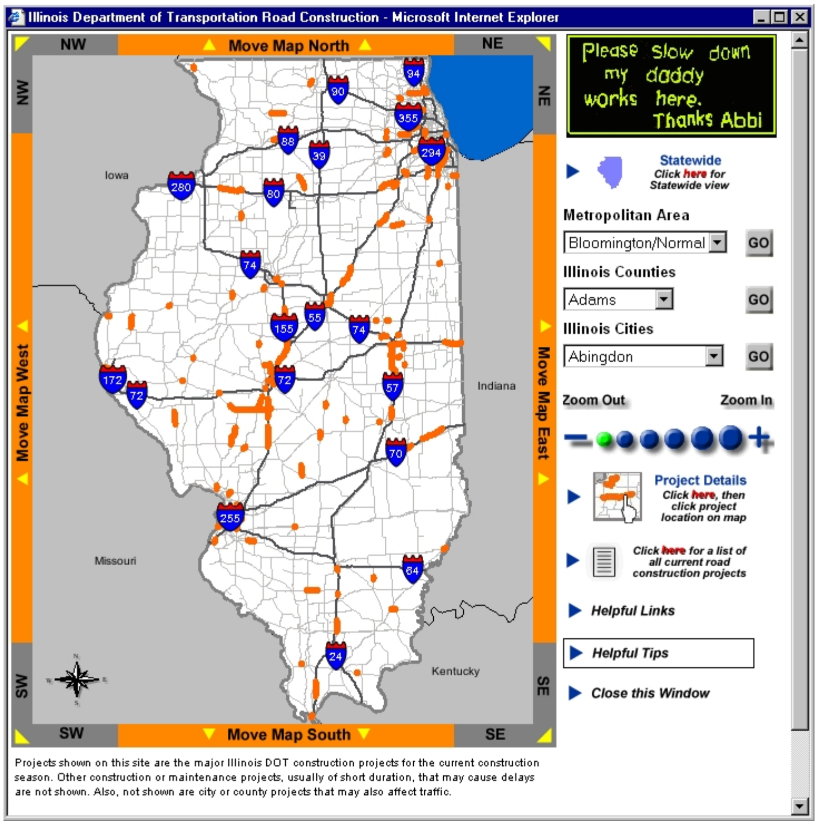


Figure 15 - Illinois DOT Web Delivered Construction Projects

9.1 ArcIMS

ESRI's ArcIMS (ArcGIS Internet Map Server) is software that enables the distribution of high-end geographic information systems (GIS) data and mapping services over the Internet. ArcIMS software allows for the integration of local data sources with Internet data sources for display, query, and analysis in a user-friendly Web browser front-end. Utilizing this type of technology would allow NJDOT to serve GIS data to in-house users over the Department Intranet, without each end-user needing an ArcGIS license or advanced GIS knowledge. Whether ArcIMS is used on the Department Intranet or over the Internet, the software allows geographic information to be shared with hundreds of thousands of concurrent users and allows them to do location-based analyses.

Key features of ArcIMS include: integration with ESRI's ArcGIS product line; the ability to combine data from multiple sources inside and outside of NJDOT; secure access to sensitive data sources; support for a wide range of GIS capabilities; highly scalable architecture; standards based; support for a wide range of clients, and support for metadata services and management. Routing features can be added to ArcIMS using the ArcIMS Route Server software. ArcIMS and ArcSDE (ArcGIS Spatial Data Engine) are used together to provide access to spatial data over the web.

9.2 Location Services

ArcIMS can be used to provide remote location services to NJDOT staff. This would allow personnel in the field to access the Department's geographic data via wireless technology. Several potential applications include using ArcIMS to deliver maps to cell phones with routing and proximity information, fleet management and dispatching information, and general information queries from the field.

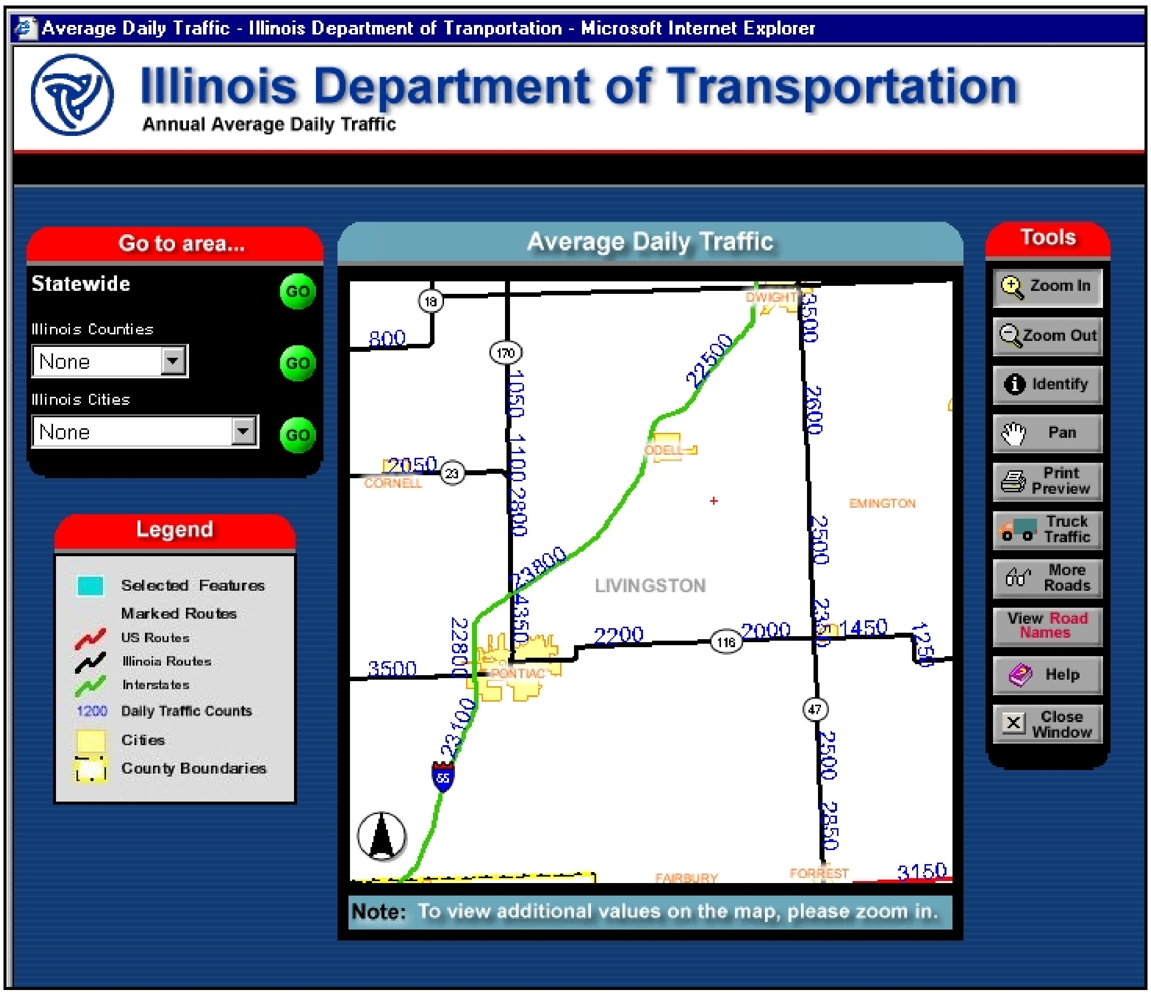


Figure 16 – Illinois DOT Web Delivered Traffic Volume Data

Figures 15 and 16 show examples of how Illinois DOT developed ArcIMS applications to aid in the visualization and query of transportation related data. Options for customization are limitless and would make access to data quick and easy.

10.0 Recommendations

The NJDOT is at an opportune time to make significant changes to its GIS in order to meet the transportation information needs of the 21st century. The change from one GIS system to another allows the opportunity to review and/or improve the database architecture, geographic source data, existing procedures, and data model. To better leverage the significant investment that NJDOT has made in the GIS, Baker recommends implementing the following strategies:

10.1 Incorporate Multiple Centerlines for Divided Roadways

Multiple centerlines allow for more precise positioning of attributes such as MMS features or accidents along the secondary direction of a roadway. With multiple centerlines, the secondary direction of a route is treated as an individual route with a separate SRI number. This is the same route numbering/mapping policy that is implemented successfully in Virginia and New Hampshire, two other states where Baker provides transportation services.

10.2 Develop and Maintain an EZ-Query Table of Common Attributes

Casual or untrained database GIS users would benefit greatly from a combined table of commonly queried database attributes. Such an "EZ-Query" table could be pre-segmented to produce homogeneous records with ten or more common attributes. Those common attributes would be the ones that are most often queried in the database. The table could be recreated on a nightly basis by an automated process.

The EZ-Query table would be regenerated on a regular basis using automated procedures from the existing relational attribute tables as part of the SLD or GIS system administration. Prototypes of procedures to populate an EZ-Query table are under development at Baker.

10.3 Leverage Third-Party Attribute Data

Many non-NJDOT public agencies as well as private companies have been compiling a wealth of information about New Jersey roads. All 21 counties have been implementing enhanced 911 systems for emergency response. Tremendous amounts of detailed data such as address ranges and access points have been accumulated from those projects. Public utilities such as electric and phone service providers have already compiled large data sets for their service areas. Commercial companies such as NavTech and GDT have numerous data collection crews that collect, organize, collate, and publish data about the road network. In fact, the most widespread application of GIS technology, web based mapping and driving directions, are based on commercial data.

It would be prudent to investigate the incorporation of this third-party data in the Department's GIS. Much data that is now collected by methods such as GPS based inventory, orthophoto digitizing, or video feature extraction may be already available from other agencies or private companies. It may be cost effective to purchase the data rather than to re-collect it internally.

10.4 Study the Incorporation of Street Address Data

There are several areas of the Department that would benefit from having street address information linked to the GIS and SLD systems. The Crash Records Section could utilize street address information to verify and consistently locate vehicle crashes that were originally described using a street address. The Department's Right-of-Way and Access Permits bureaus could utilize address information to better identify properties impacted by construction projects or that are requesting driveway access to state highways. Address information is readily available from sources such as the TIGER files from the United States

Census Bureau or from most of the commercially available mapping products. An in-depth review of these sources should be performed to quantify the costs and benefits of obtaining, verifying, and implementing address information.

10.5 Create and Maintain Network Topology

The development and proper maintenance of network topology could provide substantial cost savings and increase the utility of the GIS to the Department. Redundant efforts to maintain disparate roadway network data sets could be eliminated or reduced by implementing network topology. Software packages such as ESRI's ArcInfo contain powerful topology maintenance and editing tools that can replace or at least complement custom software tools that have been developed to perform basically the same functions.

New applications such as over-weight truck and/or snowplow routing could be developed to better leverage NJDOT staff and provide additional services to Department customers. Planning functions such as traffic modeling could use the same base network as the GIS. This would result in an increase of traffic related attribute data, such as detailed traffic counts, projections, and truck percentages available to users through the GIS and SLD systems. Applications such as incident management information could be developed to alert the motoring public to alternate routes in the event of an accident or other road closure.

10.6 Develop a Stronger Web Presence

Several states have comprehensive web sites that provide volumes of attribute data to the general public. This data is accessed via attractive GIS interfaces. A good example of a strong web presence is the Illinois DOT web site. The same model of data delivery could be implemented at NJDOT. Powerful tools like ArcIMS should be utilized to publish data such as traffic counts, accident statistics, roadway information, construction zones, and detour routing for access via a map-based interface.