Synthesis of State Practices in Developing Linear Referencing Systems

Requested by:

American Association of State Highway and Transportation Officials (AASHTO)

Standing Committee on Planning

Prepared by:

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Disclaimer

NCHRP
08-36 Task 80

Synthesis of State Practices in
Developing Linear Referencing Systems

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SYNTHESIS OF STATE PRACTICES IN DEVELOPING LINEAR REFERENCING SYSTEMS

SUMMARY Many departments of transportation (DOTs) have had legacy linear referencing systems in place since before the digital era. As GIS technology has become widely used, the issue of how to implement and integrate linear referencing systems into departmental work flows has presented a significant challenge to DOTs. The issues which contribute to these challenges include, but are not limited to, vendor implementations of linear referencing, legacy data issues, and staffing and budgetary constraints. The differences in resources available among the various DOTs have resulted in a variety of implementations of linear referencing with the GIS environment. As GIS has moved from the desktop to the enterprise environment, implementation issues have a greater impact on the ability to disseminate LRS-based data.

In light of these differences, there is a need to evaluate the current state of GIS LRS implementations among the nation's DOTs in order to take stock of what has been and is being done in order to share information and ideas.

This report summarizes the results of the National Cooperative Highway Research Project (NCHRP) 08-36 Task 80, "Synthesis of State Practices in Developing Linear Referencing Systems." The project consists of a survey of the nation's DOTs regarding their linear referencing system activities, as well as five case studies highlighting technical and institutional issues related to LRS implementation.

The survey results showed notable variations in LRS implementations among DOTs. While all respondents are using linear referencing in some fashion, the level of implementation and integration with departmental business processes range from low to very high. Of particular interest is the relatively low implementation of multimodal linear referencing systems. This suggests that most DOTs are still focusing on integrating and implementing roadway-based LRSs and have not been able to focus on other modes.

It is expected that the information in this report will provide insight into the actual state of linear referencing systems in the nation's DOTs and expose some of the gaps between the theoretical possibilities and reality. In addition, the report should benefit states by highlighting some of the practices employed by DOTs with successful LRS implementations. This information could serve as a model for other states to follow in their LRS implementation efforts.

CHAPTER 1

BACKGROUND

A significant amount of the business data used by departments of transportation is linearly referenced. These data range from physical roadway attributes (e.g., lane widths, number of lanes, etc.) to non-physical attributes such as traffic volumes and maintenance projects. These attributes, typically known as events, are related to the roadway through the use of a variety of linear referencing methods (LRMs). The particular LRM used for an event may vary depending on data collection, software application requirements and other factors. Many state DOTs store data in various LRMs. The combination of LRMs and procedures which are used to manage event data and other linear referencing activities is known as a linear referencing system (LRS).

Because much of the business data required by DOTs is linear in nature, most DOTs have been maintaining data using a variety of linear referencing methods for decades. Until the advent of digital geographic information systems (GIS), these data were often maintained on paper or in tabular form in mainframe systems.

With the advent of desktop computer GIS technology, some of these data were migrated or adapted for use on local computers. This approach often led to inconsistency among databases and contributed to the development of data silos in which data were only accessible to a few departments or individuals. In addition, these disparate databases were difficult to integrate with the overall business processes of the department.

As GIS technology has evolved from the desktop to an enterprise environment, there has been increased interest and potential for sharing data across the enterprise and integrating data with DOT business processes. Because of the linear nature of the data attributes (events), a linear referencing system provides an effective way to manage this data. Since the data can be accessed and used by individuals within a department and throughout an enterprise, there are significant scalability benefits to be realized.

In light of these developments, the TRB sponsored project NCHRP 20-27(2), whose purpose was to develop a data model for a multimodal linear referencing which could be easily implemented by DOTs. Despite this effort, the DOTs across the country are at varying levels of LRS implementation. Often the differences between the states can be attributed to resource and support issues, which limit the amount of effort that can be devoted to the establishment of a LRS. The complexity involved in establishing a robust LRS, along with the need to conduct existing business processes without interruption, can also hamper the ability of a DOT to implement a system.

The purpose of this study is to conduct an inventory of LRS-related activities at the various state DOTs in order to determine the state of the practice.

SYNTHESIS OBJECTIVES

Many state transportation agencies continue to search for optimal solutions for linking attribute data of transportation system characteristics and performance with linear referencing tools used for mapping and analyzing data. A number of ongoing issues continue to be problematic, including maintaining stable linear data over time as realignments and administrative changes occur, synchronizing traditional data system locations with map geographic coordinates, providing interoperability between data systems, expanding data systems to address both state and local roadway networks as well as multi-modal features, and developing tools for efficient and effective data analysis, mapping and reporting.

This research conducted a synthesis of state practices in developing transportation linear referencing systems and/or the applied practices of using linear referencing systems. Case studies of recent advances were documented and individual state approaches, outcomes, results and resource requirements were compared to a list of key business factors, such as:

- Stability of data over time
- Geographic resolution, including the ability to capture data on local systems
- Interoperability between systems (routes and/or data)
- Business process efficiencies
- Accessibility within agencies and among partners

METHODOLOGY

For the sake of efficiency, it was decided that an internet-based survey would be the best way to conduct the survey of all DOTs. A survey was developed which focused on current LRS activities at the DOTs. The questions were designed to obtain an overview of LRS activities, not to conduct in-depth research. Also, since AASHTO and other organizations routinely conduct surveys of DOT GIS activities, the majority of questions in this survey were restricted to LRS and not general GIS activities. Questions were grouped into the following general categories:

1	Contact Information	6	Applications and Products
2	General	7	Resource Requirements
3	Institutional	8	Comments
4	Technical	9	Documentation
5	Maintenance	10	Additional Comments

In order to maximize the response rate and minimize the burden on respondents, the survey was limited to forty questions in length. The survey questionnaire is located in Appendix A.

Once a list of valid GIS contacts for the 52 DOTs (50 states, Washington D.C. and Puerto Rico) was compiled, the survey was posted on the Survey Monkey website and email notifications were sent to the DOT contacts. The notification contained a summary of the project and an explanation of why each response was important. In order to give the DOT contacts enough time to respond, the survey was available during the month of July 2008. When the survey response time passed, the results were downloaded and analyzed.

From the pool of survey respondents, five DOTs were selected for use as case study subjects. The subjects were selected based on their responses and conversations with panel members. Case studies were chosen based on their efforts in technical and institutional areas in integrating LRS-based data with departmental business processes and reflect a variety of topics pertaining to LRS implementation.

CHAPTER 2

RESULTS

The overall response rate for the survey was 88%. Of the 52 DOTs, six did not respond, or accessed the survey but did not enter any responses. In some cases, DOTs submitted multiple responses to the survey. Sometimes several staff members from a DOT responded, possibly because different personnel were better suited to respond to certain questions. In other cases, the same person revisited the survey to provide update or more accurate responses. These multiple replies occasionally resulted in conflicting answers to questions. In cases of conflicts in yes/no questions when different staff members responded, the "yes" responses were tallied. Also, not all respondents answered all questions. In the analysis of results, the percentages are calculated based on the number of responses (46) unless otherwise specified.

The following section shows the survey responses by category and question.

<u>Contact Information</u>

1. Please enter your name.

2. Which state, district or territory do you represent?

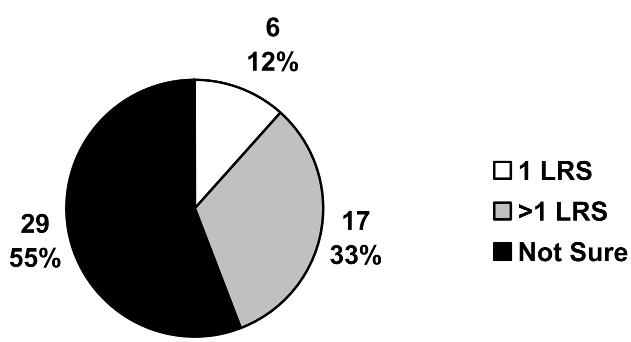
3. What is the name of your agency?

4. Please list a telephone number where we may reach you.

5. Please enter your email address.

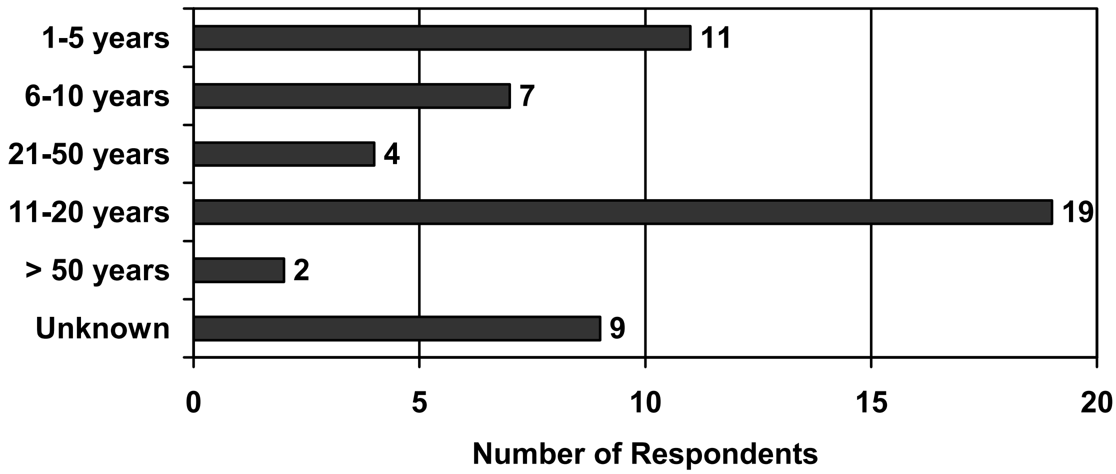
<u>General</u>

6. Does your agency have one or more GIS-based LRSs in place? (If so how many?)

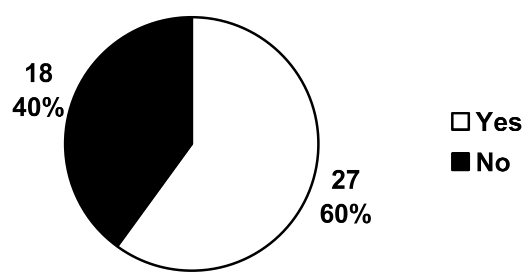


All respondents indicated that they used at least one LRS. Most states indicated that they were either using a single LRS or did not note if they were using more than one. One third of the respondents stated that there were multiple LRSs in use. While not specifically asked, some states reported that multiple LRSs were used in both highway and rail systems, others employed multiple LRS methods for the same base network.

7. How long has your LRS(s) been in operation?

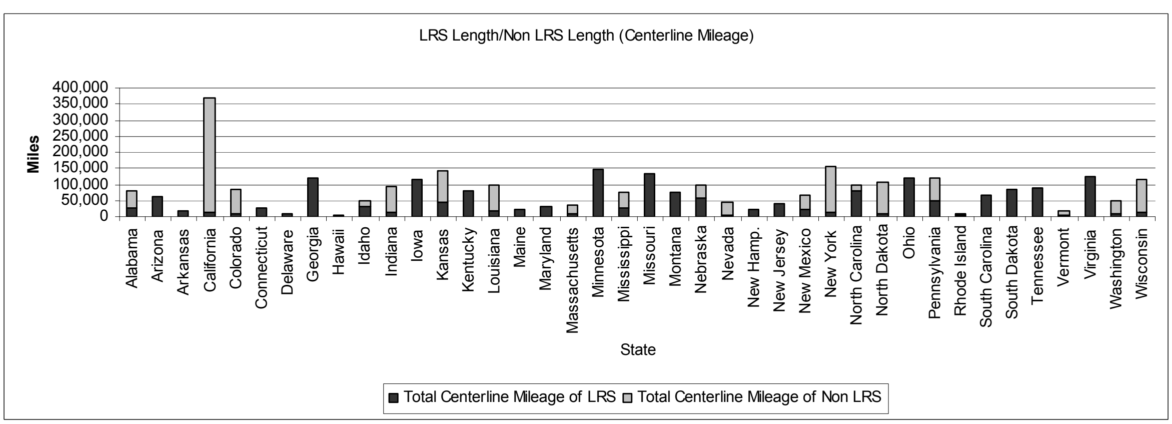


8. Does your agency have any legacy LRS systems?

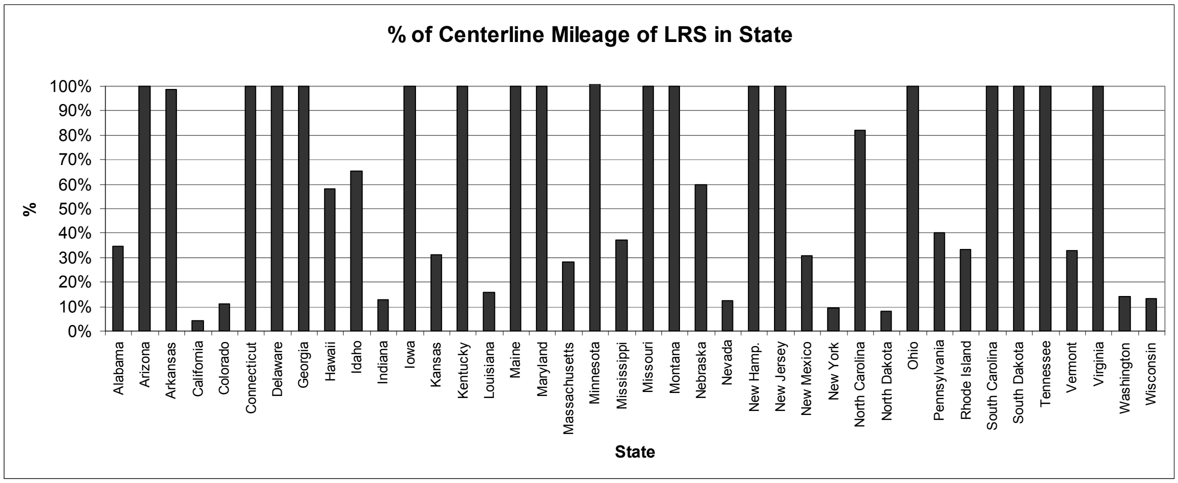


9. What is the total centerline mileage of each LRS?

In the figure below, the light bars present the centerline mileage of LRS in each state, and the dark bars are the length of non-LRS roads in centerline mileage in each state. The total value of each bar is the total centerline mileage of roads in each state.

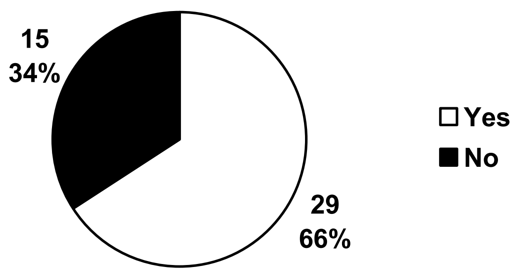


10. What is the total centerline mileage of all roads in your state?



The total LRS coverage varied greatly between respondents. Most states reported near complete coverage for the state/federal jurisdiction roads. Some states did not include local roads in the total centerline values thus impacting the results.

11. Is there an implementation plan for your LRS(s)?



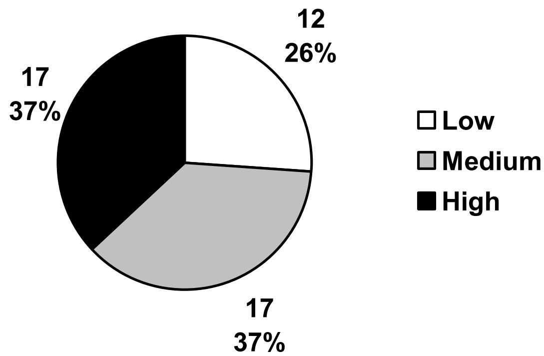
Institutional

12. What departments currently use your LRS-based information?

Respondents identified a wide range of users of their LRS-based information. Virtually all respondents indicated the use of LRS within DOT planning offices and most indicated usage by other offices in charge of engineering (pavement management, traffic safety, traffic operations, etc). Several states indicated LRS use by external state and federal agencies including the FHWA and state emergency planning, environmental and community affairs agencies. Below is a list of some of the more commonly mentioned users within DOTs:

GIS Group	Mapping
Pavement Management	Roadway Inventory
Planning	Programs
Traffic Safety	Maintenance
Traffic Operations	

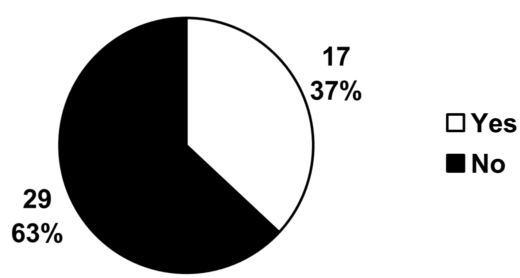
13. What is the current level of integration of your LRS with department business processes and products? Please describe.



Since a detailed set of measures could not be established within the survey, this question is subjective and relative. The purpose of the question was to identify a general sense of current versus desired LRS implementation for each state. While some respondents felt that the integration was virtually complete, far more indicated that their LRS was not being fully utilized either internally, externally or both.

In general, a department having a high level of integration may be defined as having a large number of applications that use LRS-derived information. These applications automatically retrieve and process data from the LRS. Typically, this results in non-technical staff having access to the LRS-based information. A low level of integration would refer to cases in which applications supporting business process either do not utilize LRS-based data, or do so through the manual input and manipulation of data. In these situations, LRS-based data are usually accessible only by technically knowledgeable staff.

14. Does an LRS committee or similar group exist to guide the development of your LRS(s)?

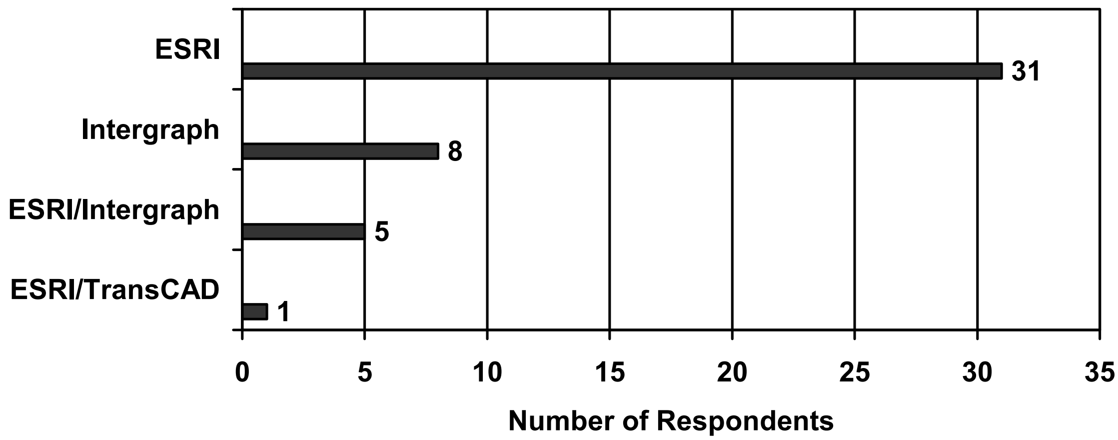


Some respondents indicated that their original LRSs were defined many years in the past. Generally speaking, these legacy systems have no formal LRS committee overseeing the maintenance of the system. Those states where newer LRSs are being developed/deployed were more likely to have an established LRS committee.

Technical

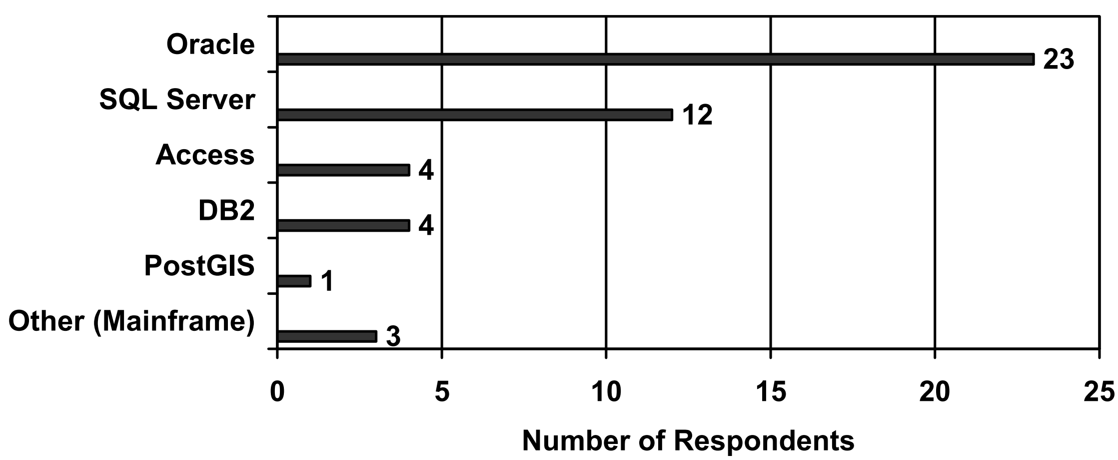
15) What GIS and database platforms are used by your agency in support of LRS?

GIS Platform



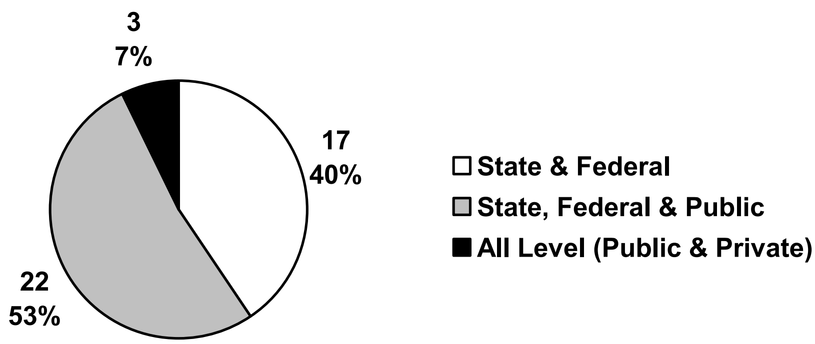
While ESRI products were predominant, most respondents reported using a combination of additional products that includes Intergraph GeoMedia, Oracle Spatial and TransCAD.

Database Platform



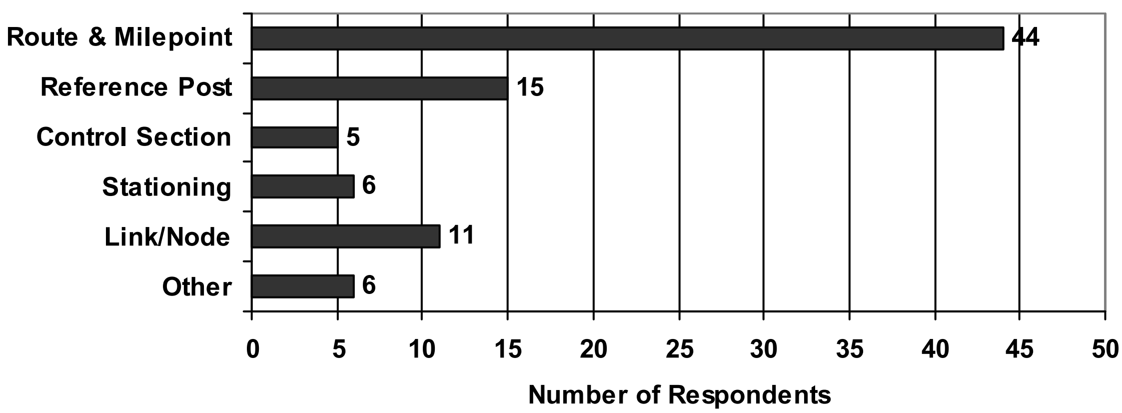
Oracle was the predominant database used by most respondents. Most respondents also use a combination of database platforms. As an example, many respondents use Oracle or SQL Server as their enterprise database platform but also use MS Access for desktop applications.

16) Describe your existing base network in terms of level of detail (state jurisdiction, local roads, etc.)



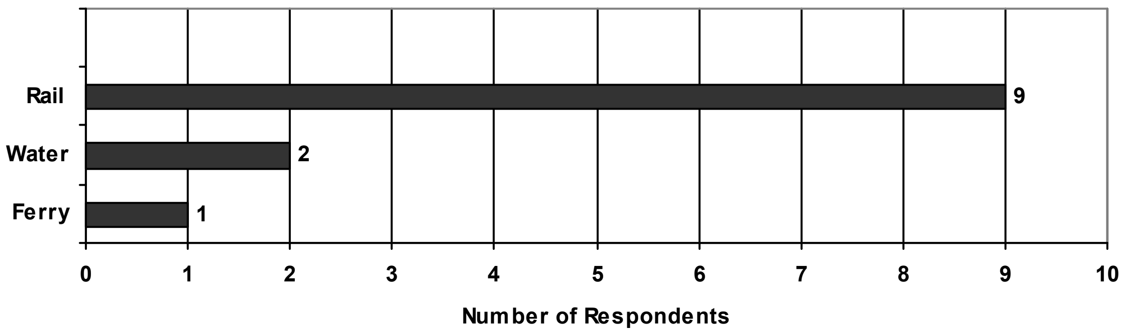
The overall majority of states indicated that their base network included only state and federal jurisdiction roads. Some states indicated that other roads of significance (intermodal connectors) were also included in the base networks. More recent LRS implementations appear to be more inclusive of local public roads.

17) Which Linear Referencing Methods (LRMs) are utilized in your LRS(s)? (Check all that apply.)



Virtually all respondents utilize the Route & Milepoint method. In addition to this method, most respondents also employed either Reference Post or Link/Node methods. Of those respondents, roughly one third of utilized both Reference Post and Link/Node methods.

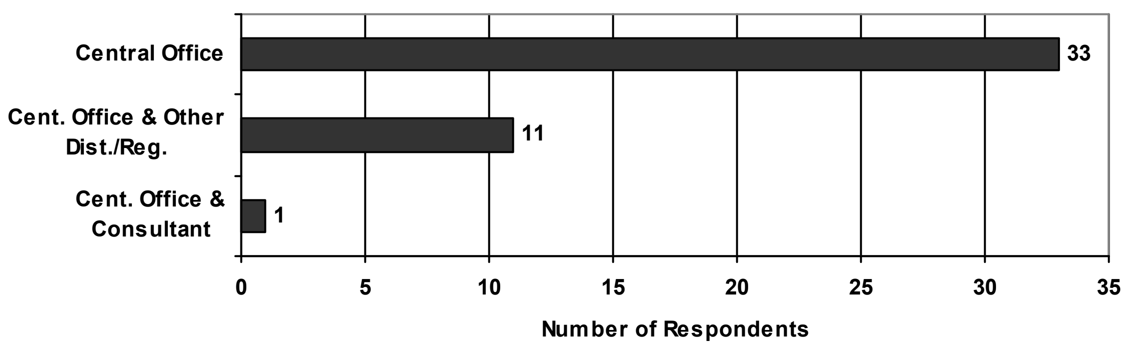
18) Have you established LRSs for modes other than highway (transit, rail, water, etc.)?



While most respondents did not indicate LRSs for other modes, those that did were primarily focused on rail LRSs. Two respondents indicated that their existing LRSs were designed for intermodal use. Less than 10 respondents indicated efforts to build LRSs for other modes and a few commented that rail LRSs were maintained by other external agencies.

<u>Maintenance</u>

19) How is responsibility for maintaining each LRS shared within your organization (central office, districts, etc.)?



The vast majority of respondents indicated that their LRS is maintained in a central office at either DOT headquarters other location. Interestingly, one state indicated that a GIS Unit has authority over the LRS but that it is maintained by an outside entity.

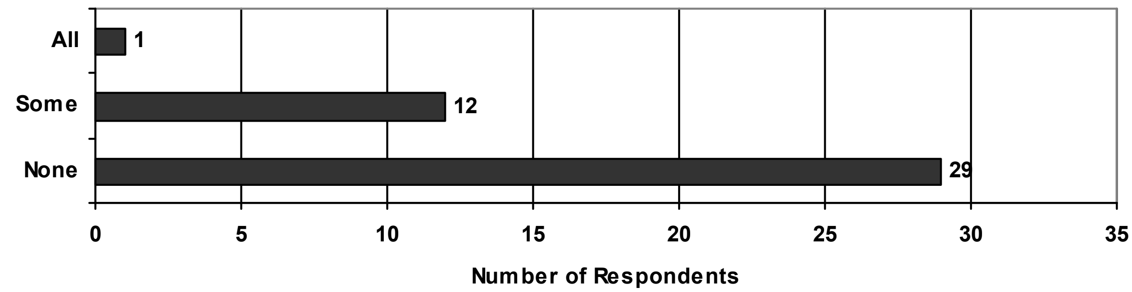
20) Who is responsible for maintaining the LRS(s)?

Responsibility for LRS maintenance varies by state, though in most cases the responsibility lies with one or multiple divisions within the central office.

21) What tools are used to maintain each LRS?

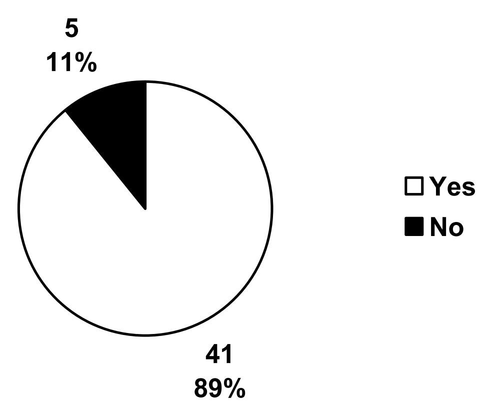
Most respondents use tools native to their GIS software for maintaining their LRS. In addition, 14 respondents mentioned the use of custom applications for maintenance.

22) What percentage of LRS activities is outsourced?

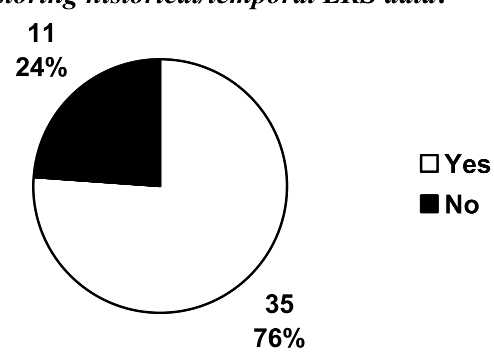


Outsourced LRS activities primarily included the development of street centerlines. Other activities included LRS maintenance activities for local roads. Most respondents maintain their LRS with in-house staff. However, some reported that outsourcing had occurred due to limited staffing.

23) Do you employ any QA/QC processes for maintenance and accuracy of the network?

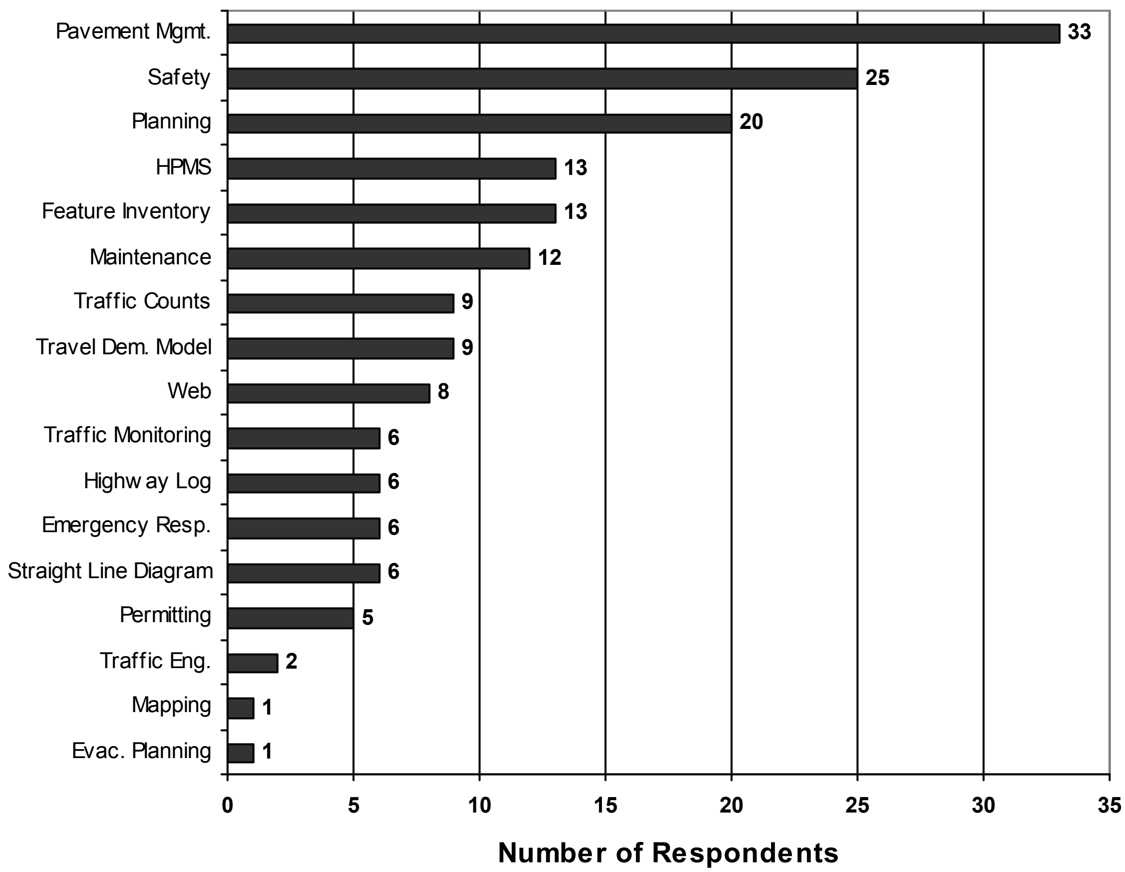


24) Do you employ methods for storing historical/temporal LRS data?



Applications and Products

25) ***What applications (within or outside the DOT) use your LRS data (for example: travel demand modeling, pavement management, etc.)?***

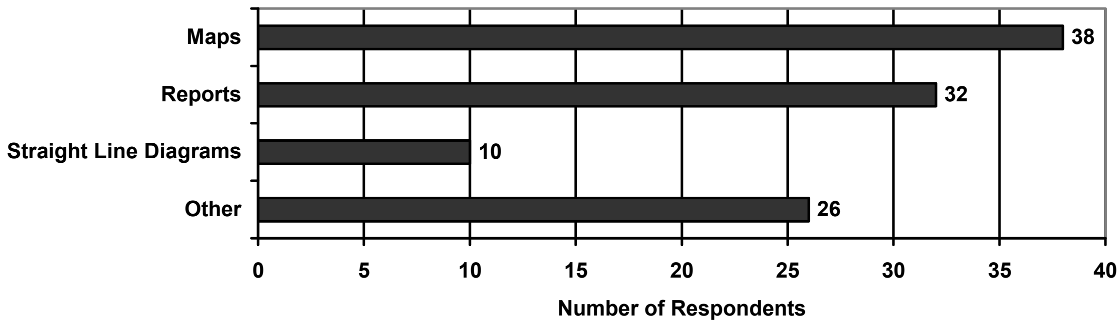


As shown in the graph, the majority of respondents utilize their LRS for planning-related activities. It should be noted that, while only 13 of the respondents listed HPMS as on of the applications, the HPMS Reassessment 2010+ program will require the DOTs to submit their road networks (including LRS) on an annual basis.

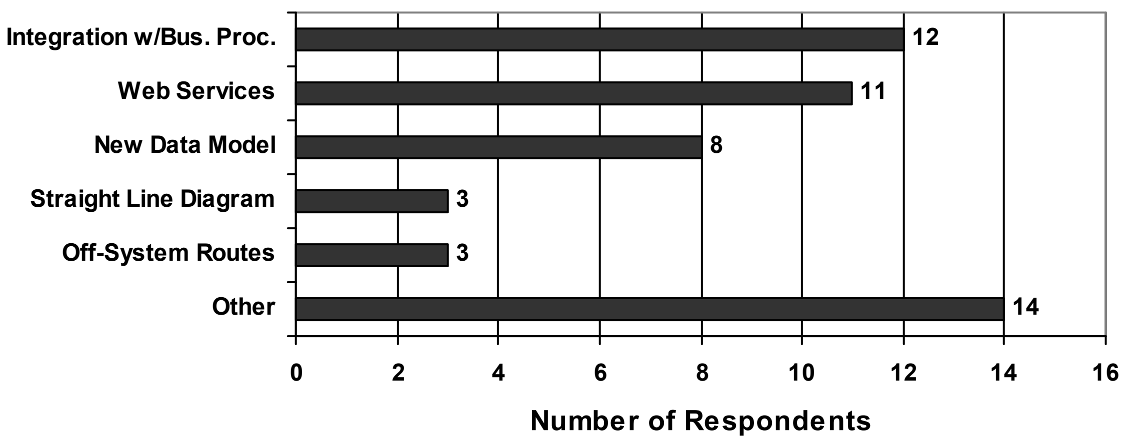
26) ***Which of the applications listed in question 25 are used by non-technical/non-GIS users?***

Responses varied by state, but approximately 60% of applications that respondents listed in question 25 are used by non-technical or non-GIS users.

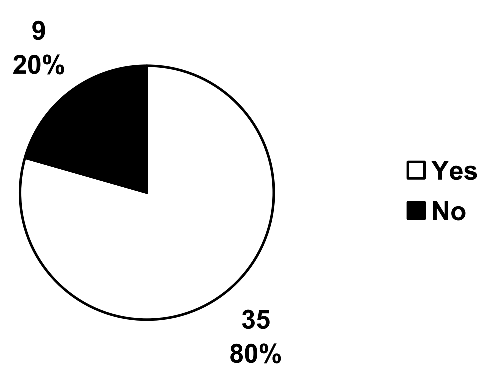
27) What products are derived or generated from your LRS(s) (straight line diagrams, maps, reports, etc.)?



28) What types of applications and products do you plan to develop within the next 1-2 years?

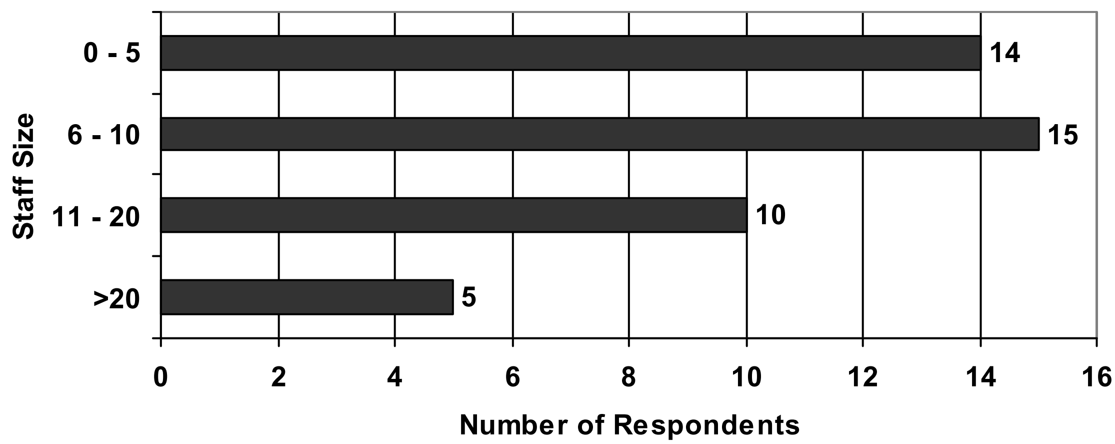


29) As part of the HPMS Reassessment in 2010, states will be required to submit an LRS with their HPMS data. Has your state implemented a plan to fulfill this requirement?

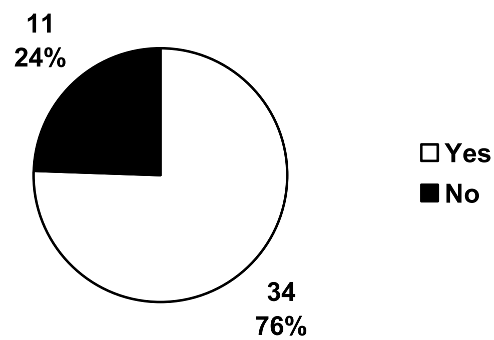


Resource Requirements

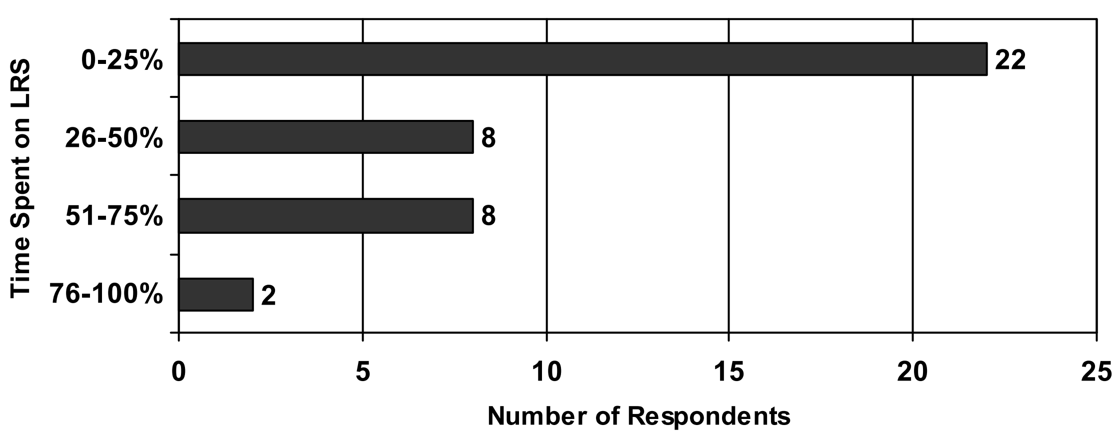
30) ***What is the size of your agency's GIS staff?***



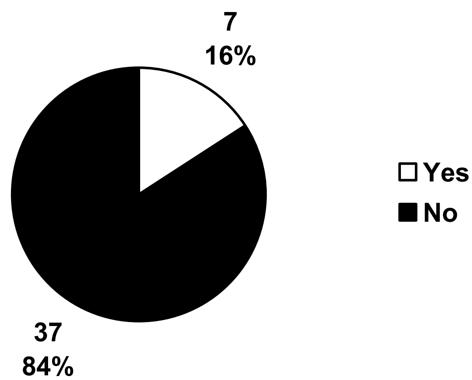
31) ***Are any staff members dedicated to LRS development and maintenance?***



32) ***Approximately what percentage of your staff's time is spent on LRS-related issues?***



33) ***Are there any cost-sharing agreements with other departments/agencies to cover the costs of LRS activities?***

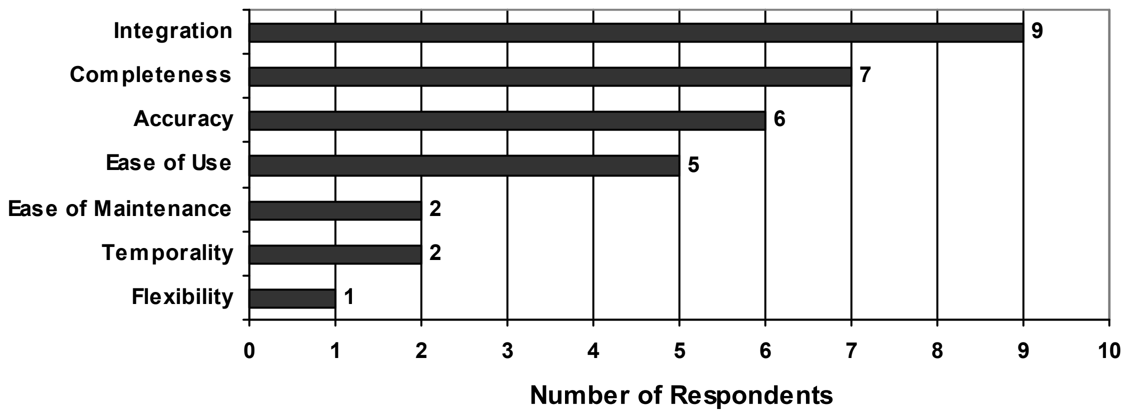


34) What percentage of your total GIS budget goes toward the following activities?

% of Total GIS Budget				
	0-25	**26-50**	**51-75**	**76-100**
Maintenance	24	8	1	1
Data Collection	21	10	3	0
Product Dev.	12	13	7	2
Other	30	1	2	1

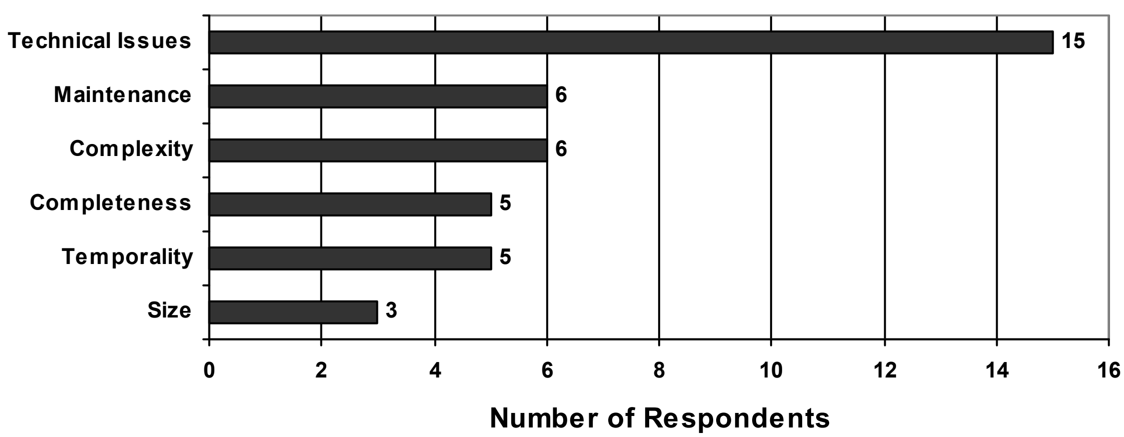
Comments

35) What do you consider to be the strengths of your LRS(s)?



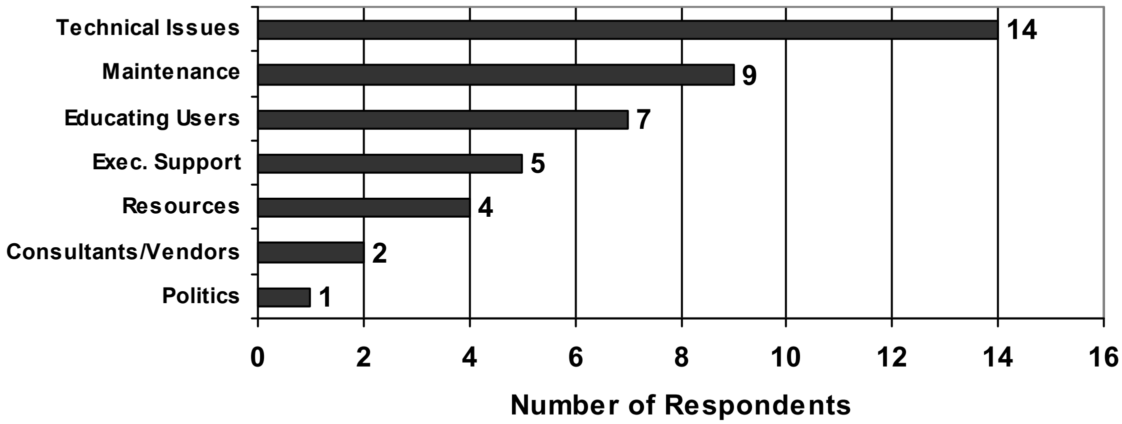
Most DOTs considered the quality of their networks and the integration of LRS in supporting business process as the strengths of their systems. Only five respondents listed ease of use as a strength.

36) What do you consider to be the weaknesses of your LRS(s)?

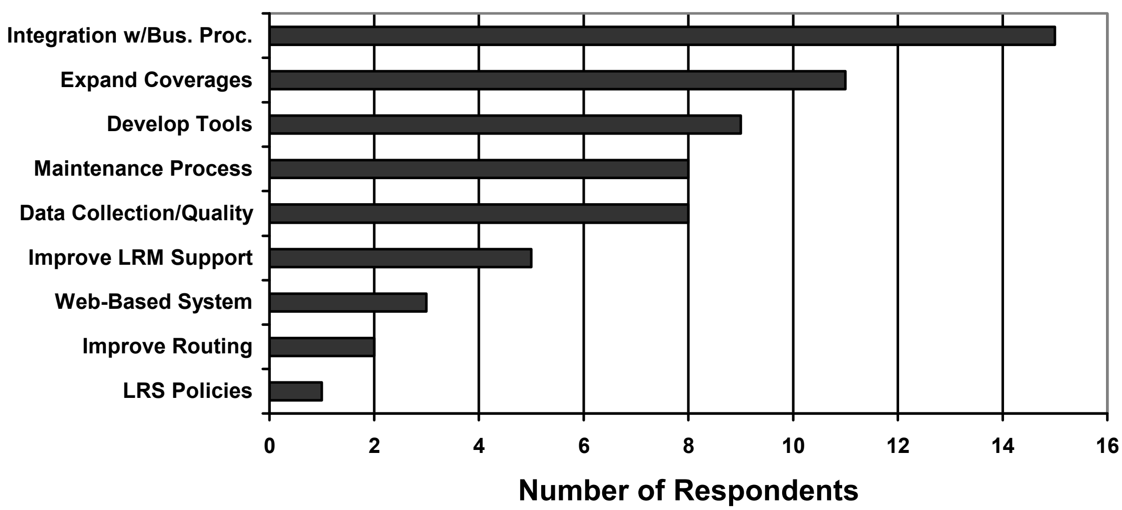


The vast majority of weaknesses listed by respondents are related to the development and maintenance of an LRS. Technical issues, maintenance and complexity are often interrelated, as the more complex the system the more likely that technical issues will arise. Among the weaknesses mentioned were problems with route naming conventions, route management and tracking changes to routes. One respondent mentioned that the overall complexity of their LRS made it difficult to explain the system to other non-technical users.

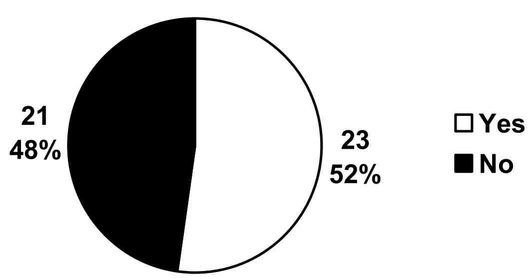
37) What have been your biggest hurdles in implementing your LRS(s)?



38) List your goals for your LRS implementation for the next 1-5 years.



39) Do you have documentation (system design & descriptions, user guides, data model diagrams, etc.) pertaining to your LRS(s) that you are able to share for the purposes of this study?



SURVEY RESULTS SUMMARY

General

All responding DOTs currently have some form of GIS-based linear referencing systems. While some DOTs have linear referencing systems that have only been in place for one year, others have been around for decades. The variation in these responses may be due partly to the lack of differentiation by respondents between GIS-based linear referencing systems and older, tabular (often mainframe-based) LRSs. Regardless of technology, the nature of DOT business processes has typically dictated some form of linear referencing system for managing roadway information. Sixty percent of respondents have legacy linear referencing systems.

Eighteen DOTs lack an implementation plan for their linear referencing system. Of these DOTs, three have an LRS committee or similar group to direct the development of the LRS. Despite the lack of a formal implementation plan, these departments do have some form of guidance for LRS. However, the remaining fifteen departments do not have a formal plan or LRS committee.

Institutional

As expected, the most commonly mentioned users of LRS-based data are traditional users of roadway data and ones whose business processes are largely dependent on this information. However, in some DOTs the user base is expanding to other non-traditional users. In California, for example, users of LRS-based data include Housing and Community Development, the DMV, the Department of Health and the Air Resources Board. It can be assumed that as LRS-based information becomes more widely available there will be an increase in the numbers of non-traditional users.

Regarding the current level of integration of LRS with business processes and products, the responses ranged from very basic to full integration. Approximately 39% of DOTs reported what could be considered high levels of integration. Most departments are in the midst of integrating their LRSs with various business processes and plan to continue doing so over the next few years. Even within DOTs that currently have full integration, this is expected to be an ongoing process as new data customers surface and new applications arise which take advantage of LRS-based data.

Out of all the respondents, 63% do not have an LRS committee or similar group to guide the development of their LRS efforts.

Technical

While there is great variation in the level of detail among the DOT networks, all responding states have at least the state-owned roads in their base network. Three states, Kentucky, Connecticut and Ohio have complete networks which contain all public and private roads.

Route and milepoint is the predominant linear referencing method and is used by nearly all respondents. For 21 respondents it is the only LRM in use, but most of the remaining DOTs use multiple linear referencing methods in their business processes. The LRMs mentioned in the "Other" category were segment-based, kilometer offset, intersection offset and FTSeg methods. In general these tend to be variations of the other LRMs.

Overall, very few DOTs have implemented multimodal linear referencing systems. Only twelve DOTs have established or are in the process of establishing linear referencing systems for modes other than roadways. The majority of the non-roadway LRSs are for railroad networks, the others being waterways and ferries. Minnesota was the only respondent with more than one non-roadway LRS.

Maintenance

The majority of respondents maintain their linear referencing systems through their central office. Approximately 24% share maintenance between the central office and districts or regions. Most DOTs conduct their maintenance activities using the tools native to the department's GIS software. Fourteen respondents mentioned the use of custom applications for maintenance. Finally, the majority of respondents (69%) do not outsource any of their LRS activities, while 29% outsource some LRS tasks. One respondent outsources all of its LRS activities. Approximately 89% of respondents have quality control procedures in place for maintenance of their linear referencing system. Most respondents (76%) also have procedures for maintaining historical data.

Applications and Products

The predominant applications that use LRS data mentioned by responding DOTs were pavement management systems, traffic monitoring, safety analysis, and roadway inventory. Several DOTs also mentioned HPMS and project management applications. Overall, roughly 17 different applications were mentioned.

Approximately 60% of the applications that were listed are used by non-technical or non-GIS staff. This number may potentially serve as a very coarse indicator of the level of distribution of LRS-based applications to non-traditional users.

The most common LRS-derived products were maps and reports, typically for the purpose of supporting business process. Only ten respondents mentioned straight-line diagrams as products of their LRS.

Among respondents, plans for LRS-based applications and products varied, depending in part on the current status of the DOT's system. Integration of LRS with business processes was mentioned by twelve respondents. In a similar vein, eleven respondents are planning the development of web services. Eight respondents are revising their data models.

Resource Requirements

The majority (66%) of responding DOTs had a GIS staff consisting of ten or fewer employees, including one state with no dedicated GIS employees. Five respondents had GIS staff of twenty or more employees. Approximately 76% of respondents had staff members who are dedicated to conducting LRS development and maintenance functions.

About 81% of respondents have cost-sharing agreements with other agencies to cover the costs of LRS activities. The majority of DOTs spend between 0-25% of their GIS budget on maintenance and data collection activities. Four states spend more than half of their budgets on these activities.

Comments

Respondents listed a variety of strengths and weaknesses of their existing linear referencing systems. The most commonly listed strengths included integration with business processes, completeness and accuracy. Technical issues, maintenance and complexity were the predominant weaknesses. These were also mentioned as hurdles affecting the implementation of their LRSs.

Most respondents did not provide general comments. However, the few that did mentioned the need for standardized transportation data models that are easier to implement than what is currently available. Another respondent expressed dissatisfaction with out-of-the-box GIS software tools.

CHAPTER 3

CASE STUDIES

IOWA – Legacy Data

Key Points

- *Identified problems in managing legacy data*
- *Developed applications to reformat legacy data*
- *Minimized impacts on existing business processes*

Introduction

Of the many concerns facing state DOTs when planning and implementing linear referencing systems, the issue of how to manage legacy data is particularly problematic. Legacy data may be defined as business data which have been implemented, and can include data stored on outdated systems or in outdated formats, as well as data conforming to current standards. Similarly, legacy applications are those which are used to conduct business processes and may use current or outdated technology. Legacy systems refer to the integration and use of legacy data and applications. Legacy data are often housed in disparate ways, in varying formats and used by many different users and applications. How to incorporate these data into a LRS while simultaneously minimizing downtime presents a real challenge to a DOT. The Iowa DOT recognized this issue during their initial LRS planning stages, and accounted for legacy data throughout the planning process. Their approach is described below.

Background

The Iowa Department of Transportation's current LRS has been in operation since 2007 and is the result of an extensive planning process which began in the late 1990s. The Department maintains 114,000 centerline miles of roads in its system, consisting of primary, county, and municipal roads as well as some private roads.

The system is used by numerous departments in the DOT, including the Office of Transportation Data, Office of Traffic and Safety, Office of Systems Planning, Office of Program Management and others, including city and county governments. The LRS is based on a modified NCHRP 20-20(2) template and is heavily integrated with the DOT's business processes. It is being used to drive diverse applications such as sign management, snowplow runs, accident locating, the five-year plan, motor carrier routing, traffic data collection, and the Geographic Information Management System (GIMS).

The IADOT conducted a thorough LRS planning process over a period of 10 years. Throughout this period, participants included DOT GIS and IT staff as well as various consultants. The process consisted of the following stages:

- Conceptual Design
- Logical Design
- Physical Design
- Pilot Study
- Redesign Strategies

During this process, the participants defined nine primary objectives of the LRS, one of which was to validate LRM data integrity. Specifically, the system would be used to validate the location integrity of IADOT business (legacy) event data. In addition, the participants specified that legacy data would not constrain the design of the LRS. In other words, the design of the LRS would not be compromised in order to accommodate legacy data.

Staging Process

IADOT utilizes a decision support system known as the GeoData Warehouse (GDW). This flexible system allows users to conduct ad hoc and predefined queries on a variety of business data, much of it LRS-based. The architecture of the GDW is illustrated below in Figure 1.

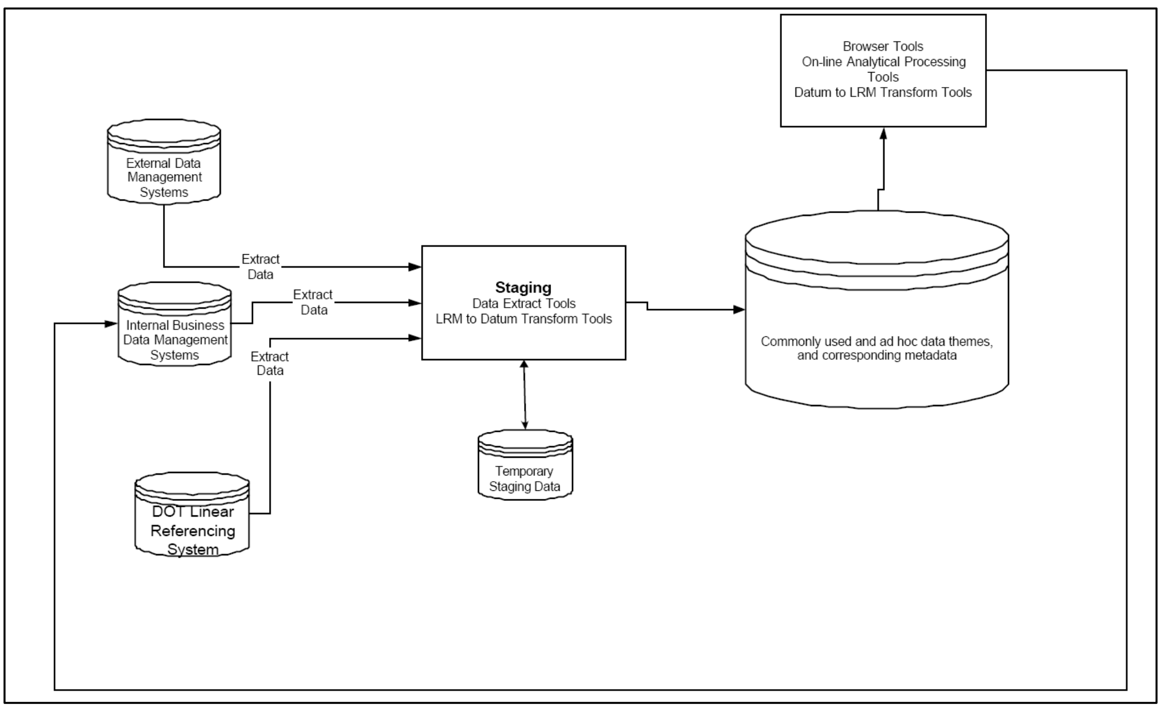


Figure 1 – IADOT's GeoData Warehouse Architectures.

The illustration in Figure 1 shows the relationships between the Operational and Decision Support Systems. In order for business, or legacy, data to be used in the decision support system, it must first be staged. Staging is the process by which business data are prepared (reformatted, linked to the LRS, etc.) for use in the decision support environment.

The DOT has large volumes of legacy data that are stored and maintained in various formats which may be specific to individual applications. As these business data are crucial to the operations of the DOT and its departments, it is important that they are available for use in the new LRS.

Issues and Concerns

During the conceptual design phase, the DOT decided that legacy data should not pose any constraints on the design of the LRS. This meant that the LRS would not necessarily accommodate legacy data in its existing form. Thus, the LRS could be designed with optimal performance in mind without being encumbered by legacy formats.

However, legacy data still needed to be incorporated in to the LRS. The decision that the LRS would not be constrained by legacy data meant that legacy data would potentially need to be modified in order for it to be used in the new LRS. In the short term this meant that additional processes needed to be implemented, but the result was that users could reap the benefits of the new LRS while using their legacy data.

Approach to Legacy Data Integration

There are at least two approaches to the technical issue of integrating legacy data with the new LRS while minimizing the impact on existing operations. One alternative is to modify the legacy data schema so that they conform to LRS requirements. The other alternative is to maintain the existing data schema, but develop applications to reformat the data to meet LRS requirements. These applications would need to be run on a regular basis to keep the data up-to-date.

IADOT chose the latter approach for several reasons. First, since legacy data are often formatted for use with specific legacy applications, it would be undesirable to convert existing data to newer formats as this could render them unusable in the legacy applications. Second, since the new LRS is to become the integrator of most business data, all legacy data and applications will eventually be "upgraded" to conform to the new LRS.

The reformatting applications are run as part of the routine Business Data Staging processes conducted by the GDW Team. Legacy data are staged at regular intervals and are always in the same format. These command-line procedures are executed from a database environment by GDW staff and legacy data managers (see Figure 2).

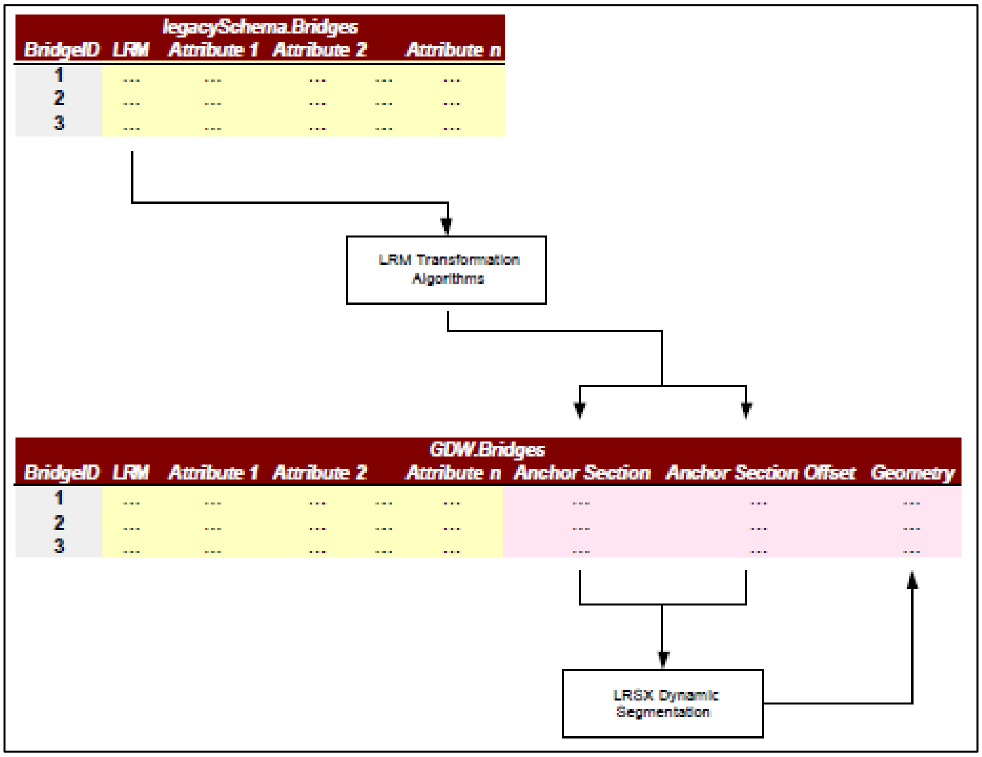


Figure 2 – Example of staging legacy data. Transformation algorithms are applied to legacy data to reformat it and incorporate it into the LRS.

Legacy Data Issues

Due to the wide variety of legacy applications and data format requirements, it is not possible to describe all the ways in which data may be represented in legacy databases. However, during the planning process IADOT identified some common problems related to how route data are stored in the legacy databases. These cases are often the result of databases that were developed independently, for specific needs, and without standardization. The following are some examples from IADOT's experience.

<u>Data With No Route Direction</u>

Legacy data often do not store a route direction with the route name, as these data are often not required by legacy applications. These missing data may cause problems with the transformation procedures which are used to convert data between LRMs. These algorithms require specific inputs and may not function if any parameters are missing. IADOT encountered this issue during its pilot study. The team identified two possible remedies: 1) Modify the algorithms or 2) develop a "wrapper" to be placed around the algorithms which would handle the missing data. The first approach was rejected as too costly and complex.

A wrapper is code that is combined with other code in order to control how the wrapped code is executed, and usually provides an interface to the wrapped code. In IADOT's case the wrappers contain rule-based procedures and utilities that fill in the missing route direction data. This approach has the advantage of not modifying the original transformation routines. New rules may be added as needed and maintenance is less costly. Finally, utility functions may be created to support the wrapper and provide users the ability to modify the inputs as required.

IADOT decided to tackle the issue of missing route directions by developing a wrapper for the transformation algorithms. Specifically, the wrapper input parameters consist of literal descriptions, coordinate routes, and milepoints. Various rules are applied and a datum location is returned.

Same Route Name in Different Jurisdictions

Another common situation which IADOT encountered during the pilot phase was routes in different jurisdictions having the same name. As shown in Figure 3, a street (19th Street) may keep the same name as it crosses municipal boundaries. Although it would be possible to create a unique name by combining other fields such as the jurisdiction, the route name itself is the same. These ambiguous names could be problematic for LRS-based functions which require unique route names as inputs. The IADOT team decided that the best approach for handling this problem was to develop utilities with user-supplied parameters to analyze the available information and determine the correct route for the route name in question.

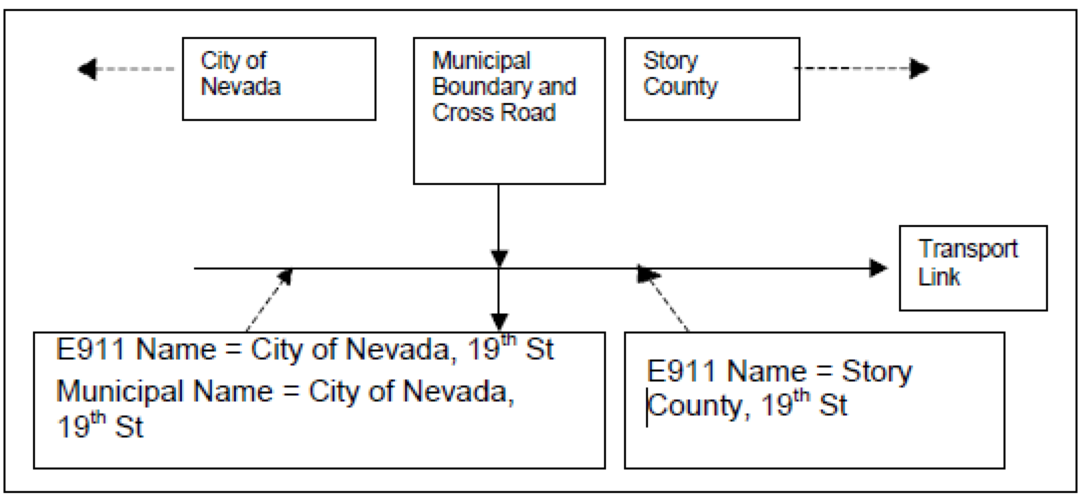


Figure 3 – Route keeps same name in different jurisdictions.

Differing Route Name Formats (Route Synonyms)

Since legacy data are often developed independently and for varying purposes, the formats in which data items are stored may vary greatly. The Iowa DOT found that route names in its legacy data were stored in different formats and often did not match the format adopted for the LRS.

Since the LRS objectives stated that legacy data were not to be modified, reformatting the legacy names was not an option. Instead, IADOT adopted an interoperability approach to match legacy route names to LRS route names. This approach involved the creation of an alias table and a synonym table. A route alias table containing common names and formats was created for each route system. The LRS is able to use this alias table during processing. The synonym table is temporary and is used to handle uncommon route names and formats.

Redundant LRS and legacy data

Occasionally LRS and legacy databases may store data which are redundant but derived by different methods. The Iowa DOT identified the following cases:

- GIMS and the LRS have sections which are similar, but determined differently
- GIMS and the LRS both utilize point data, but in different ways
- Route names
- GIMS and the LRS both maintain lengths of road sections. GIMS maintains segment lengths while the LRS maintains anchor section lengths.

Several options for dealing with these redundancies were identified. The first was to remove the redundant items from the GIMS once the LRS was established. The second was to maintain GIMS as part of the LRS, but this option violates the rule calling for the separation of LRS data from business data. The third option was for the LRS to update GIMS until the legacy systems have been redesigned. This option allows for a transition to occur and follows the interoperability rules. Once the transition takes place the redundant items are removed from GIMS.

The Iowa DOT accepted the third option for handling redundant data. The migration was expected to occur over a one year period. The end result was that the previously redundant items in the GIMS database were populated by the LRS.

Reference Post Table Fields

The redesigned Reference Post system resulted in new fields in the Reference Post table. It was necessary to keep several fields from the legacy system for the purpose of linking to legacy business data. The DOT decided to keep these fields until the legacy systems have been fully integrated with the new Reference Post scheme.

LRM to Datum Transformations

The DOT's pilot study revealed that many of the legacy data to be used for coordinate route transformation operations were incomplete or incorrect. This raised the question of how well the transformation algorithms would perform, given that they require high-quality inputs.

This issue is similar to the one discussed under the "Data with No Route Direction" section above. The viable options were to 1) modify the transformation algorithms to make them less stringent, or 2) develop "wrappers" which incorporate rules and other methods of handling the incomplete data. The first option was seen as too complex, costly and technically demanding. The DOT accepted the second option, which provides greater flexibility in terms of adding and modifying rules, is less costly and can be supported with the development of utility functions.

As is evident from the above examples, many of the legacy data-related issues faced by IADOT were due to data quality or data format issues. In keeping with the stated requirement that the

LRS design was not to be constrained and in order to not disturb legacy operations, the DOT opted for solutions which would impact existing operations as little as possible. The result was the implementation of several temporary solutions during a transition period. Eventually, all legacy systems will be re-engineered and use the LRS exclusively.

Conclusion

IADOT's requirement that legacy data issues were not to impact LRS design, while a sound long-term decision, meant that the process of accommodating legacy data would encounter problems. Careful planning allowed IADOT to identify potential issues of integrating its legacy data with its LRS while minimizing effects on ongoing business activities. The advantages of this approach were that the LRS could be optimally designed and be unencumbered by legacy issues. The drawback was that steps, such as developing code, had to be taken to incorporate the existing legacy data. Overall, the benefits of an optimally designed LRS outweighed the drawbacks. While specific legacy data concerns will vary for each DOT, IADOT's experience and approach should be beneficial to other DOTs facing similar situations.

WISCONSIN – Implementation Approach and Applications

Key Points

- *IT-based approach to LRS implementation*
- *Local roads web application*

Introduction

The Wisconsin DOT (WisDOT) has long been recognized as a pioneering organization in the field of geographic information systems for transportation (GIS-T). WisDOT's work and experience with linear referencing systems influenced the development of the NCHRP 20-27 research and models, as well as LRS implementations in vendor software. WisDOT maintains approximately 15,000 centerline miles of state network roads and over 100,000 centerline miles of local roads throughout the state. Currently, WisDOT reports a high level of integration of LRS-based information with departmental business processes. The success that WisDOT has achieved may be attributed in large part to the Department's formal, IT-based approach to geographic information and automation in general. The integration of LRS-based data with its business processes has enabled WisDOT to develop the Wisconsin Information System for Local Roads (WISLR), the country's first web-based local roads information system.

This case study will discuss both the Wisconsin DOT's approach to geographic information management as well as the WISLR application. It is expected that the discussion of the IT approach will help other states as they attempt to integrate their LRSs with their business processes. The discussion of the WISLR application may serve as an example for those states planning on improving the distribution of their LRS-based information.

Implementation Approach

During the early 1990s, the Wisconsin Division of Highways, now the Division of Transportation Investment Management (DTIM) and the Division of Transportation System Development (DTSD) developed an Information Strategy Plan (ISP) which resulted in an integrated information design for all business data. Following information engineering procedures, the plan identified twenty business areas and determined that the need for data integration was the most pressing issue. The need for integration arose in large part from the numerous disparate databases that resulted from the use of various linear referencing methods for collecting and storing data. The plan determined that location was the most appropriate way to integrate the various types of business data found throughout the division. This led to the Location Control Management Business Area Analysis (LCM-BAA) which identified location as a specific business area which needed to be addressed.

The LCM-BAA resulted in the creation of numerous projects to address different aspects of location control implementation. Among these were the following:

> **Location Policy Development** – Purpose was to review and establish location methods and policies.
>
> **State Network Link/Reference Point Development** – Created the current LRS framework and data that serve as WisDOT's Linear Datum and LRS transformation tools. These form the basis for linear location data integration.
>
> **State Road Geographic Database Maintenance** – Charged with redesigning the highway centerline cartography, known as Chains, used in GIS software and associating them to the LRS's Linear Datum.

Location Control Management (LCM) refers to the complete set of procedures, policies and practices used to manage its location reference systems in support of DOT business areas. The LCM provides detailed documentation on specific business rules and process, such as how to maintain roadway link data and how to locate linear events. The ultimate goal is to facilitate data integration and distribution and to improve the flow of information. LCM consists of three related location components: geodetic control, geographic control and linear control. These LCM components exist to support WisDOT business programs and their related business data. The goal of this approach is to allow these five areas to be managed independently, each having its own business rules.

From an information technology viewpoint, the data that comprise the three LCM components are considered to be infrastructure data. That is, they support the use of location as an integration mechanism but are not in themselves data of use to end users. However, these LCM data must be managed properly, otherwise data integration efforts suffer.

The integration of WisDOT business data was achieved by creating a standard departmental linear datum called Link/Site. Implemented in 1993, Link/Site is essentially a combination of linear datum and network link data as described in NCHRP 20-27 research. Since differing business areas may prefer or require other LRMs for data collection or other purposes, WisDOT still supports multiple LRMs. However, they are all tied to the Link/Site linear datum for purposes of data integration, thereby allowing transformation between all supported LRMs. Tying LRMs to the Link/Site linear datum instead of to each other was originally known as the

LRS "Hub" strategy. Together with the Chain cartography and LRMs, Link/Site forms the basis of WisDOT's LRS. Additional functionality, such as temporal support and managing relations between old to new linear datum elements, add to WisDOT's LRS flexibility.

The key point is that WisDOT views the maintenance of location infrastructure as its own business area within the greater enterprise. This approach ensures that location issues receive proper support and attention as important components of other enterprise business processes. Each component is subject to its own formal data models and business rules, resulting in a robust and flexible system capable of supporting enterprise processes. All business processes and rules governing geographic and event data storage and maintenance are documented as part of the LCM.

Figure 4 provides an illustration of how the three LCM components, Linear, Geographic and Geodetic Controls, fit into the overall WisDOT enterprise. Each of the boxes outlines a component which requires its own set of business rules. Note that the area represented by each box builds on the one below it. Also note that linear referencing represents the integrating link between the cartography and the enterprise business data and programs.

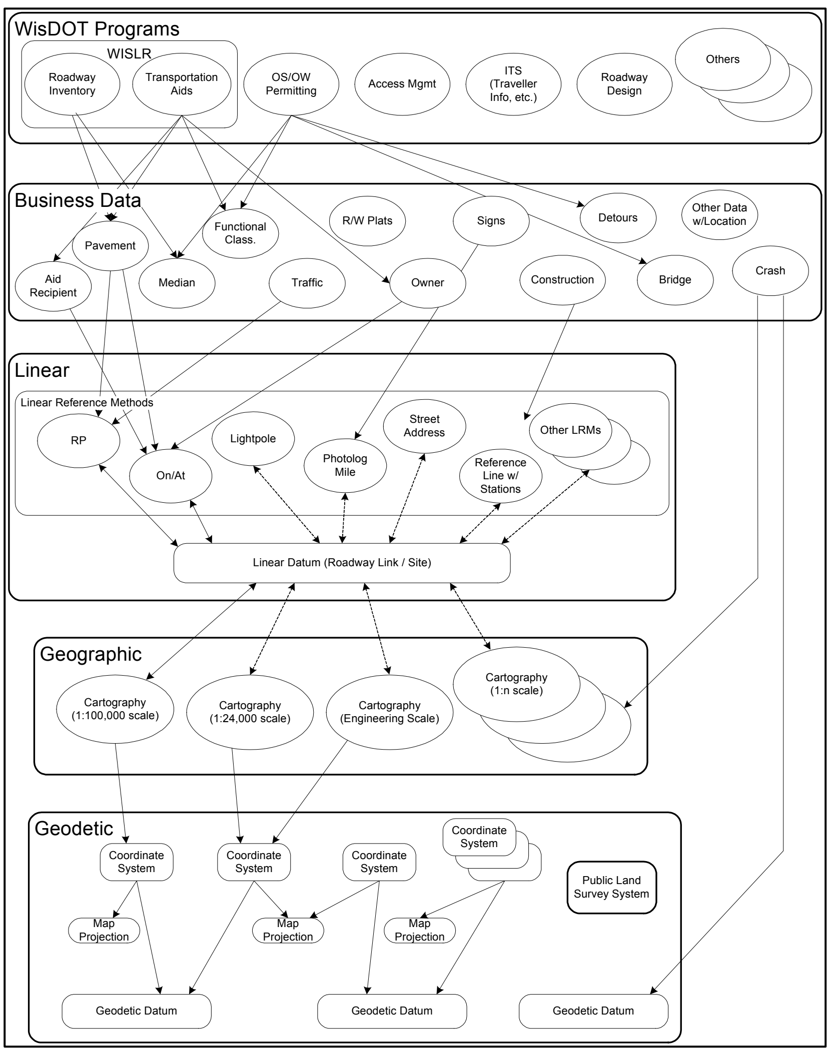


Figure 4 – LCM components and WisDOT business processes.

LRS-Based Application

The formal approach described above has provided WisDOT with the foundation for the integration and distribution of LRS-based data not only throughout the enterprise, but to outside users as well. This is exemplified by a WisDOT application which allows for the exchange of roadway information between the DOT and local governments.

Background

In an effort to update its aging local roads database and improve the dissemination of information about local roads, WisDOT embarked on a project to develop a user-friendly web-based system to be used by local governments. Launched in 2002, the Wisconsin Information System for Local Roads (WISLR) is a shared state and local resource used to ensure the quality of local roads in Wisconsin. Its primary use is local road inventory and enhancing local transportation and planning decisions, as well as assisting in the yearly distribution of approximately $400 million in General Transportation Aid (GTA) payments to local governments.

WISLR was initiated in 1997 as a project to redesign the local road database. Team members included both state and local government transportation officials. Using Data and Process modeling methods, fifteen key improvements were identified to assist local agencies in roadway investment decisions during the transportation planning process. In the past, WisDOT Regional Offices were responsible for collecting and updating local roadway information. WISLR successfully accomplished the difficult task of shifting the collection and reporting of this information from WisDOT to local government entities.

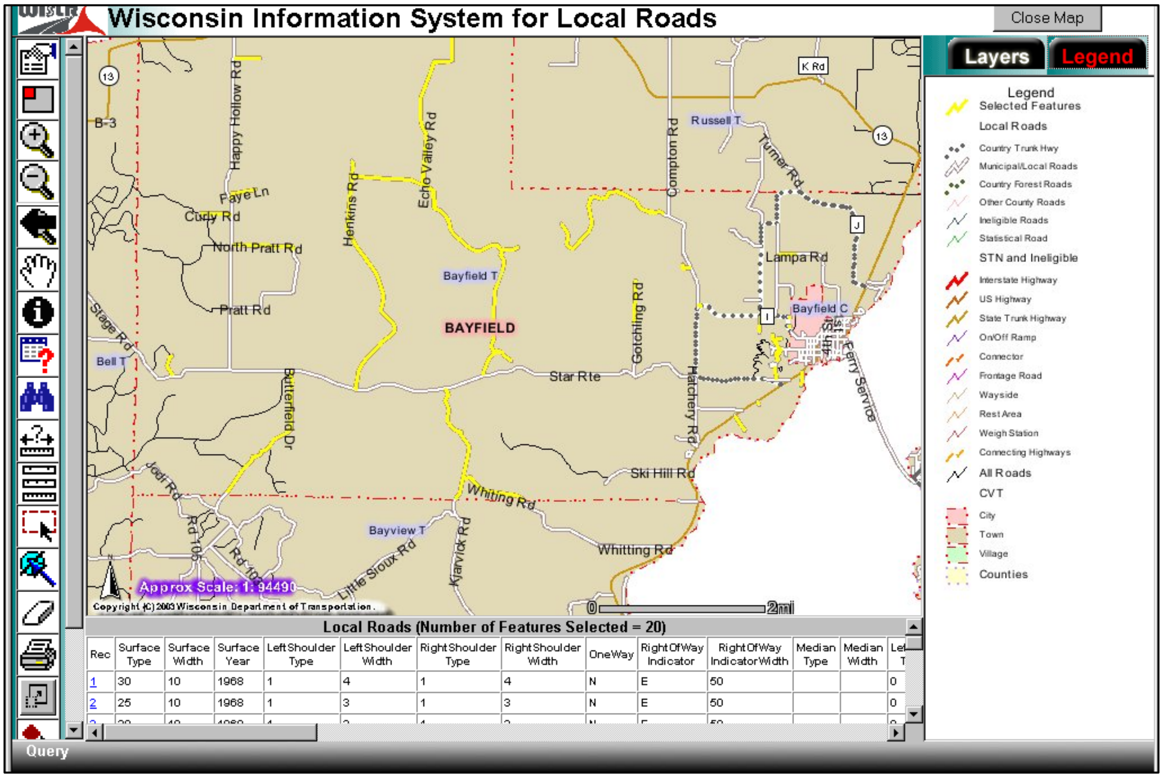
With such a large number of potential users, many of them non-technical, it was important that the system be user-friendly and flexible. During the planning stages it was determined that the system needed to accommodate the various requirements listed below:

Collect, store and report location referenced event data
User-friendly
Support various analytical and reporting needs
Support data sharing between state and local governments
Future integration with the State Road Location (LCM) Database
Allow the use of discrete locations for data entry and reporting
Allow a single location entry regardless of the length of an event
Allow the use of multiple names for a roadway (concurrency)
Allow the use of alternate names for a roadway
Support multiple location entry methods when routes cross multiple municipalities

Functionality

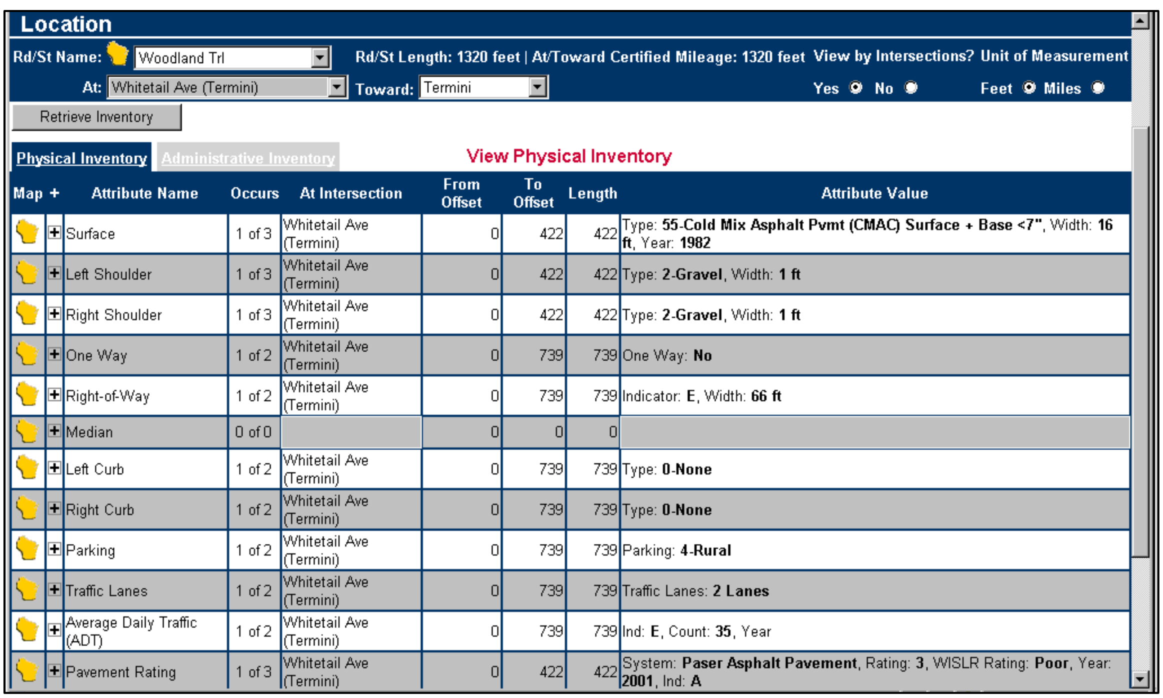
WISLR's web-based application provides local governments the ability to edit and update physical roadway attributes for roads within their jurisdiction. WisDOT staff is responsible for administrative roadway attribute updates, which include certified miles that are used in the computation of GTA payments. The key to the application is the ties of WisDOT's roadway event data to the Link/Site LRS, which allows for the display of the various physical and administrative characteristics.

The events may be displayed in the application in a map view (Figure 5) or in a tabular view (Figure 6).



Rec	Surface Type	Surface Width	Surface Year	Left Shoulder Type	Left Shoulder Width	Right Shoulder Type	Right Shoulder Width	One Way	Right Of Way Indicator	Right Of Way Indicator Width	Median Type	Median Width	Le T
1	30	10	1968	1	4	1	4	N	E	50			0
2	25	10	1968	1	3	1	3	N	E	50			0

Figure 5 – WISLR map.



Location

Rd/St Name: Woodland Trl — Rd/St Length: 1320 feet | At/Toward Certified Mileage: 1320 feet — View by Intersections? Yes No — Unit of Measurement Feet Miles

At: Whitetail Ave (Termini) — Toward: Termini

Retrieve Inventory

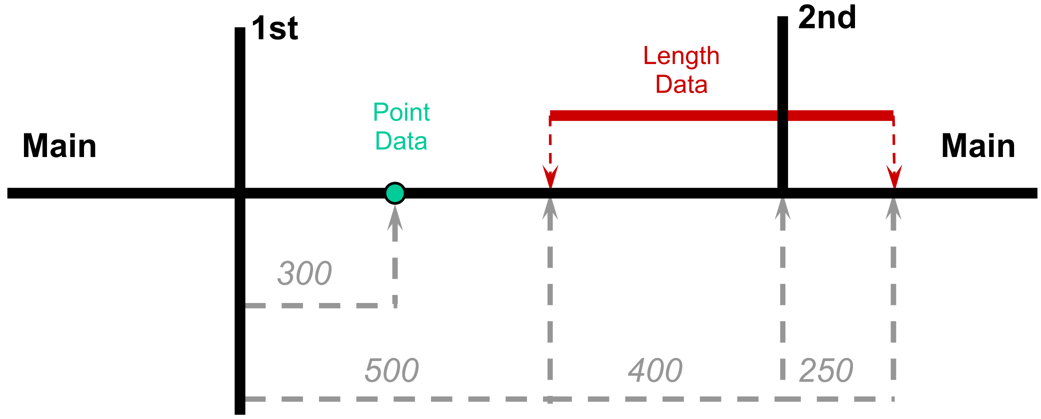
Physical Inventory | Administrative Inventory — View Physical Inventory

Map +	Attribute Name	Occurs	At Intersection	From Offset	To Offset	Length	Attribute Value
	Surface	1 of 3	Whitetail Ave (Termini)	0	422	422	Type: **55-Cold Mix Asphalt Pvmt (CMAC) Surface + Base <7"**, Width: **16 ft**, Year: **1982**
	Left Shoulder	1 of 3	Whitetail Ave (Termini)	0	422	422	Type: **2-Gravel**, Width: **1 ft**
	Right Shoulder	1 of 3	Whitetail Ave (Termini)	0	422	422	Type: **2-Gravel**, Width: **1 ft**
	One Way	1 of 2	Whitetail Ave (Termini)	0	739	739	One Way: **No**
	Right-of-Way	1 of 2	Whitetail Ave (Termini)	0	739	739	Indicator: **E**, Width: **66 ft**
	Median	0 of 0		0	0	0	
	Left Curb	1 of 2	Whitetail Ave (Termini)	0	739	739	Type: **0-None**
	Right Curb	1 of 2	Whitetail Ave (Termini)	0	739	739	Type: **0-None**
	Parking	1 of 2	Whitetail Ave (Termini)	0	739	739	Parking: **4-Rural**
	Traffic Lanes	1 of 2	Whitetail Ave (Termini)	0	739	739	Traffic Lanes: **2 Lanes**
	Average Daily Traffic (ADT)	1 of 2	Whitetail Ave (Termini)	0	739	739	Ind: **E**, Count: **35**, Year
	Pavement Rating	1 of 3	Whitetail Ave (Termini)	0	422	422	System: **Paser Asphalt Pavement**, Rating: **3**, WISLR Rating: **Poor**, Year: **2001**, Ind: **A**

Figure 6 – WISLR table.

On-At Linear Referencing Method

As with other WisDOT systems where location data is important, the functionality of WISLR is driven by WisDOT's Link/Site linear referencing system. WISLR built upon the Link/Site linear reference work implemented six years earlier for state highways. In order to make data entry as simple as possible for the user, WisDOT created the "On-At" linear referencing method (see Figure 7). On-At is a point and offset method which uses a combination of route name, intersection and offset distance to locate event locations. As with all other LRMs, On-At is tied to the Link/Site linear datum. The On-At method was selected for its advantages and relative ease of use.



	Point Data	Length Data
On Road:	Main St	Main St
At Road:	1st St	1st St
At Offset:	300	500
To Road:	2nd St	2nd St
To Offset:	---	250
Length:*	---	(650)

* *Either the To Offset or Length may be used for Length Data*

Figure 7 – Example of the On-At linear referencing method.

The On-At method has a number of characteristics that make it suitable for a widely distributed application used predominantly by users not familiar with linear referencing. The primary advantage is ease of use. Referring to locations along a road by intersection and distance is intuitive and easily understood by the layperson. This provides an additional advantage in that no special equipment or supporting documents are required for data collection in the field. Other benefits include high accuracy and the ability to collect data before the physical tables in the system are populated. A final significant benefit is that the On-At LRM requires no manual data maintenance. Since it is completely derived from other LRS elements (e.g. network links and route traversals), it is automatically populated when updates occur to other parts of the LRS.

However, there are some disadvantages to the On-At method. As a route-based method, it is vulnerable to changes in route names and requires strict standards for naming and formatting. WisDOT mitigates the route name change issue by storing only Link+Offset linear datum values for event data - On-At values are not stored. Special cases such as cul-de-sacs and loops may present problems, and the creation and maintenance of private road names in the system is a costly endeavor. However, the relative ease of use with respect to the end user outweighs these drawbacks.

While the functionality of WISLR is heavily dependent on WisDOT's linear referencing system, the management of event tables and the LRS-related inner workings of the application are transparent to the end user. For example, the end user uses On-At LRM locations in the WISLR application, but On-At data are not stored in any event tables - only Link+Offset linear datum locations are stored. The conversions between Link/Site & On-At occur dynamically behind the scenes. This simplification of complex processes is key to the success of the system. The WISLR can serve as a model for other DOTs as they develop applications to disseminate their LRS-based information.

Conclusion

WisDOT's many years as leaders in the GIS-T arena make it one of the most experienced DOTs in the country. One of the ways in which it has achieved this position has been through its view of location as a critical enterprise business function. The department's IT-centric approach has resulted in the establishment of formal business procedures and rules governing the maintenance of location-based data and systems. The result has been a solid foundation for the dissemination of data within the department and beyond. The WISLR application is an example of the type of application that can be developed from such a foundation. By allowing users to not only view, but to edit, their data, WisDOT is able to decentralize its data collection efforts while providing useful tools to its users and improving data quality.

OHIO – Business Model & Departmental Structure

Key Points

- *State mandate*
- *Decentralized organizational structure*
- *Partnering agreements*

Introduction

The Ohio Department of Transportation (ODOT) maintains one of the most complete roadway networks and linear referencing systems in the country. The ODOT LRS has been extensively integrated with ODOT's business processes and has enabled the implementation of a large number of applications which support ODOT's mission. Much of ODOT's success may be attributed to its organizational approach, business model and implementation of enterprise GIS. These factors are the focus of this case study.

Background

The first Ohio state system road inventory was conducted in 1947; the first local system survey was completed in 1951. Both inventories used a county/route logmile linear referencing method.

ODOT currently maintains approximately 121,000 centerline miles of roadways in the following categories:

State System	19,265 mi
County System	29,022 mi
Township system	41,432 mi
Municipal System	31,648 mi

Ohio consists of 88 counties and over 1,310 townships.

ODOT is considered one of the pioneers of using GIS for transportation (GIS-T), with GIS efforts dating to 1980 and including the State Accident Identification and Reporting System (STAIRS), an accident display application with dynamic segmentation capabilities. In addition to its complete roadway network, the Department also is also known for the quality of its roadway data.

Policy

Ohio has a legislative mandate for the collection and maintenance of roadway network inventory data for purposes of vehicle registration tax distribution including mileage for highways under county and township jurisdiction. This mandate is specified in the Ohio Revised Codes (ORC), which also outlines maintenance responsibilities.

Much of Ohio's roadway inventory effort is guided by the ORC. The ORC defines four classes of roads (state, county, township and municipal) and mandates the state, county and township systems. In addition, the ORC describes procedures for creating, naming and numbering county roads and bridges, as well as specifying roadway maintenance responsibilities.

As mandated under the ORC, the county engineer is responsible for the construction and maintenance of some of the bridges throughout and all of highways located in his or her county jurisdiction. There is one county engineer per county, resulting in 88 for the entire state. These county engineers are required to provide certain roadway and bridge information to the state Director of Transportation. In addition to the county engineers, each township elects a board of trustees. These elected officials meet or correspond annually with the state DOT staff.

The responsibilities of the county engineer as mandated by the ORC create a need for accurate LRS-based roadway information.

Organizational/Business Model

During the late 1990s, ODOT embarked on a major agency-wide restructuring project known as VISION 2000. As a result of this process, by the early 2000s ODOT adopted a decentralized structure which was seen as more favorable to asset management than the previous centralized system. In short, decentralization placed Central Office in charge of guidance and policy matters, while ODOT districts were given responsibility for their own budgets and projects. There are twelve ODOT districts, each with a GIS Coordinator who works with ODOT headquarters and the other districts. The Department also established the Base Transportation Referencing System committee (BTRS) which oversees and promotes department-wide communications, streamlines operations, and promotes data sharing, With respect to roadway inventory and LRS-based data, this agency-wide decentralization has enhanced the development of LRS-based data by allowing the central office GIS unit to focus on maintenance of the LRS, guidance, policy and integration of GIS with business processes while the districts focus on data collection and projects. The housing of the GIS and Road Inventory units under the Technical Services division was also a critical step in promoting the development of the ODOT's LRS, as it facilitated communication and eliminated departmental barriers that might otherwise impede progress.

In addition to the departmental structural decentralization, ODOT also decentralized its GIS activities. GIS as an enterprise activity experienced significant growth when ODOT deployed GIS in district offices and migrated its data to an enterprise database. ODOT continues efforts to decentralize GIS by integrating GIS-based tools and functionality into departmental business processes, moving it from the realm of the GIS expert to the average end user. Through applications such as the Ellis project management system, ODOT is able to use LRS-based information to support departmental business processes by making roadway information available to non-technical users. With the website www.buckeyetraffic.org, the Department is able to disseminate LRS-based roadway travel information to the general public.

Partnering Agreements

A key factor in the development of ODOT's extensive LRS road network has been the establishment of data and cost sharing partnerships with numerous counties. While the decentralization discussed above has advantages from the standpoint of efficiency and work distribution, data integrity and consistency became a concern. ODOT has addressed this issue by signing Memoranda of Understanding (MOUs) with several counties. Under these agreements, the Ohio Geographically Referenced Information Program (OGRIP) and/or ODOT pays for half of the cost of developing the county road network and the county provides the data to ODOT. Counties agree to follow data standards, thus ensuring data consistency among the different data sources.

This approach was first used for the Location Based Response System (LBRS) project currently underway. This purpose of this project is the creation of accurate street centerlines and address data for use in emergency response efforts, among many others. Funding for the LBRS is being managed through Memoranda of Understanding (MOUs), which specify data development efforts to ensure data consistency and integrity. ODOT/OGRIP funds up to half of the cost of collecting and developing the data. Actual funding varies by county and is a function of the miles of public roads in a county and the number of addressable structures. ODOT/OGRIP provides guidance and support to the counties throughout the effort.

By decentralizing data collection and creation efforts, these partnerships enable ODOT to build an extensive roadway database while maintaining data consistency. What would be an unwieldy effort for ODOT to undertake for the entire state becomes a more reasonable effort with partnerships.

Conclusion

The key factors in the Ohio DOT's success in linear referencing systems may be attributed in large part to the three factors discussed above. First, the state mandate for the maintenance of roadway information means that these activities are considered critical components of the Department's business processes. Second, the decentralization of the Department has enabled the Central Office to focus on coordination activities while data collection and maintenance are conducted by those best suited to do so, the counties themselves. Finally, the use of partnering agreements has enabled counties to afford the costs of data collection, and has resulted in high quality data for both ODOT and the counties.

NORTH CAROLINA – Linear Referencing Method

Key Points

- *FTSeg LRM implementation*
- *Event stability*

Introduction

The North Carolina DOT (NCDOT) GIS Unit currently maintains 82,000 centerlines miles of state-maintained roads in its enterprise LRS, which has been in operation since 2006. While the LRS has not yet reached full integration with all NCDOT business processes, it is already being used by various DOT departments, including the Pavement Management Unit, Asset Management Unit, Planning Unit, Traffic Engineering Unit and Traffic Survey Unit.

Background

Prior to the development of its enterprise LRS, the NCDOT's roadway information consisted of a system of disparate applications and databases. Common occurrences such as route name and milepoint changes required the constant synchronization of changes among the databases, but a lack of formal procedures meant that consistency among the databases often suffered. In addition, these data exchanges usually involved non-standardized transfers of data using a variety of formats.

These issues prompted the NCDOT to investigate the establishment of an enterprise LRS. While the need was recognized early on, an initial attempt at establishing an enterprise LRS was not successful because of vaguely defined goals and purposes. In addition, various people and groups attached different meanings to the project, and the term "LRS" itself had different meanings for different people.

In light of these initial problems, an LRS Task Force was created to guide the development of a new enterprise LRS as the NCDOT's integrator of roadway-related data. The purpose of the Task Force was to define the enterprise LRS project clearly in terms of deliverable data products, to establish repeatable business processes and to identify ways to manage these products.

Enterprise LRS Goals and Objectives

The Task Force identified a number of requirements, objectives and constraints for the enterprise LRS:

Requirements & Objectives

Integrate Core NCDOT Linear Referencing Methods

- Route & Milepost
- Generation 1 FTSegs and Offsets

- Coordinate Route
- Intersection and offset

Support Transformations between LRMs
Maintain the Linear Datum
Include State-Maintained Roads
Accommodate other (non-highway) modes
Ensure Timeliness of Data
Enable Predefined and Ad Hoc Queries
Ensure LRS Development would not Affect Existing Events
Provide choice of LRM

Constraints

Use existing NCDOT technology standards
Use existing NCDOT base map
Include State-Maintained roads
Use a Single Linear Datum
Existing Business Process and Legacy Data should place no constraints on design

The above goals and constraints were selected with the intention of using existing data and resources to the fullest extent possible in order leverage existing investments and minimize disruption to existing processes.

The Task Force chose as its preferred LRM a method which appeared in the NSDI Framework Transportation Identification Standard (Dec. 2000). This LRM is referred to as the Generation 1 Framework Transportation Segment (G1 FTSeg).

Generation 1 Framework Transportation Segments

The NCDOT's enterprise LRS currently supports four location referencing methods (LRMs):

Route and Milepost
Intersection and Offset
Generation 1 (G1) FTSeg and Offset
Coordinate Route

Of these LRMs, the NCDOT determined that the Generation 1 FTSeg and Offset method provides the greatest advantages to the enterprise. While this method is not as widely used among DOTs as some of the other methods, it has some qualities that make it advantageous for use in an enterprise system. For this reason, the NCDOT's implementation was selected as a case study. It is discussed in some detail below.

<u>Description</u>

A Framework Transportation Segment (FTSeg) uniquely identifies a specific portion of the physical roadway. It is defined as a directed path between two Framework Transportation Reference Points (FTRPs), which are specific points on the physical transportation system such as state or county boundaries, endpoints, intersections or junctions. Figure 8 shows one example of several possible relationships between FTRPs and FTSegs.

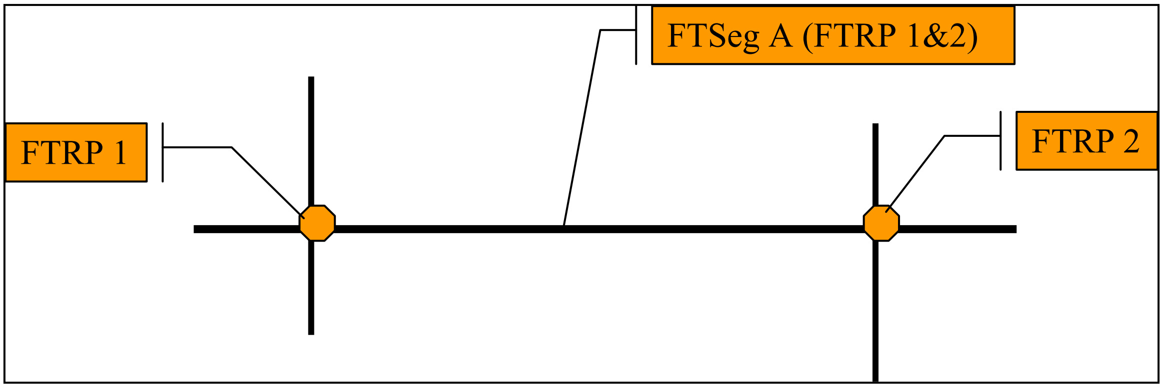


Figure 8

The FTRPs and FTSegs and their interrelationships form the core of the NCDOT's linear datum and are the basis of the enterprise LRS. Figure 9 shows the general relationship between the FTRPs and FTSegs and the other components of the NCDOT enterprise LRS.

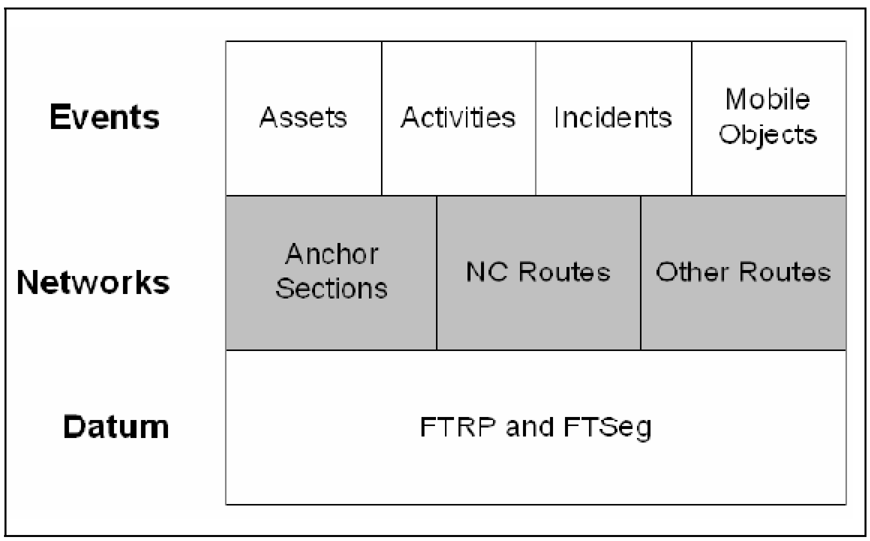


Figure 9 – Components of the NCDOT enterprise LRS.

Each FTRP and FTSeg is assigned permanent a unique identifier which does not have any specific meaning. The designator "G1," meaning "First Generation," is added to an FTSeg that was created when the original network was created, or to a new segment that did not previously exist. Any segments created by modifying a G1 FTSeg are designated as second generation, or "G2". The results of subsequent modifications are assigned "G3," "G4" and so forth as seen in Figure 10.

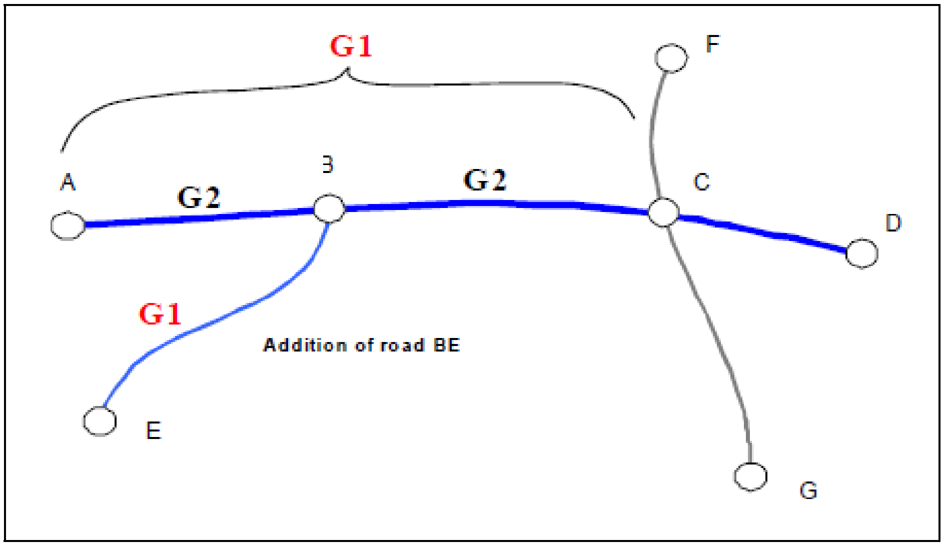


Figure 10 - Designation of segment generations. Segment AC is a Generation 1, or G1 segment. Upon the addition of road BE, two segments, AB and BC are created from segment AC. Since these physical sections of road already existed, they are now considered G2 segments. The new road BE did not previously exist, so it is designated a G1.

In the FTSeg method, point locations are referenced by specifying a combination of FTSeg ID number, and FTRP ID number, and a positive offset distance from the FTRP (see Figure 11).

FTSeg ID: 403621
FTRP ID: B
Offset distance: 0.48 mile

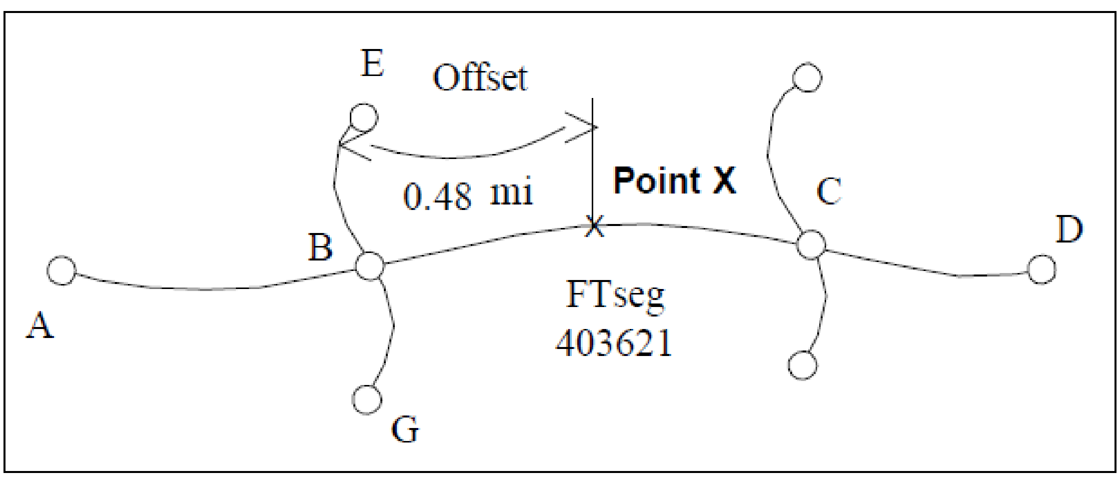


Figure 11 - Locating a point using FTSeg and Offset Distance.

Linear features are identified in a similar manner, but by providing two point descriptions for each endpoint of the feature. The offsets are measured from the same FTRP.

FTSeg Maintenance and Event Data

The following examples show how some typical network changes are managed under the FTSeg linear referencing method.

Adding a Segment

A common edit to a road network involves the addition of a new road segment. In Figure 12, a new segment, ending in Point B, has been added to the network. The result is the creation of two G2 segments, AB and AC. The old G1 segment, AC, is not deleted but instead remains in the system. Since the G1 segment is maintained, any events referencing this section of roadway do not need to be altered. For example, Table 1 shows an example event table containing crash data referenced to the network in Figure 12. Since G1 segment (AC) is not deleted, the crash locations in Table 1 are still valid and do not need to be modified.

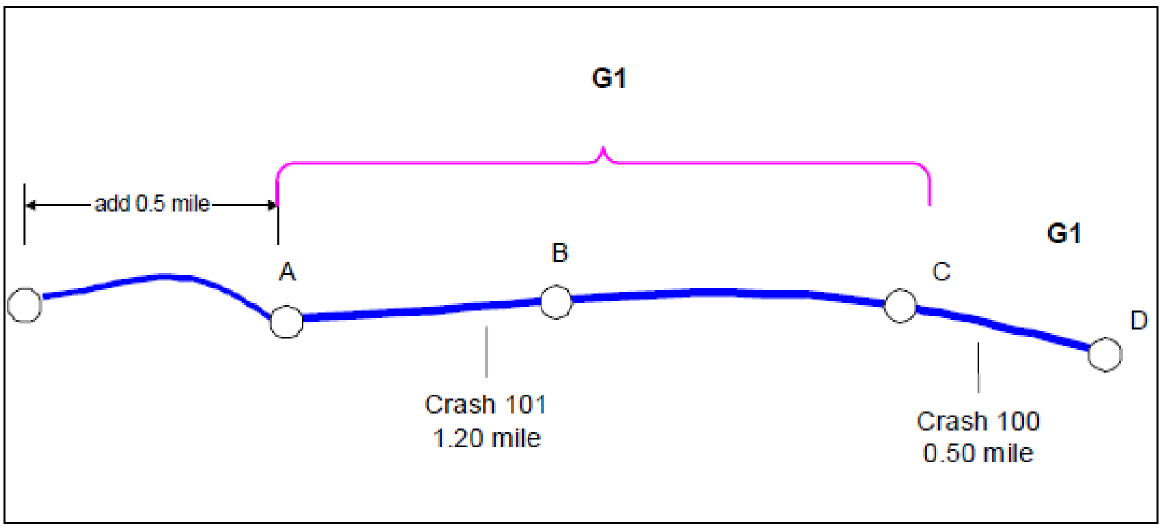


Figure 12 – Addition of a segment to the beginning of a route.

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

Table 1 – Sample crash event table.

In another example, a new segment is added to the beginning of a route (Figure 12). Although the overall route is now longer, since the event measures in the FTSeg method are not dependent on the segment length, the addition of this new segment does not affect the events that reference this route. Again, the events in Table 1 do not need to be modified. Under a route and milepost system, which is based on the length of the road segments participating in the route, the addition of this segment would require the updating of any events referencing this route.

Segment Recalibration

a) Event offset is independent of segment length

Another common network editing scenario involves the recalibration of road segment lengths (see Figure 13). Table 2 shows an example of a crash event table related to the road in Figure 13.

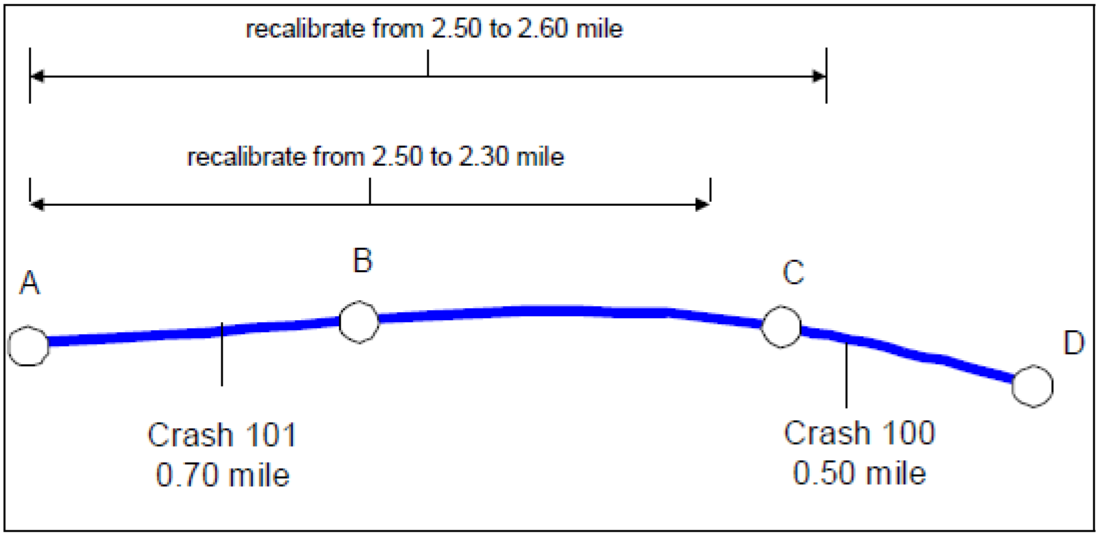


Figure 13 – Examples of recalibration.

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

Table 2 – Sample crash event table.

If the events in Table 2 use an offset that is independent of the segment length, no changes need to be made to the event table. Regardless of whether the original road length is increased or decreased upon recalibration, the events will be in their proper location.

a) Event offset is dependent on segment length

In cases where the offsets in an event table are dependent on the length of the segment, then it may be necessary to make adjustments to the offsets upon recalibration of the segment. For example, if the offset for a stop sign event is based on the segment length (see Table 3) then recalibration may cause the sign to appear on the wrong side of the intersection (see Figure 14). If the recalibration results in an increase in length, the sign will remain on the correct side of the intersection. However, if recalibration results in a decrease in length, the sign may appear on the incorrect side of the intersection.

Feature	Point	G1 FTSeg	Distance from Point
Stop Sign	A	AC	2.49 mile

Table 3 – Sample sign event table.

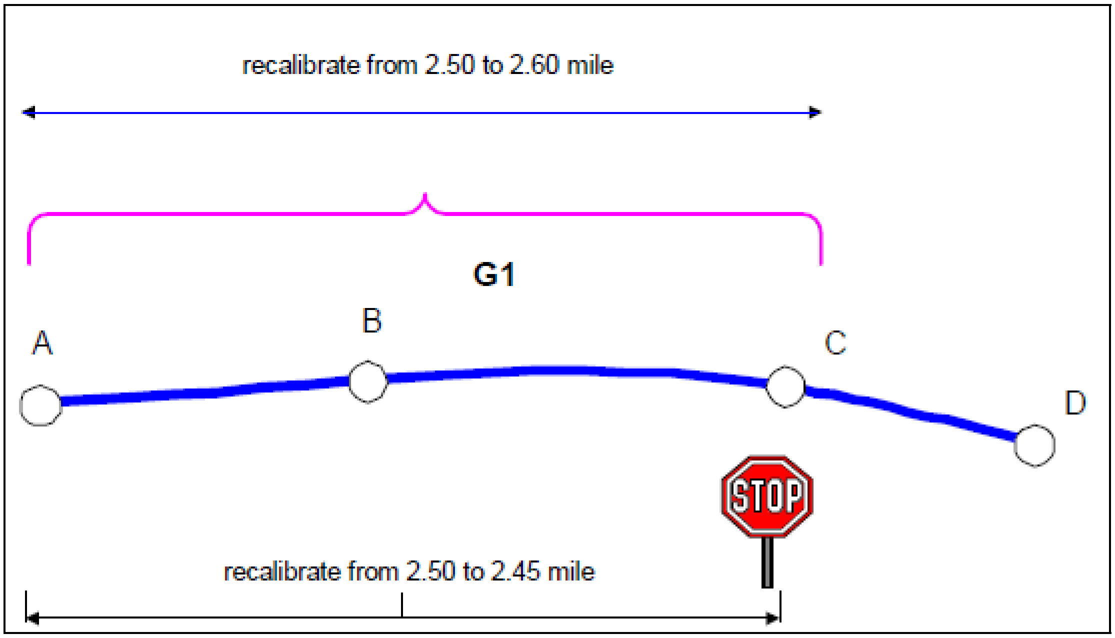


Figure 14 – Example of recalibration.

Benefits

As illustrated above, one of the major benefits of the FTSeg method is the stability of the network model and overall ease of maintenance. When new segments (Generation 2, Generation 3, etc.) are added to the network, the previous generation features are preserved, meaning that any events referenced to the previous generation segments will still be valid without additional processing. Thus, despite edits being made to the network, associated events remain stable and do not require modification.

Another significant benefit is that the preservation of all generations of FTSegs enables the historical tracking of the road network as well as associated events.

This independence from recording events based on segment length is one of the key advantages of the FTSeg approach over other LRMs such as Route and Milepost. In a Route and Milepost method, a route name and distance along the route are used for referencing events. While it is a relatively straightforward system to understand, problems arise when changes are made to a route. Any changes to route names and/or to route lengths will impact the utility and accuracy of any related event tables. Consequently, any such modifications to route names or lengths need to be accompanied by corresponding modifications to any event databases referencing the changed routes. This is time-consuming, costly and potentially dangerous to data consistency and integrity. In contrast, the FTSeg method provides stability by eliminating dependency on route names. Since it references the physical roadway rather than a route, events are not affected if a route is renamed.

Drawbacks

The drawback to the FTSeg method is its use of meaningless numbers to identify FTSegs. In other words, these ID numbers do not have any inherent meaning to the user. Whereas a route and milepoint method uses a meaningful link naming convention (the route name), the FTSeg ID is not intuitive and is not related to any physical or logical description of a roadway. This poses problems when identifying segments in the field and in communicating with the public. In these cases, maps showing roadway links and their identifiers must be used so that users can identify links properly. This makes the FTSeg method somewhat cumbersome and user-unfriendly.

Implementation and Maintenance in the NCDOT

The NCDOT strongly encourages the use of the FTSeg method for referencing events. However, due to the requirements of existing legacy applications and business processes, other LRMs, particularly route and milepost, are still in use. For example, the DOT's Pavement Management System and Road Inventory Module require that data be formatted using a route and milepost method. Eventually, however, the NCDOT expects to upgrade all applications to the FTSeg linear referencing method. Most recently, the NCDOT incorporated highway milemarkers into its system and referenced them using the FTSeg method.

The NCDOT maintains its system in the ArcGIS and Oracle environment using standard ArcGIS tools and tools developed by the GIS Unit. Figure 15 shows how the LRS fits into the NCDOT's overall roadway information system.

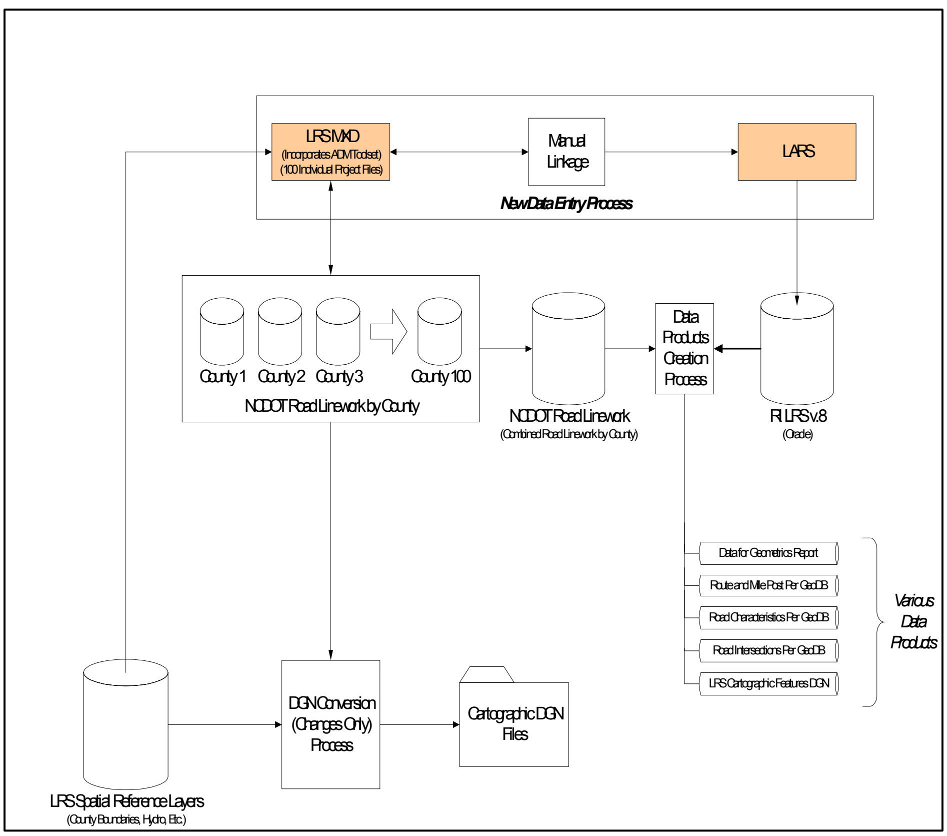


Figure 15 – NCDOT maintenance business process.

Future

One of the goals of the NCDOT is to achieve full integration of their LRS within the enterprise. Part of this ongoing effort involves the incorporation of the G1 FTSeg referencing method into more business processes.

The NCDOT is also modifying its road network data model with the goal of creating a single statewide geodatabase. Currently the NCDOT maintains an individual personal geodatabase per county (100 personal geodatabases). The large number of databases results in a cumbersome and inefficient workflow and makes it difficult to perform tasks which span multiple counties, such as planning, routing and emergency management. In addition, database maintenance and implementation of rules and domains among so many databases is awkward and can lead to data integrity issues. While the current geodatabases only include state-maintained roads, non-state and local roads will be included in the future. The FTSeg LRM will be incorporated into this new statewide geodatabase.

The NCDOT GIS Unit is also in the process of developing the Attribute Road Inventory Data (ARID) tool. ARID will be a unified LRS edit and management tool which will streamline the maintenance process for linearly referenced data. In addition, ARID will aid the GIS Unit with maintaining and preparing data for yearly HPMS submittals. The ARID tool is expected to be completed in 2009.

Conclusion

This case study has highlighted the North Carolina DOT's preferred linear referencing method, the FTSeg LRM. As implemented by the NCDOT, the FTSeg method offers stability, maintenance and cost advantages that allow the GIS staff to focus their efforts in other areas. The NCDOT feels that the benefits of the method outweigh any drawbacks and is taking steps to fully integrate the method into its business processes.

California – Service Oriented Architecture and LRS-Based Applications

Key Points

- *LRS-based enterprise applications*
- *Service Oriented Architecture*

Introduction

This case study of the California Department of Transportation (Caltrans) will concentrate on the distribution of LRS-based applications at the enterprise level. Some very brief background information will be presented to set the system into context, followed by a discussion of the linear reference system and application environment.

Background

Caltrans is one of the largest DOTs in the country, serving 58 counties, 435 cities and numerous state agencies, local governments and private and non-profit organizations. There are currently 367,000 miles of roads in the state, with 15,000 miles in the LRS. Caltrans employs a staff of 60 GIS personnel in offices throughout the state.

Like other state DOTs, Caltrans has encountered the challenges of developing, implementing and utilizing a linear reference system. Much of Caltrans' success in implementing a successful LRS may be attributed to maintaining focus while at the same time remaining flexible. The development of a strategic plan for the Caltrans enterprise GIS has allowed the Department to specify the goals for the system and incorporate these into its daily workflow and business processes. The strategic plan helps to maintain focus during the implementation and use of the linear referencing system to integrate business functions.

In order to serve such a large number of users efficiently, Caltrans has in recent years developed numerous web-based applications to distribute its roadway transportation data, many of which are LRS-based. Table 4 contains a listing of some of these applications.

CA511 WPS Projects by Query	Resource Agency Contact Info.	District 2 Chain Sign App
WPS Projects by Map	Reference Map Index	DHIPP Tile Search
Wind Data Analyst	Quad Maps z6	DEM download
Toposheets	Quad Maps z5	D11 Surveys Control
The Construction Quickie Template	Project Focus	Interactive Map Traffic Signals in Riverside County
TCSIMS	Postmile Query Tool	D8FAU
Stormwater Inventory	Postmile Log	D8 Operations Services
Google/Tabular Search	Pavement History	D8 Materials Plants
Storm Drain System Inventory	Orange Co.Multimodal Transportation System	D4 Committed Projects Web Map
Storm Drain Inventory Statewide Beta (D7 only)	Intermodal Transportation System	D2 Culvert Map
STIPP and SHOPP maps	Lake IGR Humboldt & Del Norte APN	Current Chain Control Culvert Inventory
Project location	Mendocino & Lake APN	ArcIMS Web Tool
Statewide Soundwall Inventory	GIS TMS	Culvert Inventory
Sbd Co	Elements tool	CRS Maps
Parcel Data R/W Map Search	Document Search	Control Zone 3
Riverside County Parcel Data Right-of-Way Map Search	District 2 Information Map	Control Zone 4
Control Zone 5	Control Project	Control Maps
Bond Accountability	ArcIMS	Animal Collision Information Database
Aerial Mapping Index		

Table 4 – Caltrans LRS-based enterprise web applications.

These applications reflect the high degree of integration between Caltrans' LRS and its business processes. This integration and information distribution has begun to eliminate previous bureaucratic inefficiencies and has improved the quality of the decisions made by the Department. This, in turn, improves the credibility of the Department and helps it serve the citizens of California more effectively. The approach used by Caltrans in developing and distributing these applications will be discussed in the following sections.

Primary Linear Referencing System

The current Caltrans linear referencing system has been in place for approximately 44 years. The primary linear measurement unit is the Traffic Accident Surveillance and Analysis System (TASAS) postmile. In the postmile system, the measurement origin is located in the southwest corner of a county and increases towards the north and east. A facility's measure will restart at zero whenever a county line is crossed. A system of prefixes and suffixes is used to account for realignments and modifications of the highway. The TASAS postmile system has been adopted by other offices and divisions in the state as their linear measurement system. Over the years, numerous highway realignments and modifications have resulted in a complex alphanumeric unit further complicated by the renumbering for each county.

There are two components to the TASAS system. The first is a feature class consisting of measured polylines on the state highway system which are obtained from a road network supplied by TeleAtlas. This network provides a level of accuracy that is not present in the Functionally Classified Roads (FUNC) line work that has been used by Caltrans to define the state highway system. Dual alignments are handled as separate routes.

The second component of the system is a TASAS postmile table. This table contains a point reference and the associated TASAS postmile reference including the county, route, postmile prefix, postmile, and postmile suffix. The point reference is used to determine the location along a measured polyline. A postmile can be translated to a measure by determining the measures of the TASAS postmiles on either side and interpolating.

LRS Implementation and Service-Oriented Architecture

Caltrans implemented three key strategic decisions in an effort to move beyond the bureaucratic inefficiencies that characterize many large enterprises (information silos, disparate databases, duplication of effort, etc.). Caltrans realized that integration of its enterprise roadway data was crucial to the efficient delivery of information to decision makers.

The first strategy was a thorough evaluation of the Department's basic mechanism for data organization, the route. Caltrans developed a comprehensive understanding of routes and their role in the management of the department's data. It rejected vendor implementations in favor of its own data models. To maintain flexibility, Caltrans implemented a hub-and-spoke LRM model, allowing for the use of multiple LRMs while maintaining ties to a base LRM. This approach supports the Department's multi-level linear referencing system (MLLRS),

The second strategic decision was to implement a Service-Oriented Architecture (SOA) for the Department's DynSeg (dynamic segmentation) operations. These operations consist of various web services, collectively known as the DynSeg Web Services, which provide GIS functionality and are described below in more detail. The services follow W3C web services and SOAP (Simple Objects Access Protocol) standards to enable interoperability throughout the enterprise. The decision to use a SOA approach freed GIS development from the desktop and has resulted in more rapid development and deployment of applications and data.

The third decision was to enable interoperability through the implementation of messaging services. Referring to existing XML standards for transportation data, Caltrans' Transportation Systems Information (TSI) group developed its own XML specifications for its transportation data requirements. The resulting TSI XML Message Bus employs a subscription model, whereby applications subscribe to the messaging service to share and receive the required spatial data. Thus, it is possible for spatial data to be shared between various applications in differing platforms. The results have been scalability and a high level of interoperability which have paved the way for the integration of spatial data and applications throughout the enterprise as shown in Figure 17.

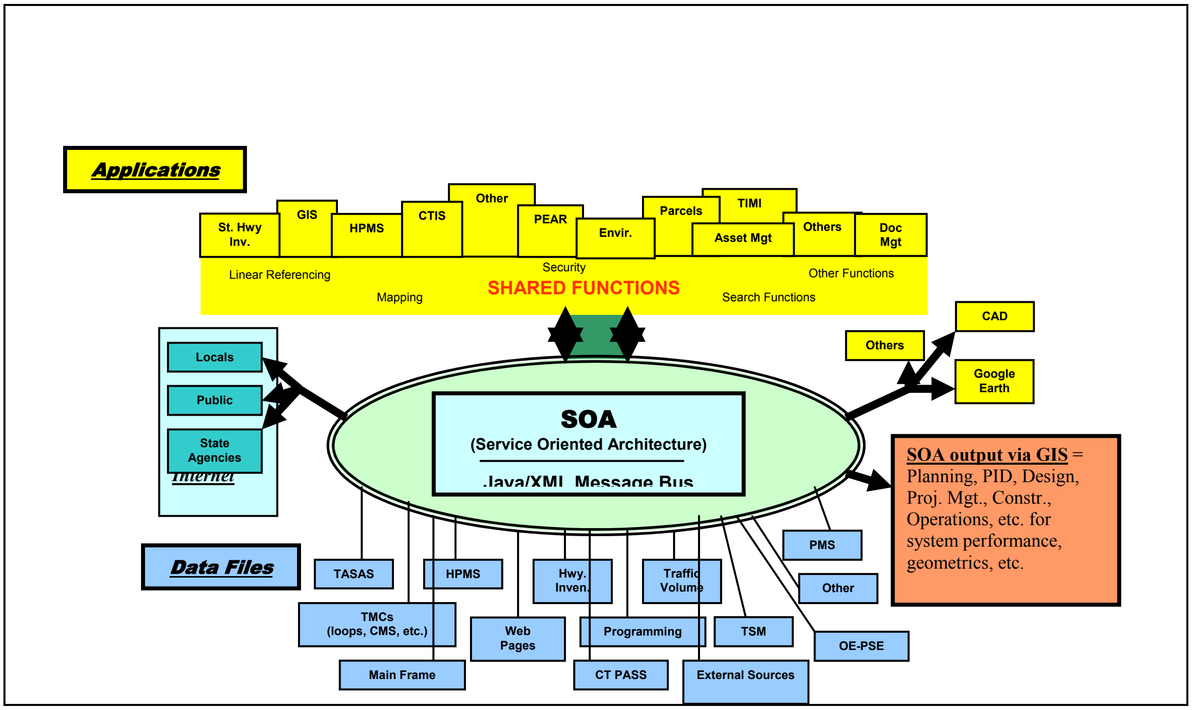


Figure 17 – Caltrans enterprise system integration via service oriented architecture (SOA).

These decisions resulted in the implementation of the dynamic segmentation (DynSeg) Web Services, which has enabled Caltrans to serve substantially more users than before centralization. Prior to the use of web services, the department processed roughly 500 dynamic segmentation transactions each day. However, after the deployment of web services the number increased to approximately 45,000 transactions per day. The large increase in users is evidence of the increased integration of LRS-based information into Caltrans enterprise-wide business processes. Figure 18 shows an example of the Caltrans Statewide Traveler Information Map, a web application which displays LRS-based data.

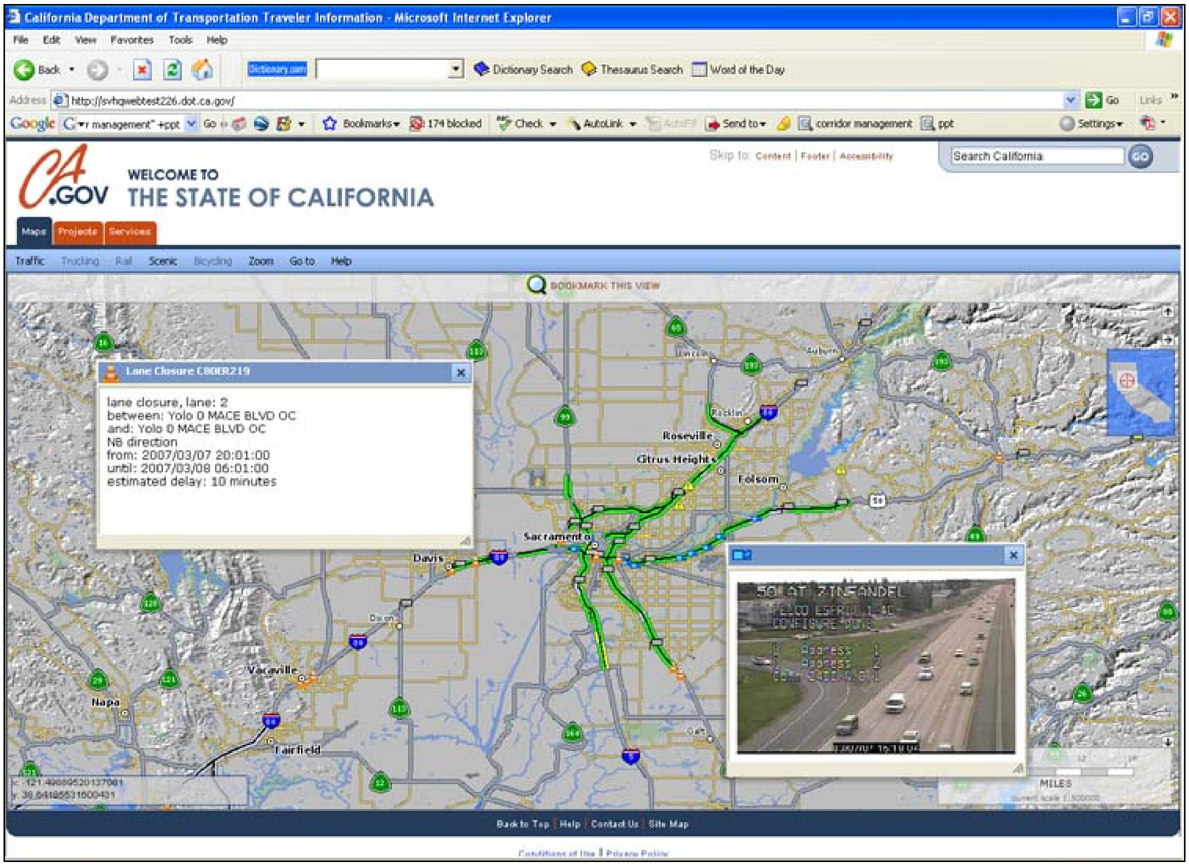


Figure 18 – California Statewide Traveler Information Map.

<u>Dynamic Segmentation (DynSeg) Web Services</u>

The DynSeg web services are housed in a central location on Caltrans servers and is accessible to users as a service via the Caltrans intranet. In a typical scenario, the client application sends an XML message containing postmile information to the DynSeg Web Service. The information in the XML message is then processed and the results sent back to the client as a GML (geography markup language) message containing point or linear geometry information (see Figure 19). For example, an application wishing to display traffic volumes using latitude and longitude would send a request to the appropriate web service which would access the traffic volumes database, convert postmiles to latitude and longitude, and send the results to the calling application for display. Although transactions take place over the intranet, it is still necessary to distribute client-side applications which manage the XML communications with the web services. However, these are relatively small and easily managed distributions.

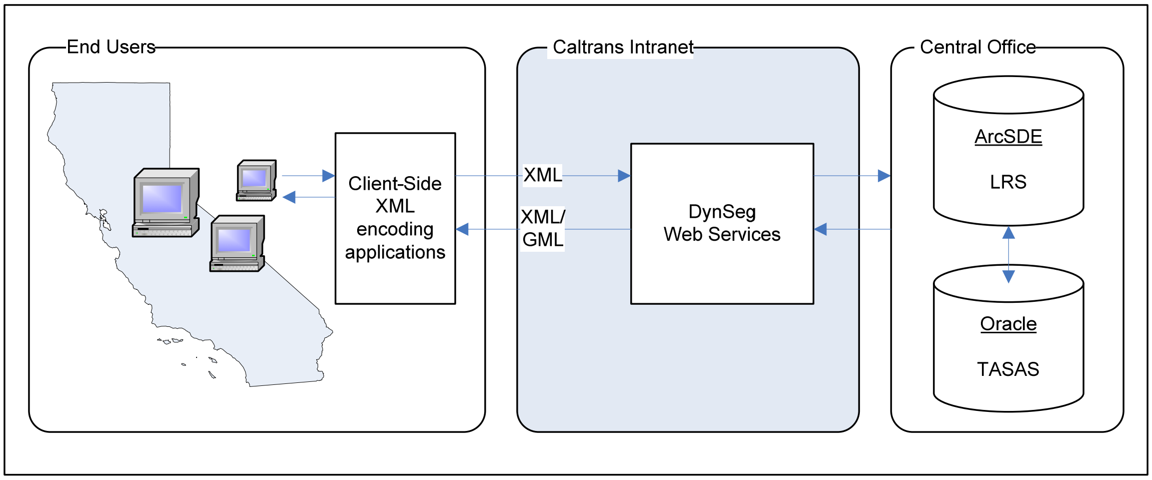


Figure 198 – Information exchange between clients and DynSeg Web Services.

The DynSeg web services were developed by Caltrans. These services conform to Open Geospatial Consortium (OGC) standards for geographic web services. A brief description of the services is presented below.

Validation Services

ValidatePostmile: Accepts a postmile in XML format and verifies its existence in the TASAS database. If an exact match does not exist, a ranked list of potential candidates is returned.

ValidatePostmilePair: Similar to ValidatePostmile. Validates a linear postmile segment by verifying the existence of the start and ending postmiles in XML format.

Postmile Lookup Service

GetpostmileForPoint: Accepts a XY (Latitude and Longitude) coordinate pair in XML format, returns the nearest postmile. The method also supports a tolerance parameter.

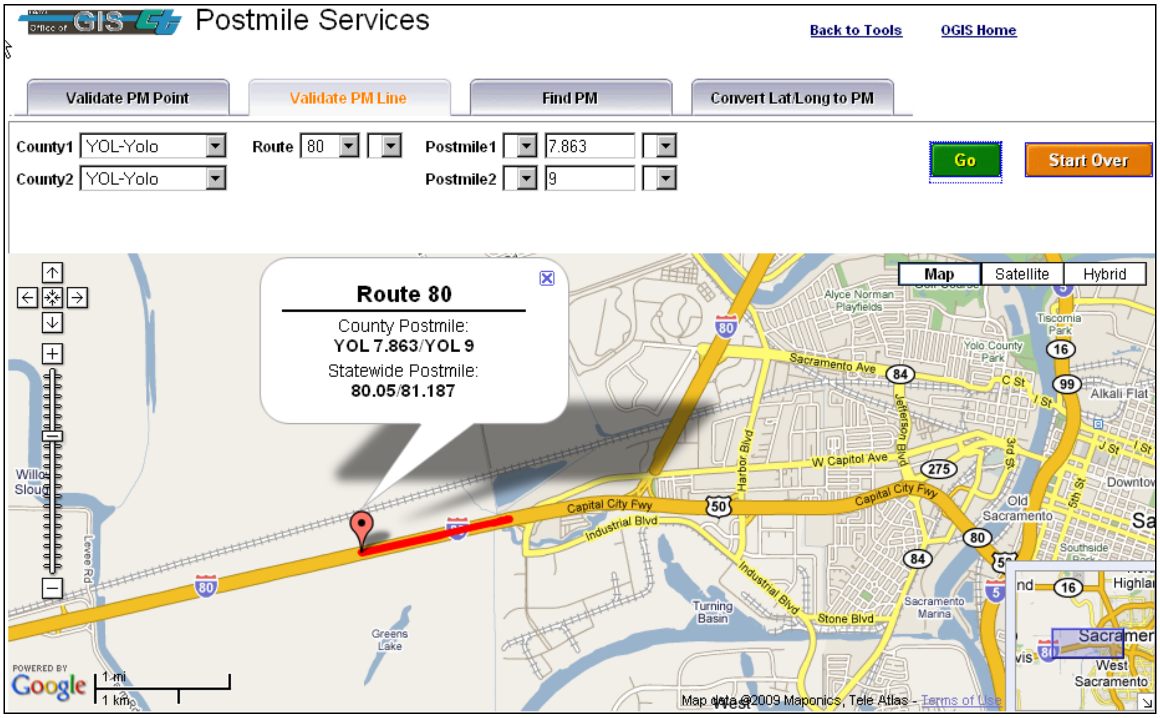
Georeferencing Services

GetCoordinateForPostmile: Accepts an input postmile and determines its location on the State Highway System. Results are returned as GML longitude/latitude coordinate pair.

GetCoordinatesForPostMilePair: Similar to GetCoordinateForPostmile. Accepts a pair of start/end postmiles, determines the linear segment along the State Highway System which connects the points, and returns a GML line segment.

Postmile Lookup Tool

One example of using the DynSeg Web Services is the Postmile Services appliction. The Postmile Services application is a Google Map web application connected to the DynSeg Web Services that allow users to map known postmiles or postmile pairs or identify the nearest postmile to a click event on the map.



ArcGIS Postmile Extension

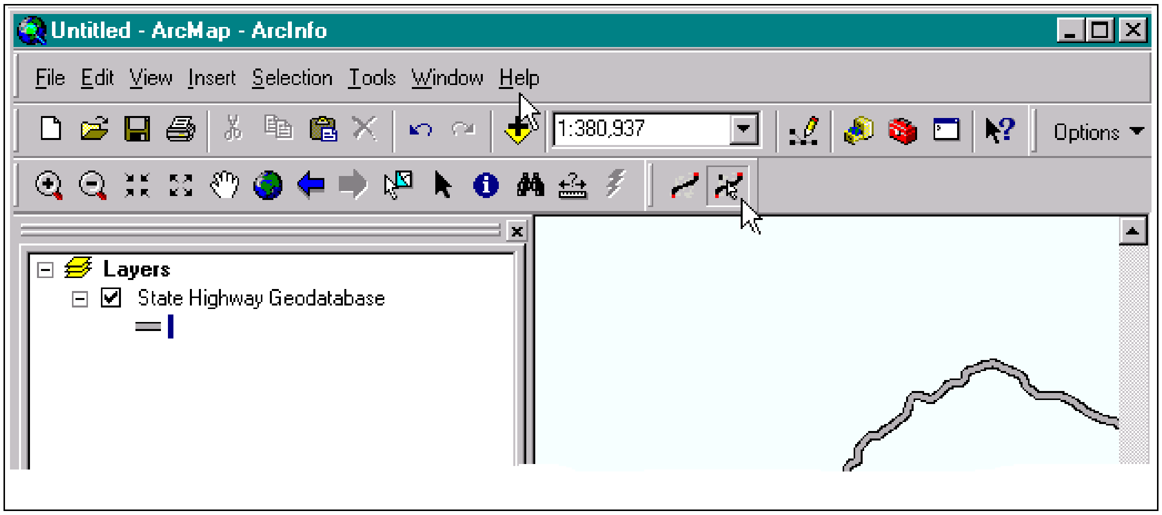
Caltrans has also developed an ArcGIS extension containing postmile tools. These tools use the same DynSeg Web Services to retrieve information and consist of the following buttons on a toolbar:

> *Postmile Validation Wizard* – Steers the user through the postmile validation process. It identifies invalid or ambiguous postmiles and suggests potential candidates and it revalidates data records after editing. Results are returned as a table which may be sorted and edited. A point or line feature may be generated from the results and displayed in ArcMap.

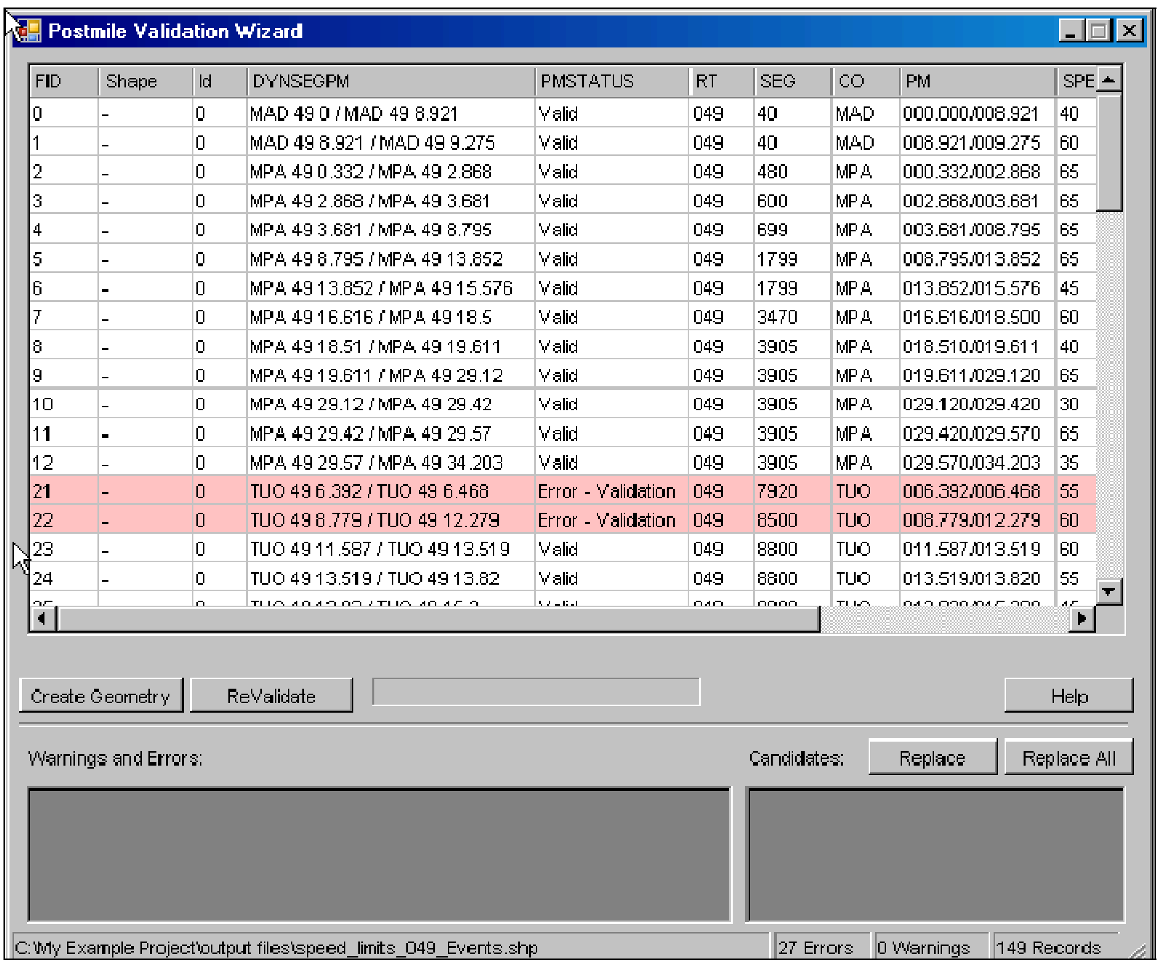
> *Postmile Query Tool* – The user clicks on a map and the tool retrieves and displays the nearest postmile as a point feature. It allows user to select locations on or near a state highway and determines the postmile value nearest to the selected location. Results are displayed in a spatial data layer.

The toolbar has been deployed throughout Caltrans and is distributed through the Department's intranet.

The toolbar adds two buttons to the ArcMap interface as shown.



The work flow will go through several menus and call the DynSeg Web Services several times resulting in record validation as shown below.



TSI XML Message Bus

In order to successfully deploy such a large number of applications, Caltrans implemented the Transportation Systems Information (TSI) XML Message Bus. This message bus serves as the lifeblood of the system by enabling communications between diverse applications and datasets. Basically, the message bus centrally manages the sharing of information between applications so that the applications can communicate with each other. This improves interoperability and eliminates the need to develop and manage individual communications between applications. The result is drastically improved scalability, as applications and data sources may be added to the system with relatively minor effort. Figure 20 below shows how the message bus helps to enable the integration of the enterprise system.

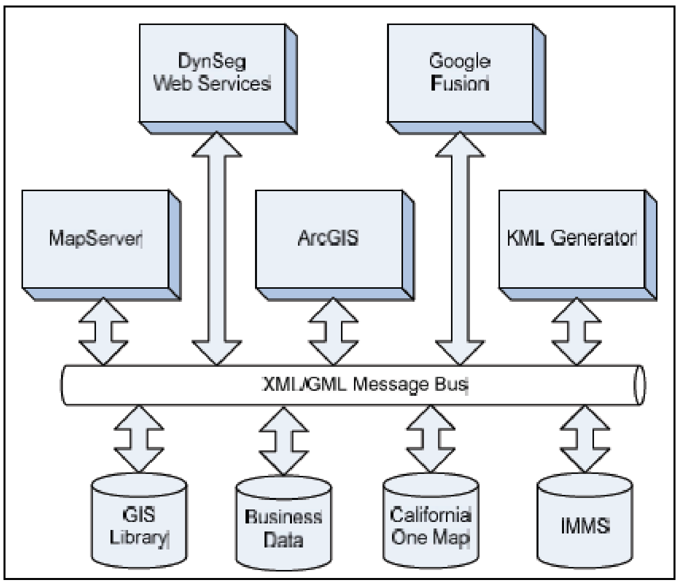


Figure 20 – Role of the XML Message Bus.

Advantages

There are several advantages to the approach used by Caltrans. The centralization of the DynSeg application means that all end users will access the most current data available. This is in contrast to the previous approach in which data were distributed and installed on individual machines which resulted in varying versions of databases scattered throughout the organization. By having all the services and databases in a central location, data redundancy is eliminated and maintenance can be performed more quickly and efficiently. This ease of maintenance ensures that the DynSeg application and its data are current with respect to highway realignments and TASAS updated throughout the year.

The primary advantage of using web services is the ability to accommodate applications written in different languages and on different platforms. Clients may be commercial, off-the-shelf (COTS) applications, custom applications or web-based applications. This flexibility means that a greater number of applications and users have access to LRS-based information, and makes it easier to integrate such information into the Department's business processes. The result is greater interoperability and reduced reliance on vendor-specific solutions. Together, the web-based distribution and interoperability result in improved scalability throughout the enterprise.

Future Goals

The next stages in Caltrans' LRS efforts involve continuing the integration of LRS with additional departmental business processes. Among these efforts are integration with the Travel Information Map Implementation (TIMI), the California Transportation Investment System (CTIS) and Google Earth. Caltrans will also continue the development of its web-based application toolset. Efforts will continue to incorporate open source solutions wherever possible for its GIS enterprise architecture in order to leverage vendor capabilities for specific business solutions. Ultimately, Caltrans plans to have a strictly web-based user interface and toolset for its LRS applications and functionality.

Conclusion

Caltrans has addressed the challenges of serving a large user base by centralizing its LRS functions and implementing a service-oriented architecture and XML Message Bus. The Department is able to achieve a level of interoperability which allows roadway data to be shared by a wide range of applications and users throughout the state. This approach results in an integration of LRS with business processes which liberates the department's roadway data from data silos and incorporates it into decision-making processes.

CHAPTER 4

CONCLUSION

This report has summarized the results of a survey of departments of transportation across the country with respect to their existing practices in establishing linear referencing systems. In addition, five departments were selected as cases studies in order to highlight topics of particular interest.

The results of the survey show a wide range of progress in the current state of linear referencing systems. While some DOTs were pioneers in the field and have well-established systems that are highly integrated with departmental business processes, others are in the early stages and have less-developed systems. The survey responses indicate that regardless of the current status of a department's LRS, DOT's realize the benefits of an LRS in conducting their business activities and are intent on continuing the development and expansion of their system. In many cases the reasons for any lack of progress may be due to a deficiency of available resources rather than to a lack of awareness of the benefits of a LRS.

Several trends may be noticed from the survey results. Not surprisingly, DOTs continue to improve the completeness of their road networks, and some states already include private roads. However, very few DOTs states currently include modes other than roadways in their LRS, although several mentioned that they plan to incorporate other modes in the future. DOTs understand the need for LRSs to become multimodal. It is becoming more important as DOT planners and engineers work to understand the present and future passenger and freight demands on the nation's infrastructure.

As departments develop their LRSs and integrate them with their business processes, there is an expansion of the user base of LRS data from the traditional, such as pavement management and roadway inventory, to new users and applications as in the case of California. A large number of respondents also mentioned plans to develop web-based applications for use with LRS-based data. Of course, this will also expand the uses of LRS-based information and will expand the user base to non-technical users including, in some cases, the general public. There is a trend toward the centralization of LRS-based data dissemination, usually through web-based applications. Data collection efforts, however, appear to be moving towards decentralization as DOTs realize the benefits of distributing data collection responsibilities.

The case studies were selected to cover a range of issues and highlight how they were addressed by leaders in the field of LRS implementation. The topics included the management of legacy data, a specific linear referencing method, departmental structure and partnering, LRS implementation approach and integration of LRS-based applications. These case studies can serve as examples for other states to follow.

APPENDIX A

NCHRP Project 8-36, Task 80 - LRS Survey

1. Survey Contact Information

The NCHRP is funding a research project to conduct a synthesis of state practices in developing and applying linear referencing systems in GIS. A portion of this study will involve a survey of all states, Washington D.C. and Puerto Rico to document their methodologies, status and experiences.

Case studies will be selected which highlight particularly noteworthy implementations and/or methodologies, and a final report and guidance document will be prepared. This document will serve as a resource for all agencies in their efforts to implement and improve the LRSs.

1. Please Enter your Name:

2. Which State, District or Territory do you represent?

3. What is the name of your Agency?

4. Please list a telephone number where we may reach you:

5. Please enter your email address:

NCHRP Project 8-36, Task 80 - LRS Survey

2. General

6. Does your agency have one or more GIS-based LRSs in place?

- Yes
- No

If so, how many?

7. How long has your LRS(s) been in operation?

8. Does your agency have any legacy LRS systems?

- Yes
- No

9. What is the total centerline mileage of each LRS?

10. What is the total centerline mileage of all roads in your state?

11. Is there an implementation plan for your LRS(s)?

- Yes
- No

NCHRP Project 8-36, Task 80 - LRS Survey

3. Institutional

12. What departments currently use your LRS-based information?

13. What is the current level of integration of your LRS with department business processes and products? Please describe.

14. Does an LRS committee or similar group exist to guide the development of your LRS(s)?

- Yes
- No

If YES, enter the name(s) of the committe or group:

NCHRP Project 8-36, Task 80 - LRS Survey

4. Technical

15. What GIS and database platforms are used by your agency in support of LRS?

16. Describe your existing base network in terms of level of detail (state jurisdiction, local roads, etc).

17. Which Linear Referencing Methods (LRMs) are utilized in your LRS(s)? (Check all that apply.)

- [ ] Route and Milepoint
- [ ] Reference Post
- [ ] Control Section
- [ ] Stationing
- [ ] Link/Node

Others (please specify)

18. Have you established LRSs for modes other than highway (transit, rail, water, etc.)?

If YES, which modes?

If YES, have they been integrated into an intermodal LRS?

If NO, are there plans to develop LRSs for other modes?

NCHRP Project 8-36, Task 80 - LRS Survey

5. Maintenance

19. How is responsibility for maintaining each LRS shared within your organization (central office, districts, etc.)?

20. Who is responsible for maintaining the LRS(s)?

21. What tools are used to maintain each LRS?

22. What percentage of LRS activities are outsourced?

23. Do you employ any QA/QC processes for maintenance and accuracy of the network

- ◯ Yes
- ◯ No

24. Do you employ methods for storing historical/temporal LRS data?

- ◯ Yes
- ◯ No

NCHRP Project 8-36, Task 80 - LRS Survey

6. Applications and Products

25. What applications (within or outside the DOT) use your LRS data (for example: travel demand modeling, pavement management, etc.)?

26. Which of the applications listed in question 25 are used by non-technical/non-GIS users?

27. What products are derived or generated from your LRS(s) (straight line diagrams, maps, reports, etc.)?

28. What types of applications and products do you plan to develop within the next 1-2 years?

29. As part of the HPMS Reassessment in 2010, states will be required to submit an LRS with their HPMS data. Has your state implemented a plan to fulfill this requirement?

- ◯ Yes
- ◯ No

Describe briefly how your state plans to fulfill this requirement:

NCHRP Project 8-36, Task 80 - LRS Survey

7. Resource Requirements

30. What is the size of your agency's GIS staff?

31. Are any staff members dedicated to LRS development and maintenance?

- Yes
- No

32. Approximately what percentage of your staff's time is spent on LRS-related issues?

33. Are there any cost-sharing agreements with other departments/agencies to cover the costs of LRS activities?

- Yes
- No

34. What percentage of your total GIS budget goes toward the following activities:

LRS maintenance?

Data collection?

Development of products?

Other

NCHRP Project 8-36, Task 80 - LRS Survey

8. Comments

35. What do you consider to be the strengths of your LRS(s)?

36. What do you consider to be the weaknesses of your LRS(s)?

37. What have been your biggest hurdles in implementing your LRS(s)?

38. List your goals for your LRS implementation for the next 1-5 years.

NCHRP Project 8-36, Task 80 - LRS Survey

9. Documentation

39. Do you have documentation (system design & descriptions, user guides, data model diagrams, etc.) pertaining to your LRS(s) that you are able to share for the purposes of this study?

- Yes
- No

40. Please enter any additional comments that you may have regarding your LRS(s).

NCHRP Project 8-36, Task 80 - LRS Survey

10. Thank You

Thank you for your participation. The survey will be conducted through August 29, 2008. Results will be collected and analyzed during Fall 2008, and the final report completed during the first quarter of 2009.

If you would like to submit documentation related to your LRS or if you have any questions regarding the survey, please contact:

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