Integrating Traffic Management Data via an Enterprise LRS

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ABSTRACT

A Geographic Information System for Transportation (GIS-T) can be a powerful tool to integrate traffic data with other data and help analyze results for transportation decision-making (e.g., program, traffic, or safety management). For successful GIS implementation, an organization must define a location reference system (LRS). The LRS manages and integrates an organization's formal location methods (e.g., maps, GPS, mileposts). Without a proper LRS design, the GIS can create islands of data that are not integrated as part of an organization's main workflows and master data resources. This presentation will explain the different location methods necessary to the LRS, how these methods are structured within an LRS, and how traffic management staff are part of the LRS.

KEY TERMS

The following terms are defined in context to this paper.

- *Enterprise* – a set of business functions that create an output of value to some customer. These business functions are not defined by organizational boundaries but by the processes and data required to create the output. Therefore, multiple organizations may be part of an enterprise.

- *Intelligent Transportation Systems (ITS)* – ITS is comprised of a number of diverse technologies, including information processing, communications, control, and electronics. Integrating these technologies with the transportation system is expected to help save lives, save time, and save money (see http://www.itsa.org).

- *Interoperability* - To maintain relative independence among systems, with the only "dependency" requirement being the interface to share data between them. How systems operate internally is typically unimportant as long as the system meets its interface requirements.

- *Location Reference Method (LRM)* – a way of describing the location of an object or event relative to some known point in space.
- *Location Reference System (LRS)* – the management of location reference methods (includes field and office data and procedures).

INTRODUCTION

A Geographic Information System for Transportation (GIS-T) can be a very powerful data integration and analysis tool. It relies on a location attribute commonly existing in disparate databases (e.g., pavement, AADT, crash), to link the databases together. The GIS-T requires that the location attributes be in some standard format, based on a pre-defined *location reference method (LRM)(1)*. For example, if a bridge location attribute is an x/y coordinate pair, the coordinate pair must be latitude, longitude or be based on a LRM of a known map projection and coordinate system (e.g., Lambert conformal conic projection and a state plane coordinate system).

A transportation enterprise actually uses many different LRMs that the GIS-T must support. These methods include different scales of cartography, various geodetic datums, and linear reference methods such as mileposts, street address, and project stationing. A transportation enterprise must ensure that all these LRMs are supported and that data can be transformed from one LRM to another so data integration and analysis can be performed. Without managed LRMs, the GIS-T can produce islands of data integration instead of enterprise-wide data integration.

The management of the LRMs (which includes both office and field procedures) commonly occurs as part of a *location reference system (LRS)* (*1*). LRS management processes include collecting data, maintaining databases, and providing access to the data that represents the location reference method. For example, the LRS includes collecting, updating, and providing access to a roadway cartographic representation or roadway milepost information.

This paper describes the LRS that is necessary to support the location needs of a large transportation enterprise. The paper first presents location requirements from common workflows that may exist in traffic monitoring and management. It then describes how transportation organizations are defining their LRS to meet these requirements. Also described is how traffic monitoring and management data and staff are part of the LRS.

FUNDAMENTAL LOCATION REQUIREMENTS

Traffic monitoring and management has broad location requirements. Real-time functions (e.g., traffic management triggered by an incident) require real-time location data at fairly high accuracy (within meters for lane-related incidents and monitoring). System analysis and planning functions (traffic data collection, traffic management, or aspects of safety management) need locations of data over long periods of time where data is most likely summarized by roadway sections or intersections (e.g., AADT). More and more transportation organizations are determining how to feed data produced by the real-time functions into the long term planning functions. In order for the LRS to support these broad requirements, it must be very up-to-date, describe transportation networks very specifically (e.g., lanes and ramps) and generally (e.g., roadways and interchanges), and help convert specific locations into more general locations.

Transportation enterprises have three different perspectives that the LRS must accommodate: operational, decision-making, and public dissemination (*2*). Both real-time and planning functions of the transportation enterprise have these perspectives. The operational perspective needs location to assist in data collection and management (e.g., incident detection, traffic collection devices, and planning data (AADT)). The decision-making perspective needs location to help pull data together, create new information from this data, and make a decision based on this information (e.g., incident dispatch or transportation system/program planning). Public dissemination needs location to help summarize and present information to the public (e.g., real time messaging, public hearings, and public publications). Each of these perspectives has different objectives and may involve different people, data structures, processes, and technologies.

Although they are different, they must work together to accomplish an organization's primary objectives. Operations must feed data to decision-makers, and decision-makers must feed information to the public. Underlying these perspectives are basic workflows, shown in Table 1. The workflows represent the core processes that are used to perform the organization's primary business functions from beginning to end. Decision-mking and public dissemination perspectives have similar workflows, but decision-support workflows are significantly more intensive. Decision-support workflows result in transportation infrastructure and operations changes over time. Public dissemination workflows simply provide information about these decisions to the public. Real-time business functions apply these workflows within minutes or hours, whereas planning functions may take months or years.

In order for the LRS to support the transportation enterprise, it must support the needs of linking these different perspectives together. These basic workflows can provide insight into more specific location requirements that the LRS must support. Selected location requirements for each workflow are described below the table.

Table 1 - Location Perspectives and Basic Workflows

Workflow	Description	Operational	Decision -Making	Public Dissemination
Data Collection	recording the location of where something is	✓		
Data Storage	storing the location so it can be transmitted or is of value over time	✓		
Data Access and Integration	mining data based on location and massaging the data for a particular purpose		✓	✓
Data Analysis	interpreting the massaged data in order to make a decision		✓	
Data Reporting	presenting the findings to those impacted by the decision		✓	✓
Real World Action	taking some action to a real world location based on the decision made		✓	✓

Data Collection

Those who collect data need to be able to use LRMs that are the most effective for the task. GPS, wireless, and upcoming commercial satellite technologies have great potential for achieving significant efficiency gains in data collection – such technologies are also favorable for meeting real-time data collection requirements. When the public records a location, a cross-street LRM description might be more appropriate (e.g., ‘On Main Street, 100 meters from 1st Street towards 2nd Street). The milepost is an example of a legacy LRM that is regularly used by transportation officials, law enforcement, and the public along limited access (e.g., interstates) and rural roadways. For real-time data collection for Intelligent Transportation Systems (ITS), packaging location data for messaging and broadcast are necessary. GPS (x/y) and cross-streets are standard LRMs for ITS.

However, the decision-makers who apply the data may not use these LRMs. Much of the analyses currently performed by transportation organizations use tools (e.g., TransCAD) that rely on link/node data structures. Clearly this is not the same as GPS-based location reference methods (x/y coordinate pair).

While there may be LRMs that are very effective for data collection, the workflows require the need to transform such reference methods into reference methods of use to the data consumers.

Data Storage

When updating planning databases, route-based LRMs (e.g., milepoint and milepost) create long-term temporal problems. Routes can change more frequently than the roadway characteristics they represent. It is disturbing when the safest roadway in the state is the one where no crashes occurred only because the route assigned to the roadway was changed but was not changed in the crash database. Therefore, more stable LRMs are required for storage or more advanced referential integrity processes are required for ensuring changes are propagated throughout the enterprise databases.

Data Access and Integration

Data consumers have constantly asked for ways to ease the pain in obtaining access to and applying disparate databases. The basic requirements include the ability to identify what data is available, determine the characteristics of the data (using metadata), extract the data of interest, transform the data into formats necessary for the user application, load the data, and subsequently combine the data for analysis.

As more data-based decision-making is performed, there is an increasing need to aggregate and massage data based on linear locations and linear proximity. For example, there is a growing interest in deriving roadway deficiency sections based on significant changes in continuous data measurements (instead of predefining them). Another growing data access challenge is the need to provide access to disparate data in real-time. These new challenges are driven by incident management real-time decision-making and public dissemination (roadway conditions).

Transportation organizations also require access to data from external sources. This data may come from regulatory, private, or public organizations. The transportation organization may need to interpret and transform the LRM used by these other organizations to an LRM used by the transportation organization.

Data Analysis

The increasing challenge for data analysts and decision-makers is the need to consider so many different parameters and to seek patterns, trends, optimal budgets, or hot spots in the myriad of newly derived data provided to them. Visualization, especially via maps, can significantly improve analysis.

Therefore, these requirements include integrating data, perhaps in an ad hoc fashion, and portraying the results on a map on the screen.

Data Reporting

Data reporting includes outputting locations in LRMs that are the most appropriate for the users. For public dissemination of incidents (e.g., construction or crash delays), the trend is using web technology and the Internet to provide lists or maps, or using sign messaging and telecommunications to describe incident locations relative to where travelers are located. For planning data, this may mean outputting milepost locations of AADT counters even though it was collected using GPS. Data reporting also requires that data be output for not only regional or statewide reports, but also for more local area reports, perhaps a specific pavement study.

Real World Action

A real world action results from a decision being made. An example is installing a stoplight at an intersection because of a decision resulting from an incident analysis project. A key location requirement here is ensuring that the action is applied at the correct location along the transportation facility. For planning functions, this implies that more detailed and more accurate location information will be required to support a more detailed analysis of the specific location.

A LRS FOR A TRANSPORTATION ENTERPRISE

This section of this paper provides a detailed description of a LRS that a large transportation enterprise would most likely require. First, the basic design, structure, and content of an Enterprise LRS is provided. This is followed by how this LRS can meet the general workflow requirements presented above.

Enterprise LRS Design

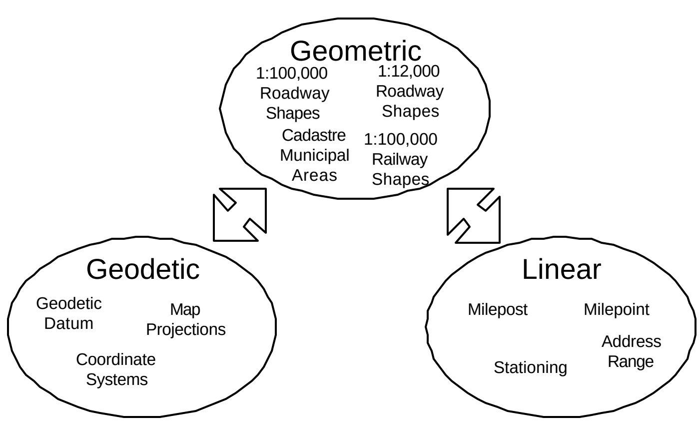
The intent of the above review of location requirements was to provide general insight into fundamental LRS requirements for traffic monitoring and management. The list of requirements is neither complete nor rigorous. A more rigorous account of transportation LRS functional requirements, including temporal requirements, can be found in current research (*3*). Rather, the review illustrates the key requirements for an Enterprise LRS. First, a transportation enterprise has the need for numerous LRMs. Second, a transportation enterprise needs to transform between these LRMs to support business workflows.

The need for multiple LRMs is not profound. Each offers different advantages. For example, some are great for data collection (GPS), while others are necessary to support legacy systems that perform data integration and analysis (links/nodes). Some are more appropriate for discrete objects (mileposts for monitoring device locations) while others are more appropriate for continuous events (logmile for pavement condition measurements). Some LRMs are required to provide rather accurate locations (lanes on an interstate) while others are required to be more general (describe the location of an entire interchange for a statewide analysis).

Past efforts have organized the myriad of potential transportation LRMs into three groups (4): geodetic, geometric, and linear. Figure 1 provides examples of each of these groups. Geodetic LRMs provide a way to describe locations on the earth's surface. Geometric LRMs represent discrete features on the earth. Linear LRMs describe locations along discrete features. Traffic monitoring and management functions require LRMs found in all three groups.

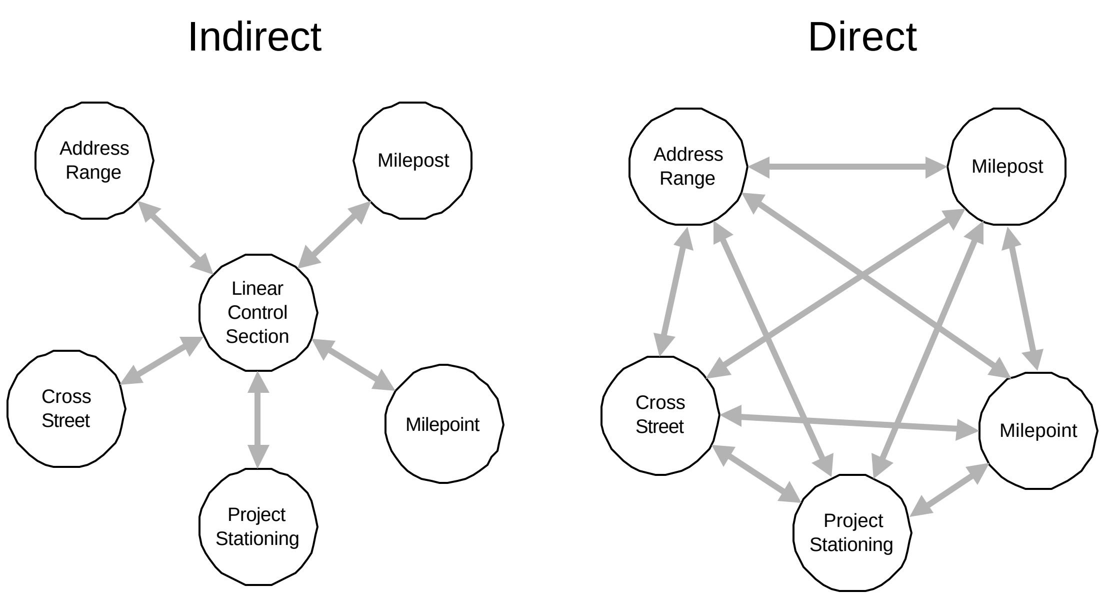
Transformations between the LRM groups are illustrated in Figure 1. Linear locations can be converted into geodetic locations but it must first be assigned a geometric representation. For example, a milepoint location (linear) can be transformed into a latitude, longitude location (geodetic), but this can only be determined by first knowing where the milepoint location exists along some cartographic representation of the roadway (geographic). Another example is to transform an incident located with GPS to a milepoint location. The GPS x,y coordinate must first be converted to the same datum and coordinate system space as a cartographic representation of a roadway. The point must then be snapped to and position along the cartography. Finally, this point is then converted to a milepoint.

Figure 1 – LRM Groups and Their Relationships



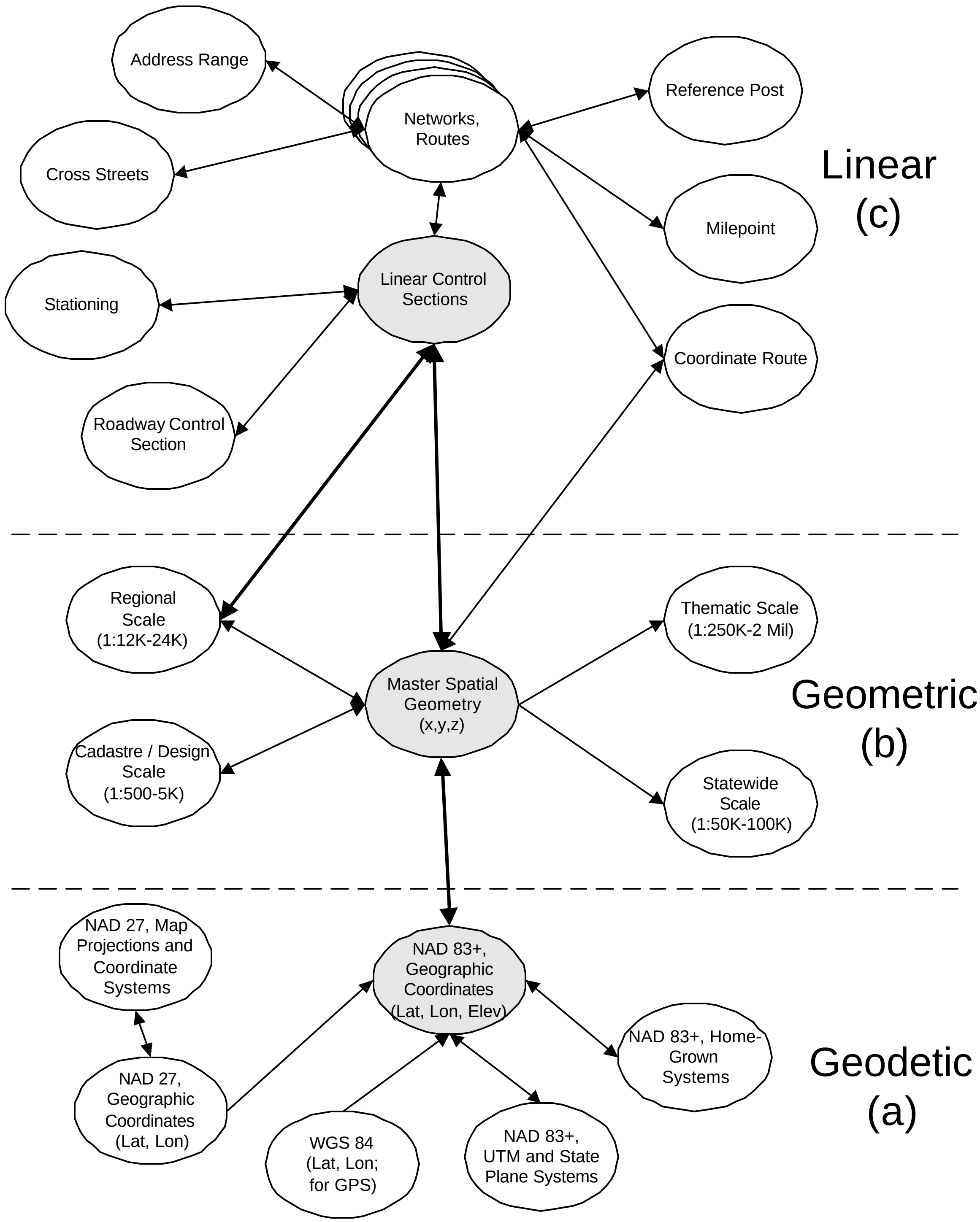
Given a transportation LRS can have many LRMs within each group, choosing the approach to transformation implementation is critical. Figure 2 illustrates two basic approaches to implementing the LRM transformations: indirect and direct. There are several advantages to the indirect approach. First, it requires maintaining significantly fewer transforms than the direct approach. Second, adding a new LRM typically requires adding only two transforms. Third, information system development efforts are focusing on making sure there are reliable data interfaces between systems (called systems interoperability). The indirect approach helps simplify the interoperable interface development effort. The primary advantage of the direct approach is that no neutral location reference form must be managed.

Figure 2 - Transform Approaches



The general trend to implement an Enterprise LRS is to apply the indirect approach with some direct transformations included. A typical transportation Enterprise LRS is illustrated in Figure 3. It includes all three LRM groups. The specifics of each of these groups are described below.

Figure 3 - An Enterprise Location Reference System



Geodetic LRMs

Most existing GIS and GPS software comfortably handle the geodetic LRMs. These software transform between map projections and coordinate systems using the indirect approach, where geographic coordinates are the hub of the transform (latitude, longitude). At the present time organizations are migrating or have migrated from the older, less accurate datum (North American Datum of 1927) to a more accurate datum (1983 or more recent adjustments). This is not a simple mathematical conversion and is typically performed only once to data (hence, the one way arrow in Figure 3a). A primary advantage of the conversion is to be more compatible with GPS technologies.

Geometric LRMs

The general trend is to move from a single-scale, cartographic map base to a multi-purpose spatial database that may contain cartography of varying scales and accuracy. This master spatial database is illustrated as the master spatial geometry in Figure 3b. Organizations are migrating to more detailed spatial databases, storing a roadway representation at the highest level of accuracy and resolution possible. For most state DOTs the goal is to at least represent multi-lane divided roadways as separate cartographic features. Organizations are using feature level metadata to characterize the database's variability in quality and reliability.

Advances in GPS, wireless, and remote sensing technologies (e.g., orthophotography and satellite imagery) are allowing for this change. Organizations are also increasing their data sharing activities, allowing them to get more accurate and detailed information from others, such as centerlines from cadastre database systems (land records), roadway design and as-built plans for roadway design and construction, or even purchasing source data from private vendors.

As our workflow review indicated, there are still requirements to make map products that are consistent in scale and detail, but the maps are at different scales and detail. Displayed around any state DOT are many examples of maps with various business data displayed on them: state highway maps, district maps, county maps, corridor maps, interchange maps, etc. The trend is to derive more generalized representations of the roadways from the master spatial database. This is illustrated in Figure 3b for statewide and thematic scales.

Regarding the geodetic – geometric group relationships, the trend is to store the master spatial database in geographic coordinates and then transform the cartography to other projections and coordinate systems on the fly using GIS-T software.

Linear LRMs

Probably the most debated topic in GIS-T at this time is how to structure the Linear LRMs. Various modeling efforts over the last several years have used information system development practices, data sharing practices, and analogies to the geodetic group to help determine the best approach. The design presented in Figure 3c is based on work done primarily for transportation asset management functions (*5*).

This approach establishes a very simple, temporally stable representation of the roadway (called a linear control section in Figure 3c). This is more commonly known as the *linear datum*, composed of anchor points and anchor sections. The datum acts as the primary indirect hub for all linear LRMs. Basically, all linear LRM locations can be broken down to a position along an anchor section. For example, a culvert has a reference post-offset of 'US12E 123 35' (highway US12E, post 123, offset .35 miles). This location can be transformed to an anchor section, offset location: anchor section #3245, offset 2600 feet (the reference post does not need to be at the beginning of an anchor section).

The network (link/node) and routes that traverse the network also act as an indirect hub for all route-based linear LRMs (see Figure 3c). The datum, network, and routes actually contain fundamental data on which the linear LRMs are built (roadway existence, distance, road connectivity, and routes). Therefore, the datum, network, and routes act not only as a transform hub but significantly reduce the effort to individually maintain the linear LRMs.

The GIS-T software development community still debates on how best to structure the linear LRM group and the interface between the linear LRM group and the geometric LRM group. Past software solutions used the cartography in the geometric LRM group to transform between various linear LRMs instead of the linear datum. In response, various state DOTs developed their own transformation tools to provide pure linear-to-linear transformations independent of cartography. The next generation of commercially available software may provide similar options.

Meeting Location Requirements

The Enterprise LRS design described here attempts to support the various workflow location requirements described earlier in this paper. Below is a description of how the Enterprise LRS supports these requirements.

Data Collection and Storage

The LRS supports data collection workflow by allowing the use of the most effective LRM for the type of data being collected. The LRM attribute for the data can then be transformed to LRMs more appropriate for data maintenance and storage. In the past, transportation organizations maintained large databases where much of their business data was indexed to the same variable length or fixed roadway sections in order to support data analysis. This led to breaking data even though the data values did not change. The transformation capabilities of the Enterprise LRS now allows data that begins and ends at different locations along the roadway to be maintained independent of other data and brought together only when needed in analysis.

The Enterprise LRS can also support data integrity requirements. The issue of a stable location attribute over time can be resolved by using the linear datum to check the integrity of a location attribute value prior to the data being used for analysis, so data (like crashes) will always have a valid LRM location.

Data Access and Integration

More and more organizations are separating operational data, decision-support data, and data presented to the public. Operational data is structured to optimize collection and maintenance). Decision-support data is structured to optimize data access, analysis, and decision-making). Data presented to the public is structured and summarized to optimize simple query and reporting, and is typically placed outside of an organization's security firewall).

However, there is a direct relationship between these databases. Operational data is staged (extracted, transformed, and loaded) into a decision-support environment. Decision-support data is read only (editing is done in the operational environment). Public data is also staged but may come from either the operational or decision-support environments.

Data warehouse solutions (including data marts) are becoming more common to meet the decision-making and public access needs of organizations. The LRS and GIS-T functionality should be a part of the staging, mining, and analysis capabilities of these solutions. Current warehouse solutions still require pre-determined, explicit foreign key relationships between databases. The LRS and GIS-T use existing LRM attributes in the data without trying to force knowing all needed database relationships up front. Using the LRS and GIS-T to transform business data locations and subsequently combine (overlay) disparate databases is increasingly common. For example, analysts can use dynamic segmentation tools to combine AADT sections and crash locations to produce basic crash rates and subsequently show the results on a map. To successfully use GIS-T the LRMs used by business data must be standardized across the enterprise. A purpose of the Enterprise LRS is to formalize the LRMs.

For the growing interest in using more complex location manipulation tools (like linear proximity analysis), the LRS indirect transformation approach will allow algorithms to be developed against a single and more simple location form (i.e., the linear datum) instead of attempting to accommodate multiple forms.

For data sharing, the ability to easily add another LRM improves the likelihood that data sharing with external agencies can occur. For example, a both a state and local government may have their own roadway sections to which their traffic data and most other transportation data is linked, but want to share the data so as not to duplicate collection or data entry. Instead of having either government be forced to use the other's LRM they can agree to mutually maintain a link between at least one LRM in each organization. If either or both use the indirect method, the neutral form would be a favorable choice.

For real-time data integration needs, solutions are becoming more prevalent. For example, there exists a web-based application that accesses historical and real-time data to predict travel time in near real-time (next few hours and next morning commute) (*6*). The LRS enterprise can help improve the reliability of real-time responses by integrating more types of information.

Data Analysis, Reporting, and Real World Action

For data analysis, the Enterprise LRS can support the need to portray data in tabular and map forms. The LRS can support a variety of details if the geometric data is available. It should be stated that while tools already exist to help meet data analysis requirements, the tools are still somewhat cumbersome. What-if scenarios and multivariate mapping are tasks still performed more by GIS-T experts than business decision-makers. Like data analysis, data reporting requirements are supported by the LRS, and while some of these requirements can be met with current tools, they are still somewhat cumbersome.

Finally, in order to support real world actions in response to decisions made, the Enterprise LRS can help drill down to more detailed data found at specific locations along the transportation network via nested linear networks and varying scales of cartography.

BUSINESS STAFF INVOLVEMENT IN THE LRS

The success of the LRS hinges on satisfying location requirements that come from those who perform an organization's primary business workflows. The staff who perform these business workflows need to explicitly document and pursue meeting their location requirements. Requirements include positional accuracy (relative or absolute), whether the data being referenced is continuous or discrete, and the currency needs of the data. If possible, the staff need to make their efficiency needs known as well (e.g., an organization would like to reduce their data collection efforts by 25% in the next year). From these needs the staff can determine the most effective and efficient LRM solution for a particular workflow. This determination may mean improvements to an existing LRM or the need for a new LRM altogether.

The business areas should bring its LRM requirements and recommendations to the organization group that oversees location management. More and more organizations are forming location reference or GIS committees to handle development and maintenance of the Enterprise LRS. This committee may not treat the Enterprise LRS as an explicit, identifiable entity but the objectives of the committee and the LRS are quite the same (data integration and sharing via location). The staff from business areas must be part of this committee. The intent of the Enterprise LRS is to improve the effectiveness and efficiency of business workflows. If no such committee exists, the business area should encourage and participate in the formation and management of one.

Business areas may already be an implicit contributor to the Enterprise LRS. Typically, no single business area in the organization manages all the LRMs of the LRS. If the Enterprise LRS is not an explicit entity in the organization, many LRMs are managed implicitly, and typically by a key user of the LRM. For example, pavement management staff may have a milepost database they use to locate pavement sections. Business areas that manage such LRM information may be duplicating work elsewhere or may be able to share their efforts with other LRM users.

CONCLUSIONS

An Enterprise LRS should improve the efficiency and effectiveness of business workflows. One improvement strategy is to support a myriad of LRMs and the ability to transform between them. Without LRM transformations, islands of data will continue to exist and the intention of GIS-T as a data integration environment is diminished.

Although business areas should pursue improving their internal processes, they should be sensitive to the needs of their customers. The workflows outlined in the paper are part of a bigger process to create the outputs for the organization. The Enterprise LRS should help improve the flow of data through these workflows. However, if there is not a LRS in place, business area staff may not be able to perform their work using the most effective LRM. For example, data collectors should not use GPS technology if their data customers have link/node-based applications and have no way of transforming the data.

Like most enterprise-wide solutions, building the Enterprise LRS will most likely be difficult and take a long time. LRS implementations can take years. However, it can be done. Given the design outlined in this paper, the Enterprise LRS can be implemented incrementally, starting with the indirect hubs in each LRM group and adding LRMs over time.

Traffic monitoring and management professionals can benefit from their involvement in an Enterprise LRS. Traffic monitoring and management has basic LRS requirements similar to other transportation functions (real-time location information may be the exception). Using an Enterprise LRS, traffic-related data can become easily integrated with other transportation enterprise data. As more and more organizations implement data-based decision-making tools (end user GIS-T tools) and public dissemination tools (e.g., web technology), the access to this data will increase and so will its value.

REFERENCES

(1) Baker, W. and Blessing, W. *Highway Linear Reference Methods, Synthesis of Highway Practice 21*. National Cooperative Highway Research Program. National Academy Press. Washington, D.C., 1974.

(2) *A Summary Needs Assessment for the State of Iowa Department of Transportation's Linear Reference System*. Analysis of Trends, p.13. Analysis prepared by David Fletcher. Iowa Department of Transportation. Ames, Iowa. August 12, 1999.

(3) Adams, T., Koncz, N., and Vonderohe, A.P. *Functional Requirements for a Comprehensive Transportation Location Referencing Systems*. NATMEC 2000 Proceeding. Madison, Wisconsin, August 2000.

(4) Ries, Tom. *Design Requirements for Location as a Foundation for Transportation Information Systems*. Geographic Information Systems for Transportation Symposium. Albuquerque, New Mexico. March 1993.

(5) Vonderohe, A.P., Chou, C.L., Sun, F., and Adams, T.M. *A Generic Data Model for Linear Referencing System*s. Research Results Digest 218. National Cooperative Highway Research Program. Transportation Research Board, Washington, D.C., 1997.

(6) TrafficCast, www.trafficcast.com.