A Conceptual Design for the Iowa DOT Linear Referencing System

Date: January 31, 2000

Prepared by

GeoAnalytics™

1716 Fordem Avenue Phone: 608-241-7100
Madison, Wisconsin 53704 Facsimile: 608-241-7116
E-mail: office@geoanalytics.com
URL: http://www.geoanalytics.com

Fairview industries

2836 Jefferson Drive Phone: 608-437-6701
Blue Mounds, WI 53717 Facsimile: 608-437-6702
E-mail: fairview@fairview-industries.com
URL: http://www.fairview-industries.com

GeoDigm – Geographical Paradigm Computing, Inc.
P.O. Box 40483 Phone: 505-833-3309
Albuquerque, NM 87196 Facsimile: 505-833-5582
E-mail: fletcher.d@worldnet.att.net

Bluegrass GIS

108 Canvasback Court Phone: 502-695-9314
Frankfort, KY 40601-8641 Facsimile: 502-695-9316
E-mail: jml250@aol.com
URL: http://www.bluegrassgis.com

Dr. Alan Vonderohe
W10751 Wildwood Way, Route 3
Poynette, WI 53955
E-mail: vonderoh@globaldialog.com

Table of Contents

Table of Figures

Table of Tables

Conceptual Design for the Iowa DOT Linear Referencing System

I. OVERVIEW

The Iowa DOT Linear Referencing System (LRS) Development Project has several phases. The LRS Design phase is decomposed into three tasks – Conceptual, Logical and Physical Design. The Conceptual Design is a high level model of the system that captures the "*should be*" situations. It includes a broad system definition of how the LRS interfaces with the other Iowa DOT systems as well as the scope and expectations of the system. The Logical Design task defines the "*what*", "*when*", "*where*", and "*how often*" situations of the system such as system requirements, performance needs, configuration of the technology, and the relationships between the components. The Physical Design defines the "*how*" of the system by taking the logical requirements and putting them into a real computing environment. This includes database design, technology frameworks, applications, and so on.

The following document presents the Conceptual Design for the Iowa DOT LRS, and is based on work accomplished in workshops and meetings conducted by the Project Team. The Needs Assessment is the source of informational input to the Conceptual Design. The Project Team's design efforts are guided by the primary LRS objectives, the LRS constraints, and the key requirements and benchmarks. The Conceptual Design will then be used to guide Logical and Physical Design decisions and to narrow and guide project-scope decisions.

II. LRS OBJECTIVES

The Project Team identified the following nine primary objectives of the LRS. These are not the objectives of the project, but the objectives of the LRS. That is, these objectives define what the LRS must provide to the Iowa DOT for the LRS to be successful. The Project Team used the findings from Needs Assessment to compile these objectives.

1. Integrate the Iowa DOT Linear Reference Methods (LRMs).

This has been a prime objective from the Project's Request for Proposals (RFP) and the needs assessment process. The interoperability decision was made in part for this one objective (see section IV.A). The list of supported LRMs is given below. Street Addresses (discrete locations) and Street Address Range (block address ranges that interpolate locations) are included in the overall Conceptual Design because there seems to be growing interest at the Iowa DOT in having these reference methods. However, street addressing issues are not within the scope of the project. All but one of the LRMs are route-system based, which means they all require a route designation as part of their definition and operation. The exception is the Base Record Segmental LRM.

- Reference posts (milepost)
- Milepoint
- Base Record Segmental
- Stationing
- Literal Description

- GPS-Route
- Cartesian-Route
- Link-Node
- Street Addresses
- Street Address Ranges

2. Maintain the Linear Datum.

Conceptually, this is a new “system” at the Iowa DOT. How it will be implemented, given the existing data and processes, will be determined throughout the rest of the project. The datum will have both field and system components, and will have standard guidelines on how it will be maintained and applied.

3. Validate LRM Data Integrity.

This means ensuring that the data quality will meet expectations. There are two validations that must occur. The first is business system location integrity, where the event locations from the legacy databases are validated. The second is intra-LRM integrity, where the data that defines the LRMs within the LRS are validated.

4. Manage LRMs.

This objective ensures that the LRMs will be taken care of over time. This objective will be achieved if guidelines, maintenance and use standards are developed, maintained and applied. LRM maintenance occurs in both the field and in the information system. On-going training and support should be provided.

5. Support Multi-Modal Locations.

The LRS must be able to define and integrate between linear locations defined for all transportation modes (roads, rails, water, transit, air, and pedestrian). The LRS must be able to provide a known accuracy of a linear measure within any of these transport modes.

6. Integrate the LRS with Spatial Databases.

The LRS must allow the Iowa DOT to integrate linear-referenced data with spatial data (i.e., map data, most likely from the Iowa DOT GeoData Warehouse). As part of the integration, the LRS must support the ability to define a relationship between linear distance and cartographic length, and must support the ability to determine a two-dimensional (2D) accuracy of a LRM and locations based on that LRM. Therefore, the LRS must support linear to and from planar (2D) location data so users can perform spatial analysis. The Project Team plans to develop an interoperable relationship between the LRS and spatial data.

7. Define and Maintain Temporal Data Integrity.

The LRS must resolve the need to have operationally current data (up-to-date) versus temporally stable data (as of a certain date). The LRS must resolve the issue of data timeliness: urgency (information latency), granularity (sampling frequency), resolution (e.g., hourly, annually), and states (anticipated, current, and historical). The goal is to make both location and time fully integrated as fundamental characteristics of the LRS.

8. Provide Ad hoc and Predefined Data Processing.

This objective means the LRS will allow user access to LRS and business data, will facilitate the use of decision support systems, and will allow reporting (map and tabular). Users should be able to use pre-defined access and reporting tools, or be able to create various scenarios based on what-if conditions.

9. Be a Scalable System.

The LRS must be extendable to all road systems (primary, secondary, etc), all transportation mode systems, and various information systems.

III. LRS CONSTRAINTS

The Project Team identified the following constraints on the LRS design. These constraints directly influence how the system will be defined, developed, and implemented.

1. The LRS should not mandate which of the standard LRMs should be used in the field for data collection.

2. The LRS must preserve existing business system boundaries. This especially refers to processes and organizational boundaries. For example, to move the maintenance of an LRM from one organizational area to another would not be acceptable.

3. The LRS will be developed using the Iowa DOT's technology standard product lines: Windows NT, Oracle, and Intergraph GIS. This holds true at least through the pilot phases.

4. The LRS must use existing Iowa base map data, although perhaps not in their current structure (the Base Record data are undergoing redesign).

5. The LRS must have one linear datum that supports both asset management and Intelligent Transportation Systems (ITS) data, and their processing requirements.

6. The LRS design should minimize placement of field monuments.

The Project Team also concluded that the legacy data and existing methods of operation should provide no constraints on the LRS design. That is, the LRS design can alter these systems. This most likely will happen because of the Iowa DOT's need to accommodate both temporal and location attributes. In fact, there must be an established process to add or modify such attributes to the legacy database systems in order to link them successfully to the LRS.

IV. Conceptual Design Analysis

A. Architectural Strategy

During the Needs Assessment Phase, the Project Team determined that the Iowa DOT should pursue an interoperable LRS design. The Project Team considered two choices: integrated and interoperable. An integrated design has characteristics of a single system, where all processes and data are standardized, data is administered centrally, and responsibility belongs to a single unit. An interoperable design is characterized by sharing between multiple systems, where data flows between them are standardized, and overall responsibility belongs to a steering committee. Given explicit constraints on minimizing organizational impact during LRS implementation (per the Iowa DOT instructions), the Project Team chose the interoperable design approach.

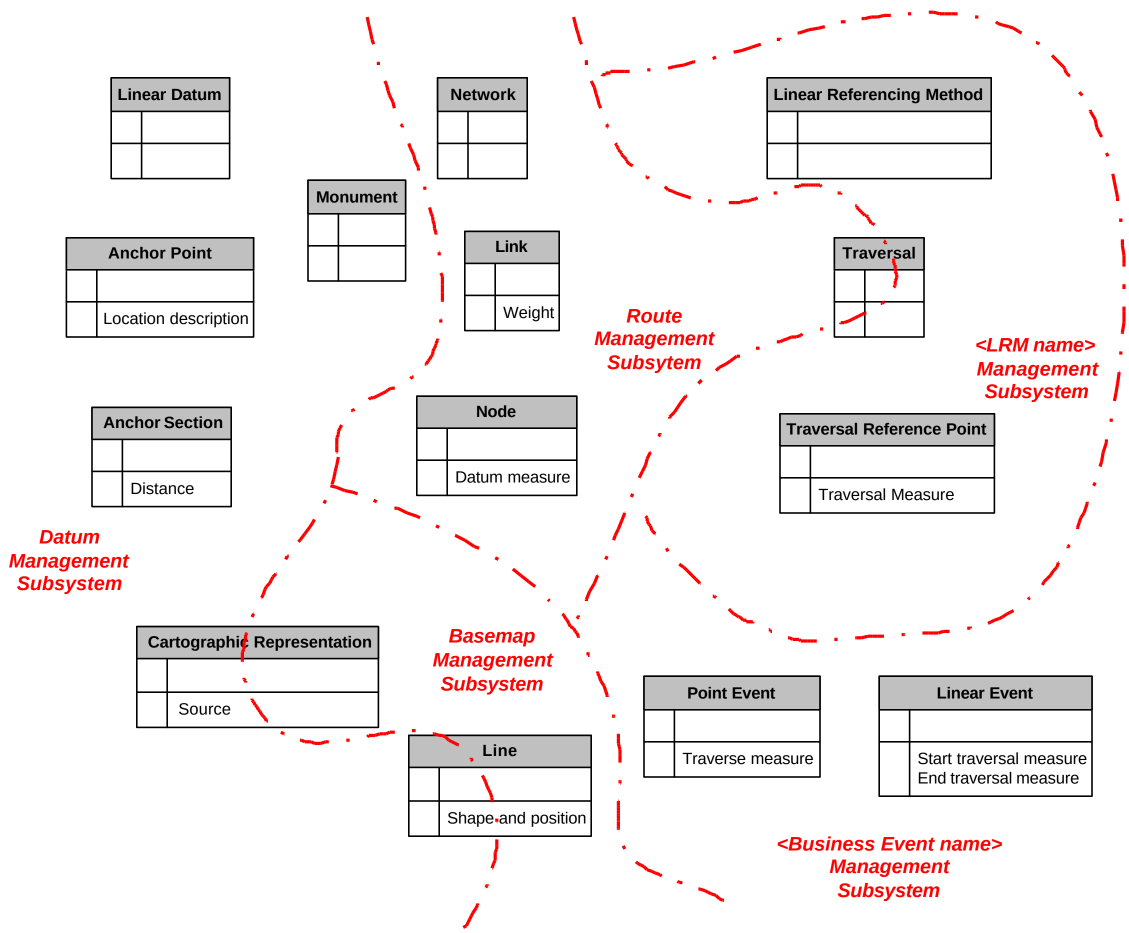
During initial analysis in the Conceptual Design phase, it became apparent from the Needs Assessment that the Iowa DOT had needs for both an operational and decision support architectures. These two architectures are very different. Typically, operational databases are structured to ease data maintenance and promote data integrity, whereas decision support databases are structured to ease data use and promote decision-making. A more detailed discussion of the differences between these two architectures can be found in Appendix A.

The Project Team's analysis of this information and the Needs Assessment findings suggested that the Iowa DOT needs to consider an interoperable architecture for LRS operational needs, and an integrated architecture for LRS decision support needs. What this means is that the LRS needs to accommodate the two types of architectures in its design. The first is for daily operational activities like data maintenance and business operations. This architecture would attempt to maintain existing business activities, and ensures interfacing between them. More specifically, the LRS's component maintenance functions would be interoperable. The second architecture would focus on broader, more tactical and strategic decision-making for asset management. It would create a new decision-support structure for the Iowa DOT, since a formal one is not in place at this time. More specifically to the LRS, the LRS would be used to help integrate data for this decision-making.

B. Operational Architecture Analysis

The Project Team first focused on the operational architecture. This is due to the fact that the Iowa DOT is basing the LRS design on the NCHRP 20-27(2) LRS data model which focuses on an operational architecture. A version of this model is shown in Figure 1. Given the interoperable strategy for the operational architecture, the Project Team determined which entities were tightly coupled and which were loosely coupled. An entity is basically a table of similar information, and databases are typically composed of various tables. "Tightly coupled" means that the entities are more difficult to separate, or that it would be difficult to think of having or using one entity without the other. "Loosely coupled" means just the opposite. The bounding lines in Figure 1 group tightly coupled entities. The bounding line that crosses the cartographic entities means that roadway graphic centerlines do not easily fit within only one of the groups. This implies that while the Iowa DOT will have one master set of roadway centerlines they may take different forms when interfaced with the linear datum.

Figure 1 - A Modified 20-27(2) Model



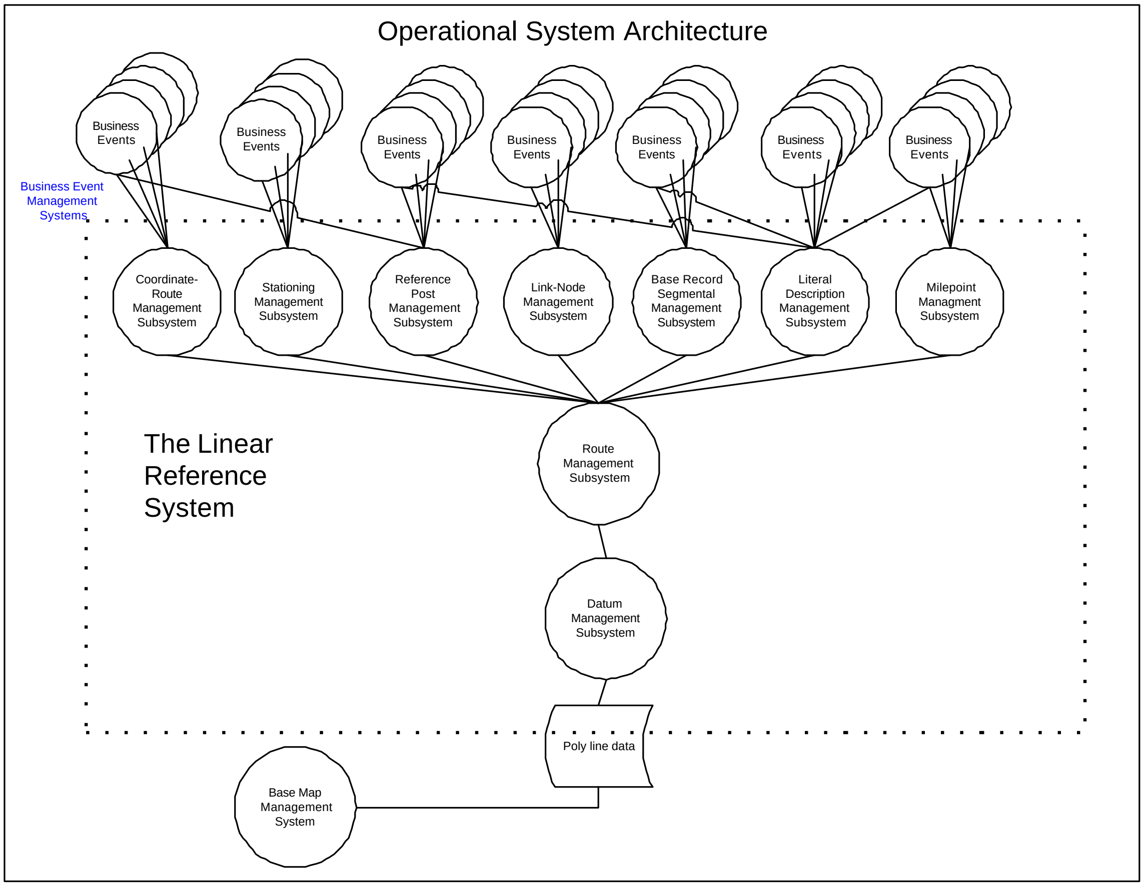
Given these couplings, the Project Team created a diagram of the Operational System Architecture. This diagram is shown in Figure 2. The Project Team made several key decisions. The first decision is the establishment of subsystems for the management of tightly coupled entities. The intent of these subsystems is primarily based on satisfying the System Objective “Manage LRMs”. That is, the subsystem will perform the functions listed under this objective. It is important to note that the Project Team combined the GPS-Route and Cartesian-Coordinate Route LRMs into one subsystem called Coordinate Route because of their similarities in data content and process.

The second key decision is the scope of the LRS. This scope is illustrated as a bounding box on Figure 2. Overall LRS policies, standards, and improvements over time will directly influence the subsystems within the LRS. Business event data are not within the scope of the LRS. The Base Map Management Subsystem data are not within the scope of the LRS. However, the cartographic data of roadways (called “polyline”) will be shared or transformed between the Base Map and Datum Management Subsystems.

The final decisions are based on the need to maintain interoperability between subsystems. There is a need to maintain relative independence among the subsystems. The subsystems should be able to operate themselves, with the only “dependency” requirement being the interface between them. The responsibility of the interface will belong to the more complex subsystem of an interface relationship. Figure 2 illustrates this responsibility. For example, an interface exists between the Datum and Route Subsystems. Although a key element of the overall LRS design, the Datum Subsystem, is, by definition, the simplest subsystem, the Datum Subsystem will not be responsible for maintaining any interfaces. However, the Datum Subsystem is responsible for defining how other subsystems will interface with it. For example, the Route Subsystem will be responsible for maintaining the interface with the Datum Subsystem using the Datum Subsystem interface standards. In another example, the Route Subsystem must define its own interface standards, but it is up to the different LRMs to maintain the interface to the Route Subsystem. This also holds true for the business events management subsystems and their relation to a LRM.

However, this concept does not mean the less complex subsystems do not have responsibilities to the more complex subsystems. The interface standards, data content, and other aspects of the less complex subsystems will evolve over time based on feedback from the more complex subsystems.

Figure 2 LRS Operational Architecture

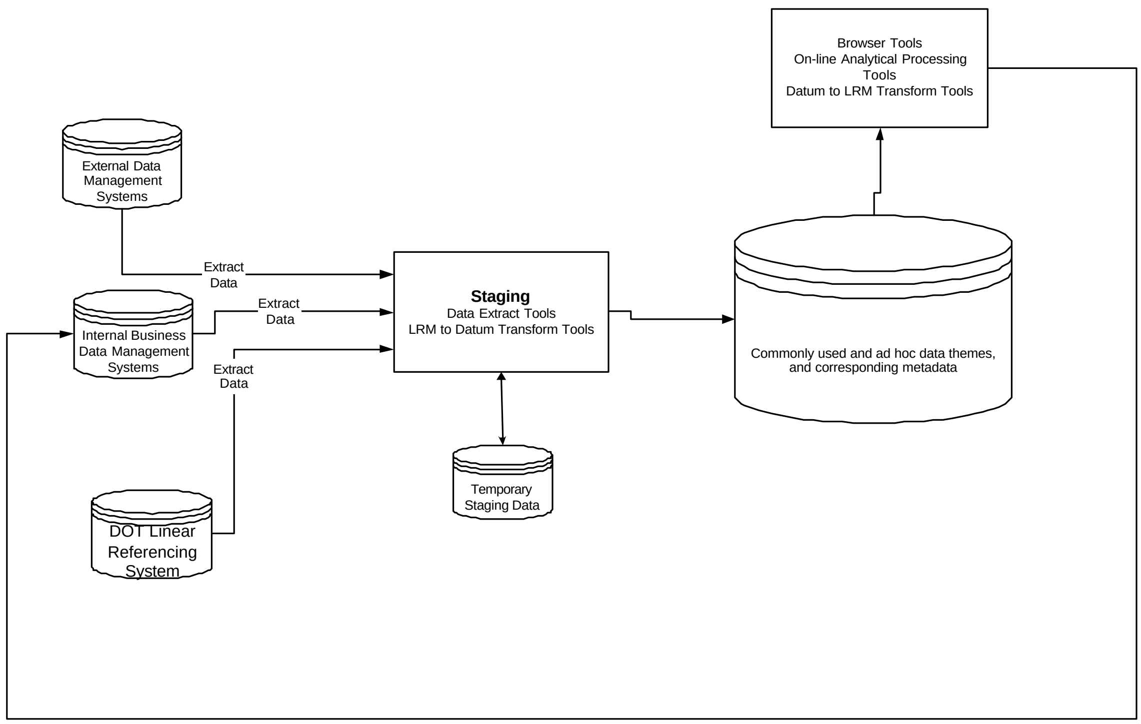


C. Decision Support Architectural Analysis

Early in the Conceptual Design process it became evident that the Iowa DOT had begun to implement one of two strategies for decision support systems. The Iowa DOT GeoData Warehouse (GDW) is a very flexible decision support system. It represents the one strategy that creates data views for whoever needs them. It is a bottom-up approach. This approach is very attractive when it is desired to make better use of departmental data or GIS-based analysis in the decision-making process. This is the case at the Iowa DOT. This approach allows the Iowa DOT to explore and become comfortable with decision support environments. It allows for temporally and spatially independent data views to be created for ad hoc data view creation and analysis, and for the use of all spatially referenced data.

Figure 3 illustrates the GeoData Warehouse Architecture. Its primary purpose is to satisfy the LRS objectives “Integrate the Iowa DOT Linear Reference Methods”, “Validate LRM Data Integrity”, and “Provide Ad hoc and Predefined Data Processing”. The data that reside in the subsystems of the Operational Architecture are on the left side of this diagram. The “Staging” process extracts data from these systems and puts the data into easy-to-use, integrated forms. All data with linear locations are converted to datum locations. Data stability over time and data integration is maintained through the linear datum. Data users (in the upper right) can query the data and develop different scenarios for their own purposes. New data that are created can then be stored as new business data (i.e., the loop back to internal business data management systems).

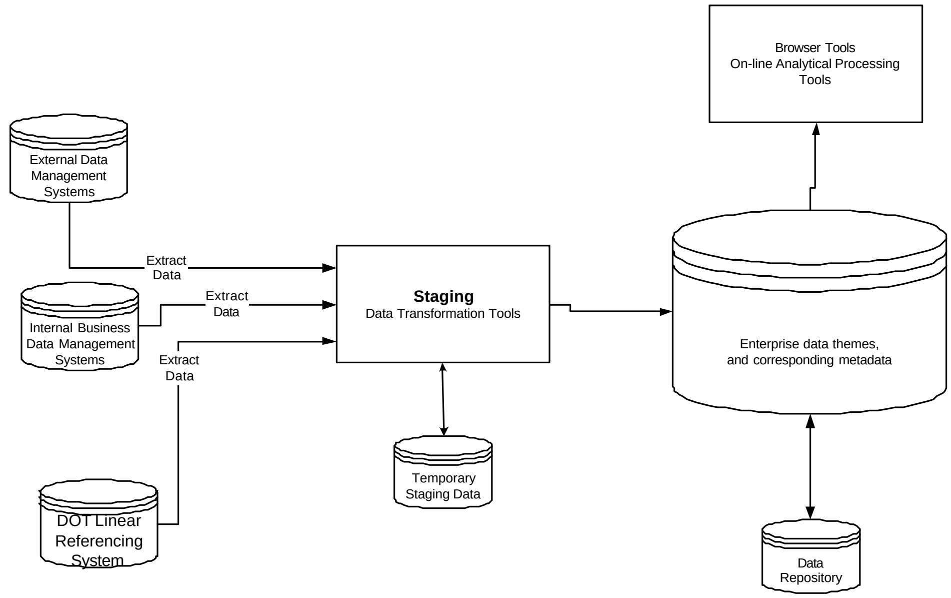
Figure 3 The Iowa DOT's GeoData Warehouse Architecture



Access to data via the GDW will be one-way only and through browser tools that are compatible with the existing technology. The data presented in the browser tools will be read-only and any data updates will be accomplished through the operational systems and posted back to the GDW through the staging process.

The other decision support strategy is an enterprise-wide, top-down data warehouse. If done correctly, it can be a very powerful environment for decision-making. It is typically a large, long-term, and expensive effort. Iowa’s state government is exploring such a strategy. Typically, the data in a data warehouse are temporally and spatially consistent, only the official data are used, and most data in the warehouse are contained within pre-defined data themes. Figure 4 illustrates the Enterprise Data Warehouse Architecture. Although the diagrams illustrating these two strategies do not look that different, the two strategies are very different and produce different results.

Figure 4 Enterprise Data Warehouse Architecture



The Project Team concluded that the Iowa DOT will need both of these decision support solutions. The GeoData Warehouse is a required interim solution, while the longer-term solution is the Enterprise Data Warehouse. What is learned from the implementation of the former will significantly benefit the design of the latter. Significant benefits of this approach are learning the need to include, and understanding the benefits of, spatially based data integration and decision-making. Spatial data and spatial data processing are not prevalent in current data warehouse implementations across the industry due to the only recently developed spatial database tools.

The Project Team believes that detailing the Operational Architecture and certain components of the GeoData Warehouse are within the scope of this project. The Enterprise Data Warehouse is not within the scope of this project.

D. System Component Analysis

The Project Team began a component analysis of the LRS Conceptual Design. This means the Project Team began to explore how various processes, data, technology, and organizational units map onto the design.

1. Process

Currently, LRS component data collection and maintenance processes are within the corresponding LRS subsystems of the Operational Architecture. The collection and maintenance processes for business event data (pavement, average daily traffic, etc) are outside the scope of the LRS. Applications that need to integrate and analyze data (Pavement Management Information System (PMIS), Safety Analysis, Snowplow Routing) will use the GeoData Warehouse Architecture staging, browser, and analytical tools and processes. The Iowa DOT will also need to ensure data access services are provided for Warehouse users who are inexperienced or would rather "contract" data access activities. GeoData Warehouse management processes may also fall into this category. In this project, only selected business data and LRS-specific components of the staging, browser, and analytical tools and processes will be further designed.

2. Data

LRS data are maintained in the Operational Architecture and are part of the corresponding subsystem. Business data will reside in their own legacy data management systems. Managers of these systems will be responsible for interfacing with the LRS through the LRM Subsystem interface standards. Data that is packaged for use will reside in the GeoData Warehouse Architecture. Managers of the legacy applications that use these data will be responsible for staging data from the legacy data systems into pre-defined forms in the GeoData Warehouse. Individual data users performing ad hoc analysis will be responsible for their own data. Data created from an application analysis in the decision support environment may be transferred to a data management system in the Operational Architecture.

3. Technology and Organization

Specific organizational and technological considerations for each of the LRS subsystems of the operational architecture are summarized in Table 1. As described in the Needs Assessment Document, LRS Components (now called **LRS Subsystems**) will need managers. The Project Team attempted to identify the various Iowa DOT business areas that should be involved in design of each subsystem. These areas are shown in Table 1. Whenever possible, the Project Team identified a business area that would be the most likely candidate to become the LRS Subsystem Manager (these are identified as ***bold italics*** in the table). Those without an identified manager will be determined as the project progresses. There will most likely be a governing body over the LRS. This body will most likely be made up of the LRS Subsystem Managers and will be chaired by a LRS Manager. The table also lists key technological considerations for each of the LRS Subsystems.

It is anticipated that the LRS Manager would be responsible for the overall operational system working with the LRM Subsystem Managers as well as with the GeoData Warehouse Manager(s). Each Subsystem Manager should be responsible for their business area's data, procedures, and standards for incorporation into the LRS.

Table 1 LRS Subsystem Organizational and Technological Considerations

LRS Subsystem	Organization (*Likely Subsystem Manager*)	Technology (***Likely to be used)***
Base Map Management	***Transportation Data***	Oracle, MicroStation
Datum Management	GIS Staff Photogrammetry Transportation Data Pavement Management Team	Oracle, MGE Suite
Route Management	Transportation Data (currently primary system only)	Oracle, MGE Suite
Reference Post Management	***Pavement Management*** Transportation Centers (Field Maintenance) Transportation Data	VideoLog, MPTS technologies, SAS
Milepoint Management	***Transportation Data***	Oracle, MicroStation
Base Record Segmental Management	***Transportation Data***	Oracle, MicroStation
Coordinate-Route Management	***GIS Staff*** VideoLog Safety Pavement Management GPS / AVL Maintenance Project (snowplowing, paint striping, vegetation) CTRE (crash location tool)	MGE Suite, AVL technologies, National ITS standards
Literal Description Management	Safety Transportation Data Pavement Management Team	ITS X-Streets standards
Stationing Management	***Photogrammetry*** Design Construction Maintenance	CADD
Link / Node Management	***Safety*** Transportation Data	Oracle, SAS, MicroStation

Table 2 GeoData Warehouse Organizational and Technological Considerations

GDW Processes	Organization (***Likely Function Manager***)	Technology (***Likely to be used)***
Overall GDW Management *(performance monitoring, data administration, hardware and software infrastructure management, etc).*	***GIS Team*** Data Services	Not defined.
Staging Tools Management *(used to transform data from operational to decision-support environment, including between the datum and the LRMs)*	Transportation Data ***GIS Team (LRS Tools)*** Data Services	Visual Basic, SQL, and others not yet defined.
User Tools Management *(general browse/query/report tools and analytical tools used to apply data to specific business functions: subsetting, overlay, proximity analysis, etc.)*	***GIS Team*** Data Services	Access, GeoMedia Pro, Visual Basic
LRS Data Staging *(publishing the data: the act of migrating specific LRS data from the operational to decision-support environment)*	Custodian (see LRS Subsystem Table) Customer will not perform this. ***Staging Services (GIS Team)***	Oracle, Visual Basic, SMMS
Business Data Staging *(publishing the data: the act of migrating specific business data from the operational/legacy systems to decision-support environment)*	Custodian Customer ***Staging Services (GIS Team)***	Oracle, Visual Basic, SMMS
GIS Data Staging *(publishing the data: the act of migrating specific GIS data from the operational/legacy systems to decision-support environment)*	Custodian will not perform this. Customer ***Staging Services (GIS Team)***	Access, GeoMedia Pro, SMMS
External GDW Data Sharing *(addressing the technical, organizational, and policy isssue surrounding data sharing; and the act of performing data sharing).*	***GIS Team***	GeoMedia Pro, SMMS

V. CONCEPTUAL DESIGN SUMMARY

The Project Team analyzed and concluded that the Conceptual Design accommodates the LRS objectives and constraints outlined in earlier sections. This design includes three related architectures: the Operational Architecture, the GeoData Warehouse Architecture, and the Enterprise Data Warehouse Architecture.

The Operational Architecture is composed of inter-operable subsystems which will have individual managers but work together to manage the overall effectiveness and efficiencies of the entire LRS. The GeoData Warehouse Architecture allows ad hoc or pre-defined data extracts from the Operational subsystems for data integration, analysis and decision-making. The Enterprise Data Warehouse is a long term, top-down design that includes the LRS. This architecture is outside the scope of this project.

This completed Conceptual Design primarily addresses the data and process design issues, since conceptually, the technology is already determined. Organizational roles will continue to evolve over the life of the project.

VI. APPENDICES

Appendix A – Operational and Decision Support Architectures

NOTE: This appendix contains several acronyms and terms from the Information Technology Industry. These acronyms and terms are described in the Glossary appendix of this document.

I. The project objective is to integrate heterogeneous data from multiple sources, using multiple location reference methods with efficiency and confidence for DOT operational and/or decision-making purposes. There are many ways to accomplish this.

II. It is important to determine the focus of the architecture. There seem to be three choices: 1) focus on enterprise architecture for operational systems; 2) enterprise architecture for data warehouses; and 3) both, including a migration strategy to move between the two worlds.

Operational vs. Decision Support Architecture Focus

Aspect	**Operational**	**Decision Support**
Data Operations	CRUD	Read-only
Data model	ERD	Star
Defined by	Process and data needs	Decision needs
Target environment	Operational data stores	Data warehouses, marts
Goal	Normalized for optimal OLTP	De-normalized for optimal OLAP
Patterns	Range of patterns	Fully integrated data

III. Architectural pattern choices for operational systems.

Independent	**Interfaced**	**Interoperable**	**Integrated**
No shared processes, data	No shared processes Data exchange only	Some sharing of common processes and data	Interdependent processes, all data are standardized
No coordination required	Data exchange standards necessary	Data flows and interfaces standardized	All processes and data stores standardized
No metadata necessary	Local metadata only	Local and global metadata	Global metadata only
N/A	Adopted exchange standards	Negotiated process interfaces	Central data administration
N/A	Standards group responsibility	Steering committee responsibility	Single unit responsibility
e.g., stovepipe applications	SDTS, NSDI	OGIS, ITS	ERP systems

Independent	Interfaced	Interoperable	Integrated
Unknown no. of systems	Many systems	Few system pairs	One system

IV. Although decision support architectures are, by definition, integrated, there are two common approaches:
1. Build a single enterprise data warehouse and then extract multiple data marts, as necessary, or
2. Build small data marts first and then aggregate into a data warehouse.

Most industry experts recommend the first approach when practical and feasible.

V. Our task is to reconcile institutional, technological, process and data architectures in the concept stage. For example, if a fully integrated architecture is chosen, then a single unit with functional responsibility may be appropriate. If an interoperable architecture is chosen, then a representative steering group approach may be more appropriate. The key question is what architectural strategy is more viable in the Iowa DOT. Viable criteria that should be considered include technical infrastructures, financial aspects, institutional cooperation, and ease of migration considerations.

VI. The overriding considerations in DOTs today are making, justifying, tracking and communicating resource (e.g., budgets, people, facilities) allocation decisions consistent with policy-derived performance measures. Resources, time and location are the key dimensions of these general user needs. That is, most decisions involve committing or tracking some resource, at some location, in some period of time. Additionally, DOTs have several primary levels of these decisions: system or statewide level, program level, or project level. The location architecture needs to support these overarching needs at a minimum.

The most atomic level data elements will likely belong to several different location hierarchies. Have these geographies been identified and addressed?
1. First, civil geography: address to minor civil division to county to district to state to region.
2. Second, network geography: site to link to section to traversal to network.
3. Third, physical geography: geocentric (X, Y, Z) to latitude/longitude to projected coordinates (e.g., state plane).

VII. Other exogenous factors which may influence the architecture:
1. Public administration trends: The trend in government is to privatize or outsource many technical and professional activities. How will this influence the architecture? This scenario speaks to an interoperable architecture with encapsulated systems and standard data flow protocols.
2. Technology trends: The clear trend is toward thin client based computing (i.e., the Internet and Intranets) from both fixed and mobile locations. What are the implications of this? There are several location standards evolving in the marketplace – GDF, OGIS, and digital earth. How will the architecture handle these?
3. DOT missions trends: DOTs are evolving away from engineering and highway management organizations serving the AEC industry to full transportation service

providers serving a bewildering variety of constituents, many of whom have location based needs. Have their needs been taken into account? Does the location architecture reflect these needs? Under this scenario, DOTs will look like transportation centric ISPs. This indicates the desirability of a data warehouse approach.

Engineering	**Transport Operations**	**Retail**	**Inter-Governmental**	**Administrative**
Planning, design, construction, maintenance	Examples: traffic operations, CVO	Vehicle and driver's licensing, over-legal permits	Local road aids, transit aids, courts	Human resources, financial, legal
Customers: AEC industry	Travelers, carriers	Constituents	Other governmental agencies	Other DOT units
Network and project locations	System locations	Customer and service outlet locations		

Appendix B – Glossary

AEC - Architecture Engineering Construction; see www.aecinfo.com for more information on this industry of software that includes CADD.

Anchor Point - A zero-dimensional location that can be uniquely identified in the real world in such a way that its position can be determined and recovered in the field. Each anchor point has a "location description" attribute that provides the information necessary for determining and recovering the anchor point's position in the field. Forms of location descriptions can vary and be quantitative or descriptive or both.

Anchor Section - A continuous, directed, non-branching linear feature, connecting two anchor points, whose real-world length (in distance metrics), can be determined in the field. Anchor sections are directed by specifying a "from" anchor point and a "to" anchor point. Anchor sections have a "distance" attribute that is the length of the anchor section measured on the ground. Values are expressed in units of linear distance measure (e.g., kilometers).

Cartographic Representation - A set of lines that can be mapped to a linear datum. The set of lines can be either fully or partially connected. That is, the set can consist of groups that are externally unconnected but internally connected. Cartographic representations have a "source" attribute that denotes the source (scale and lineage) of the object. Scale values are expressed as ratios or as equations that relate distances measured on the source form of the cartographic representation to distances measured on the ground. Cartographic representations provide coordinate references; the basis for to-scale visualization of other components of the linear referencing system model; and linkages to extended topological, vector-based GIS data models.

Chain – A directed non-branching sequence of nonintersecting line segments and (or) arcs bounded by nodes, not necessarily distinct, at each end. Three types of chains are defined: complete chain (complete topology), area chain (left/right polygon topology), and network chain (start and end node topology). (SDTS definition (USGS, 1992))

Component - A part or element of a system.

Conduct - To provide the direction for or manage an activity.

CRUD - Create, read, update, and delete; these are the basic actions one can apply to a data entity or attribute; and is typically used in system requirements gathering models.

CVO - Commercial Vehicle Operations

Entity - Basically, a table of similar, grouped information

ERD - Entity Relationship Diagram

ERP - Enterprise Resource Planning

Goal - A specific, measurable performance target (state) of an objective.

ISP - Internet Service Provider.

ITS - Intelligent Transportation Systems

Interoperability - The ability for a system or components of a system to provide information portability and inter-application, cooperative process control. Interoperability, in the context of the Open GIS (OGIS) Specification, are software components operating reciprocally (working with each other) to overcome tedious batch conversion tasks, import/export obstacles, and distributed resource access barriers imposed by heterogeneous processing environments and heterogeneous data.

Legacy system – An existing application or business system that involves activities necessary to administer transportation programs and to develop and maintain transportation components. These activities are outside the scope of this analysis.

Line - "A generic term for a one-dimensional object" (SDTS definition (USGS, 1992)). The Spatial Data Transfer Standard (SDTS) goes on to define five specific kinds of lines: 1) line segment, 2) string, 3) arc, 4) link, 5) chain. A line, as defined herein, can be any of these except a link. This is because lines, as defined herein, have a "shape and position" attribute.

Linear Datum - The collection of objects which serve as the basis for locating the linear referencing system in the real world. The datum relates the database representation to the real world and provides the domain for transformations among cartographic representations. The datum consists of a connected set of anchor sections that have anchor points at their junctions and termini. No attributes are assigned to the datum.

Linear Event - A one-dimensional phenomenon that occurs along a traversal and is described in terms of its attributes in the extended database. Each linear event has "start traversal measure" and "end traversal measure" attributes that locate the linear event along the traversal. The traversal measures are offsets measured from the traversal reference points that they individually reference. Linear event traversal measures are in the same units as the traversal measures of the traversal reference points that they reference. Rules for direction of measurement are identical to those of point event traversal measures.

Link - A topological connection between two ordered nodes. **Note:** This is a modification of the definition provided by SDTS. Modification is necessary to require directionality. Each link has a "weight" attribute that is a linear measure of impedance associated with travel along the link. Weights are often expressed in distance measure, but they could be in other linear metrics such as travel time or cost.

Network - Within the context of the linear referencing system data model, a network is an aggregate of nodes and links and is, thus, a purely topological object. The network component of the model provides the basis for analytical operations such as path finding and flow. A network is without two-dimensional objects or chains. If projected onto a two-dimensional surface, a network can have either more than one node at a point and (or) intersecting links without corresponding nodes. **Note:** This is a modification of the definition provided by SDTS. Modification is necessary to exclude chains.

Node - A zero-dimensional object that is a topological junction of two or more links, or an end point of a link. **Note:** This is a modification of the definition provided by SDTS. Modification is necessary to remove reference to chains. In this data model, nodes do not have coordinates. They are located geometrically by reference to the datum. Each node has a "datum measure" attribute that is used to locate it on an anchor section. "Datum measure" is an offset measured from the "from" anchor point of the anchor section. "Datum measure" is expressed as a distance measure in the same units as the "distance" attribute of the associated anchor section.

NSDI - National Spatial Data Infrastructure; see website at http://www.nsdi.usgs.gov

Objective - A statement of direction and extent for the availability, quality or performance of a system.

OGIS - Open Geographic Information System; see consortium details at www.opengis.org

OLAP - On-line analytical processing. A term from the Information Technology community, specifically the Data Warehouse community. Basically, it means analyzing and making decisions from data while using and interacting with computer applications.

OLTP - On-line transactional processing. A term from the Information Technology community, specifically the Data Warehouse community. Basically, it means making updates to data while using and interacting with computer applications, instead of in batch mode.

Performance - The functional effectiveness of a system component.

Point Event - A zero-dimensional phenomenon, that occurs along a traversal and is described in terms of its attributes in the extended database. Each point event has a "traversal measure" attribute. "Traversal measure" is an offset measured from the referenced traversal reference point to the point event. Point event traversal measures are in the same units as the traversal measures of the traversal reference points that they reference. A positive point event traversal measure expresses measurement in the direction of the traversal. A negative point event traversal measure expresses measurement against the direction of traversal.

Policy - A declaration of transportation related public value, formal public mandates, mobility constraints or vision.

SAS – The SAS System is an integrated suite of software for enterprise-wide information delivery. Available from the SAS Institute, Inc (see www.sas.com).

Scalability – The LRS must be designed to meet requirements that are beyond the business functions scoped for this project. For example, Iowa DOT should be able to apply the design to railways, pedestrian ways, waterways, etc – only roadways are within the scope of the project. Another example would include cartography. Iowa DOT should be able to integrate the DOT's linear-referenced data with cartography at different map scales and levels of detail, and with cartography from sources external to DOT (local governments).

SDTS - Spatial Data Transfer Standard. See homepage at www.mcmcweb.er.usgs.gov/sdts/

SMMS – Spatial Metadata Management System. A software program from Enabling Technologies that allows metadata to be put out into HTML format so it can be accessed via the web.

SQL – Standard Query Language. The syntax and format typically used to interact with tabular data bases.

Star - The star model is the basic structure for a multi-dimensional data model for decision support. It typically has one large central table (called the fact table) and a set of smaller tables (called the dimension tables) arranged in a radial pattern around the fact table. An example is provided for sales information. Sales is the fact table in the center. Arranged around the fact table are the dimension tables of time, customer, seller, manufacturing location, and product (*Data Modeling Techniques for Data Warehousing*, Ballard et. al., February 1998; www.redbooks.ibm.com).

State - A physical or operational condition of being.

Traversal - An ordered and directed, but necessarily connected, set of whole links. Coding conventions are required for establishing traversal directionality (in contrast to link directionality) and for specifying non-connected traversals. No attributes are assigned to traversals.

Traversal Reference Point - A zero-dimensional location along a traversal that is used to reference events along the traversal. Each traversal reference point has a "traversal measure" attribute that is used to locate it along the traversal. "Traversal measure" is an offset measured from the initial node in the traversal to the traversal reference point. It is in the same units as the "weight" attribute of the links in the traversal.