Location Referencing System Team Report

January 15, 1998

Iowa Department of Transportation

Location Referencing System Team Report

Final Report
January 15, 1998

By

Location Referencing System Team

Table of Contents

Executive Summary

Combining information from different data sources within a department of transportation has been an information processing concern. With the mandates contained within the Intermodal Surface Transportation Efficiency Act (ISTEA), the integration of this data is increasingly important. ISTEA did not suggest how this integration is to take place. Since the vast majority of the data collected by the Iowa Department of Transportation (DOT) is referenced to the Earth in some manner, the use of spatial location and Geographic Information System (GIS) products is the logical choice to accomplish this integration.

The Iowa DOT's Geographic Information Systems Coordinating Committee (GISCC) recognized the integration potential of the spatial information. In October 1996 a Location Referencing Issues Workshop was held, at the request of the Office of Transportation Data, to increase the knowledge of DOT personnel. The results of the workshop led to the formation of a Location Referencing System (LRS) Team. The team was charged with defining a system that coordinates the collection, storage, and access to location referencing information by developing an LRS to be used throughout the DOT. This report is a culmination of the work done and defines the recommendations as determined by the LRS team. These recommendations will be presented to the Information Processing Steering Committee for approval to move forward with implementation.

The LRS team is recommending the establishment of a Linear Datum within the DOT. This datum will allow the department to correlate data between referencing methods and will allow easier integration of the DOT's data with other disparate data in GIS packages.

It is recommended the Linear Datum be evaluated in a pilot project. Inclusion of other political entities such as counties and cities should be considered.

Additionally, it is recommended that the team remain operational in an advisory/overseeing role as the recommendations are implemented. In order to ensure implementation of the recommendations, adequate resources must be committed. The team

will meet quarterly to receive an update on the progress being made by the GIS Coordinator for the DOT, since the GIS development will be dependent on the LRS implementation.

The team also recognizes the DOT must have one referencing system; this system must incorporate all existing referencing methods and be stable over time. This single referencing system should also facilitate referencing needs within the DOT's management, business and information systems.

These recommendations should be considered within the context of the agency's GIS plan. In addition to the recommendations from the LRS team, issues such as dynamic segmentation and a new base map need to be addressed.

It will also be necessary to integrate this implementation across all functional boundaries within the department. The implementation of LRS in conjunction with GIS will enhance the DOT's ability to use its information in an efficient manner.

VOLUME I

Introduction

Integrating data from different divisions within a department of transportation has always been an information processing concern. This integration between divisions was necessary to effectively implement mandates in the Intermodal Surface Transportation Efficiency Act (ISTEA). Although it was known for some time that the integration was needed, the ISTEA mandates did not suggest any methods to accomplish the integration. In the past few years it has been proven that spatial location is often the best integration medium for this disparate data. A vast majority of the data collected by the Iowa Department of Transportation (DOT) is referenced to the Earth in some manner. This reference to the Earth's surface may be as simple as northing and easting coordinates from a survey, latitude and longitude from a Global Positioning System (GPS) receiver, or a road name and an associated milepoint distance.

The Iowa DOT's Geographic Information Systems Coordinating Committee (GISCC) recognized the integration potential of the spatial information. In October 1996 a Location Referencing Issues Workshop was held, at the request of the Office of Transportation Data, to increase the knowledge of DOT personnel. The results of the workshop led to the formation of a Location Referencing System (LRS) Team. The team was charged with defining a system that coordinates the collection, storage, and access to location referencing information by developing an LRS to be used throughout the DOT. This report is a culmination of the work done and defines the recommendations as determined by the LRS team. These recommendations will be presented to the Information Processing Steering Committee for approval to move forward with implementation.

Location Referencing System Team

The team was formed in November 1996 and consists of representatives from the following:

Name	Organization/Office/Division
Ralph Crawford	System Planning/Planning & Programming
Zachary Hans	Center for Transportation Research and Education
Annette Jeffers (Team Leader)	Bridges and Structures/Project Development
Kevin Jones	Materials/Project Development
Steven Kadolph (Team Leader)	Planning Services/Planning & Programming
Peggi Knight	Transportation Data/Planning & Programming
David Oesper	Data Services/Operations & Finance

(Continued)

Name	Organization/Office/Division
Jaime Reyes	Traffic Safety/Engineering
Richard Rothert	Drivers Services/Motor Vehicle
Francis Todey	Maintenance Operations/Maintenance
Alice Welch	Design/Project Development

In addition to the members of the team the following served as alternates or in an ex-officio status:

Tom Muhlenbruch	for Dave Oesper
John Nervig	for Jaime Reyes
Scott Neubauer	for Annette Jeffers
Jason Omundson	for Kevin Jones
Pat Cain	for Peggi Knight
Bill Schuman	(Geographic Information Systems [GIS] Coordinator)
Sonjia Amensen	(Planning and Programming Division Support Team)
Steve Vannoy	(Application Technology Support)
Jean Sargent	(facilitator)
Karen Carroll	(facilitator)

Mission and Work Plan

The team adopted the following mission statement:

> Develop a Location Referencing System for the Department.

Guiding Philosophy:

> To ensure GIS compatibility, seek effective data processes, and develop enterprise communication as the team works to improve the LRS in the department.

The work plan (see appendix A), in an abbreviated form, is as follows:

1. Research state of the practice of location referencing.
2. Inventory current Location Referencing Methods (LRM) used within the DOT.
3. Investigate specific location referencing needs of each division.
4. Develop a Location Referencing System and methods.

The committee dealt with the first three tasks from the work plan by forming subgroups to pursue these items simultaneously. Gathering and reviewing this background information provided the foundation necessary to begin LRS discussions.

Scope of Document

Volume I contains the executive summary, an overview of the processes used, conclusions and recommendations. Volume II contains 3 chapters related to items 1, 2, and 3 in the work plan listed above.

The introduction explains how the team was formed and what its objectives were. Information on why Location Referencing is important and the definition of key terms is covered in the background. Additional topics covered in the background included education and training, literature research, inventory of current methods, and development of the teams recommendations.

Background

The effective use of GIS and management systems demands that data is available for manipulation within a system that allows for cross referencing data from various sources with different formats. Departments of transportation collect, store, maintain and access a great deal of information about features and attributes along transportation facilities. Methods are used for referencing location data to linear features (i.e. route, railroad, river, etc.). Recently, with the development of GPS, collecting data with a spatial reference is becoming more widespread. Over time, different referencing methods evolved for various applications throughout the Iowa DOT. Integrating data from the various methods is crucial for analyzing data from disparate sources. In many cases this is difficult to do because each method evolved independently rather than as a system. Development of a common referencing system that integrates linear and spatial data is essential in facilitating the efficient exchange of information among the Iowa DOT business systems.

The following definitions will be useful in understanding the report:

Location Referencing System - Automated procedures used to manage the collection, storage and access of location referencing information. The system includes the integration of location referencing methods.

Location Referencing Method - Procedures by which users can locate an object and access its attributes.

Linear Referencing System - Procedures used to locate features along a roadway, river, railroad, etc.

Education and Training

In order to give each member an understanding of the methods/technologies being discussed, the following presentations were made to the team:

- Link-node system
- Iowa DOT GIS pilot projects
- Coordinate system parameters
- Non-NHS Pavement Management System
- Base records
- GPS
- HARN
- Videologging van
- Stationing

Research Current Practice

The team conducted an extensive search of current published literature and information on the Internet. Eighty-one documents were reviewed, including journal articles, white papers, conference proceedings and reports. A detailed review of the literature is found in Volume II, Chapter 1.

Significant research and implementation work in LRS and Linear Referencing Systems is in progress. Linear Referencing Systems are evolving from an ad hoc series of methods to a rigorous scientific procedure. The theoretical work by Alan Vonderohe (Civil Engineering Department of the University of Wisconsin), completed for NCHRP 20-27(2), was the basis for some of the team's recommendations. Systems and Applications Architecture for GIS-T identified a fundamental need for a generic data model for GIS for transportation to provide the linkage to linear referencing components. Vonderohe's paper, "A Methodology for Design of a Linear Referencing System for Surface Transportation,"[38] was identified as an important document.

Another important part of a Linear Referencing System is location control. The Wisconsin Department of Transportation has done considerable work in this area. In 1995, they developed a Location Control Management Manual that is used throughout the Wisconsin DOT. A copy of this manual was reviewed.

Intelligent Transportation Systems (ITS) will clearly play an important role in the future of transportation. The work to integrate ITS with existing location data is under development with a considerable amount of theoretical work and standards available. However, field tests of these standards are still under development. Steve Gordon from Oakridge National Laboratories was contacted about the development of data interchange standards for ITS.

Inventory Current LRM

Relevant reports and a survey conducted by the LRS team were used to compile information on current LRMs used in the Iowa DOT. For a detailed discussion of this review and the associated advantages, and disadvantages of referencing methods, see Volume II, Chapter 2.

Results of this review identified the following LRMs used within the DOT:

Mileposts
Milepoints/kilometer points/meter points
Stationing
GPS (latitude and longitude)
Link-nodes
Cartesian coordinates (map projections)
Segmental referencing techniques (Base records)
Literal descriptions.

The following important coordination issues were identified:

- The Iowa DOT must have one location referencing system.
- This system must incorporate all existing methods.
- Stability over time must be assured.
- The single referencing system should facilitate all of the referencing activities within the Iowa DOT.

Investigate Specific Referencing Needs

Referencing needs of numerous offices throughout the Iowa DOT were surveyed. Information from the GIS survey conducted by CTRE was the basis for this survey. The primary objectives of the survey were to provide an inventory of current location methods, and current and desired accuracies for these methods.

Seventy-three percent of the surveys were returned. There were 210 features identified by different offices as being used or desired. Features were frequently duplicated on the surveys returned. Volume II, Chapter 3, contains the information gathered by this survey.

Develop Recommendations

The team determined desirable characteristics and capabilities of the LRS, summarized as follows:

- ability to reference point, linear, polygonal and spatial data;
- at a minimum, primary highways must be included;
- capable of integration with the federal aid eligible system;
- include other transportation systems (rail, water, etc.);
- existing methods must be maintained;
- adequate staff must be assigned;
- it should be easy to use;
- enterprise communications should be developed; and
- it needs to be friendly to new and emerging technologies.

After looking at the inventory of data obtained from the survey, the team realized there was a real need to be able to locate features by using a distance from a known location. In order to do this, the team recommended that a Linear Datum be established.

Linear Datum - The collection of objects which serve as the basis for locating the Linear Referencing System in the real world.

A Linear Datum is one of the core items needed by the Iowa DOT because most of our data is linear in nature. The team made specific recommendations in regard to establishing a Linear Datum for the DOT. A Linear Datum will establish rigorous rules allowing for the integration of the data gathered by the various referencing methods used within the department. A Linear Datum is defined by using anchor points to identify transversals (i.e. part of a route or routes) within a network. Two anchor points define an anchor section. These anchor points are located in such a way that a specified accuracy is met. The measurements are a distance (as traveled) from one point to another. These anchor points must be easily identified in the field since all location referencing methods must ultimately be referenced to these points.

In addition to establishing a Linear Referencing System, the team also decided to make specific recommendations regarding divided highways and ramps. Specific rules need to be developed for any changes to current procedures required by implementation of these recommendations.

Existing methods should be maintained as reference methods. Stationing should be developed as a new data access method; however, no linkage to historical project station data need be established. Coordinates and literal descriptions should be developed as access methods.

Other recommendations were also made to include moving the base records from a static to a dynamic record (real time updates), and treating structures as linear features on the roadway.

Conclusions

The LRS team is recommending the establishment of a Linear Datum within the Iowa DOT. This datum will allow the department to correlate data between referencing methods and will allow easier integration of the DOT's data with other disparate data in GIS packages.

It is recommended that the Linear Datum be evaluated in a pilot project. Inclusion of other political entities such as counties and cities should be considered.

Additionally, it is recommended the team remain operational in an advisory/overseeing role as the recommendations are implemented. In order to ensure implementation of the recommendations adequate resources must be committed. The team will meet quarterly to receive an update on the progress being made by the GIS coordinator for the DOT, since the GIS development will be dependent on the LRS implementation.

The team also recognizes that the Iowa DOT must have one referencing system; this system must incorporate all existing referencing methods and be stable over time. This single referencing system should also facilitate referencing needs within the DOT's management, business and information systems.

Location Referencing Team Recommendations

Recommendation #1: Adopt the following location referencing system characteristics.

1. Scope of Location Referencing System.

Allow referencing of point, linear, polygonal (area) and spatial (volumetric) data in four dimensions (i.e. X, Y, Z, and time).

Support data relating to various transportation modes and functions, including:

- highway (road)
  - encompass, at a minimum, primary system
  - capable of potential integration with non-NHS, federal-aid-eligible system
  - include ramps
  - support concurrent routes (i.e. single route with multiple names), duplicate routes (i.e. different route with same name), and temporary routes (e.g. detours)
  - allow maintenance of two directional data (maintain data for each direction and possibly by lane)
  - relate legs of intersections to an intersection
- navigable and recreational waterway
- rail
- pipeline
- aeronautical
- bicycle and pedestrian
- transit
- utility

2. Implement support, maintain existing referencing methods until such point that they are no longer used, and integrate multiple referencing methods (into referencing system).

3. Assign adequate staff and clear responsibilities to implement, support and maintain the location referencing methods and system as a whole.

4. Easy to:

locate and/or identify features and events in the field
collect data
maintain and manage location referencing system
use location referencing system

5. Develop enterprise communications to:

facilitate intra-agency communication
communicate recommendations to local governmental agencies
partner with local governmental agencies

6. Friendly to current and emerging technologies, e.g. Geographic Information System (GIS), Global Positioning System (GPS), and Intelligent Transportation System (ITS), and easily adaptable to future technologies.

Linear Datum

Recommendation #2: A linear datum should be developed for use in the collection, management, and integration of spatial data. The linear datum development should initially be on a small scale (e.g. county level) and then assessed with respect to cost and practicality.

Naming Convention for Anchor Points and Sections

Recommendation #3: The basic identifier (name) of an anchor point or section should be unique, should never change, nor be defined by attributes that may change. Furthermore, the basic identifier should not be used to locate points, sections or access data. However, other attributes, such as a jurisdictional identifier, may be appended to the basic identifier so the name is meaningful to users.

Measurement of Length along Anchor Section

Recommendation #4: Several criteria should be used to identify the best technique to measure the length along an anchor section (distance between anchor points). These criteria should include cost, repeatability, accuracy, and ability to measure the horizontal, vertical and curvilinear nature of a roadway. Techniques that should be evaluated include the use of: videolog van GPS coordinates, videolog van distance measurements, Roadware™ van GPS coordinates, Roadware™ van distance measurements, field inventory distance measurements, cartographic representations of roadways, plan (project) controls and distance measurements, and/or a utilization of any of these techniques in conjunction with each other. Although a single technique should be used to measure the length along an anchor section (distance between anchor points), lengths calculated using other techniques may be maintained as additional attributes.

Multiple Representations of Roadway

***Recommendation #5*:** If a roadway is physically divided, multiple representations of the roadway should be maintained. However, rules should be established to address specific occurrences of divided roadways, such as intersections. In general, northbound/eastbound and southbound/westbound lanes should be represented separately. Length and other attributes should also be maintained for each direction of travel.

Primary (Main) Route

Recommendation** (Two-lane, Bi-directional Roadways) **#6: The linear datum distance measurement for two-lane, bi-directional roadways should be the centerline of the right (through) lane in the north/eastbound direction.

***Recommendation** (Divided, Bi-directional Roadways) #7*: The linear datum distance measurements for divided, bi-directional roadways should be the centerline of the right (through) lanes for each direction of travel.

***Recommendation** (Ramps) #8*: Ramps should exist as an anchor section, or collection of anchor sections, within the linear datum.

Location Referencing Methods

***Recommendation** (Stationing) #9*: Project stationing (English and metric units) should be developed as a new data access method. No linkage to historical project station data need be established. Historical data should, however, be maintained upon initial development of this access method.

***Recommendation** (Mileposts) #10*: Existing mileposts should be utilized as reference posts and developed/maintained as a data access method. Whenever possible, mileposts should be referenced in the field as reference post number ± displacement, where displacement can be in any clearly defined unit (meters, feet, miles, etc.). Positive displacement indicates displacement along the direction of increasing milepost number. Negative displacement indicates displacement along the direction of decreasing milepost number.

***Recommendation** (Milepoint) #11*: Milepoint (meterpoint) should be maintained as a data access method.

***Recommendation** (ALAS nodes) #12*: ALAS (Accident Location and Analysis System) nodes should be maintained as a data access method.

***Recommendation** (Coordinates) #13*: Coordinate data (e.g. northing/easting/elevation and latitude/longitude/elevation) should be developed as data access methods.

***Recommendation** (Literal Description) #14*: Literal description should be developed as a data access method.

Accuracy Items

Recommendation (Relative Accuracy) #15: Relative accuracy (allowable error in linear distance measurements between an anchor point and a reference point on the same anchor section) of 10 meters or less should be achieved.

Recommendation (Absolute Accuracy) #16: Absolute accuracy (the allowable error in longitude, latitude, and elevation on the reference ellipsoid) of known points, specifically anchor points, must be one meter or less.

Miscellaneous

Base Record

Recommendation #17: Move from a static (historic) base record to one that is updated in "real time" as changes occur.

Structures along Roadway

Recommendation #18: Structures located along a roadway should be maintained as linear features. The beginning and ending linear extents of such structures should be maintained with respect to the centerline of the roadway.

VOLUME I

APPENDIX A

WORK PLAN OUTLINE

APPENDIX A

<u>IOWA DOT -- LOCATION REFERENCING TEAM</u>

MISSION: DEVELOP A LOCATION REFERENCING SYSTEM FOR THE DEPARTMENT

WORK PLAN STEPS	RESPONSIBILITY	RESOURCE(S)	TIMEFRAME
Research the state of the practice.	**Alice, Steve and Dave**	**Peggi, Iowa DOT Library Internet and CTRE**	**3 months**
Collect information from other agencies. Research new reference methods. Review, compile and summarize results inventory.	**All team members**		
Inventory current LRSs used within the DOT.	**Annette, Dave and Rich**	**CTRE**	**3 months**
Identify offices and methods in use. Identify benefits and shortcomings of the methods in use. Identify internal coordination issues encountered by CTRE. Compile and summarize results.			
Investigate the specific reference needs of each division.	**Kevin, John N., Francis, and CTRE**	**CTRE**	**3 months**
Analyze the GIS strategic plan and supporting information. Evaluate gaps in current information. Determine if more information is needed. Identify accuracy requirements. Compile and summarize results.			
Develop system and methods.			**3 months**
Determine desirable characteristics and capabilities of the system. Define the scope of the system (primary/secondary networks). Define acceptable accuracy. Determine how the methods will fit into the system. Identify existing methods that can/cannot fit into the new system. Develop final report and recommendation for implementation and time lines, include benefits, etc.			

VOLUME I I

Research Current Practices

Eighty-one items have been reviewed to date. These items have come from a number of different sources: magazines, white papers, conference proceedings, reports, and electronic documents from Internet sites.

Of the 81 items reviewed, 37 were identified as relevant by the LRS team. An additional 29 items were identified as fairly relevant. Relevant items are referenced by number fairly relevant items are referenced by a number and letter (see Appendix B). These documents have been examined in order to identify the Location Referencing Systems and Methods used or recommended. A considerable amount of the material reviewed was either theoretical or not yet implemented. In most cases what had been implemented deals with a Linear Referencing System and not with a Location Referencing System (LRS).

In addition to the literature review, phone conversations took place with:

Steve Gordon (Oakridge National Labs)

Location Referencing Standards for ITS.

Ed Shuller (North Carolina Department of Transportation)

Implementation of a Linknode System.

The following people had e-mail exchanges with the LRS Team:

Christopher Rowley (Idaho Department of Transportation)

Anchor Points/Anchor Sections.

Alan Vonderohe (University of Wisconsin)

Linear Datum Theoretical Modeling.

A Linear Referencing System is an important part of a LRS but does not address the issue of wetlands, rights-of-way, census data, and other features that are polygonal or based on centroids.

The following quotations and paraphasing demonstrate the importance of a Location Referencing System to the agency.

"Any generic model for GIS-T must include linear reference components."[19b]

"Many transportation agencies now are faced with the need to integrate both linearly and geographically referenced distributed attribute data."[18b]

"The Transportation Research Board has concluded that 'data integration across different application areas is an urgent, long-standing need of the DOTs.'" (Vonderohe, 1993)[25]

Sixty percent of DOT data has location as a principle reference.[4]

"Spatial information is believed to be a component of over 75 percent of government's activities and data."[21b]

"Eighty percent of data has a location component."[5]

"Location referencing has a tremendous influence on virtually all areas of business in a DOT."[8]

"Over the past decade, information analysts in all three domains" (transportation facility operators, civilian and military transportation users) "have independently concluded that location is a primary information need and a central information integration strategy."[37]

This literature review will attempt to address the following:

What referencing systems are being used/recommended?

What are the implementation requirements for an LRS to meet identified future needs?

The following Appendices are based upon reviews by the LRS team:

Appendix A - Glossary of terms and definitions

Appendix B - Relevant research documents with titles/objective/contact person

Appendix C - Location referencing systems by type

Appendix D - Location referencing methods by type

Appendix E - Other relevant system issues as identified by reviewer

Appendix F - Conclusions in papers as identified by reviewer

What Reference Systems Are Currently in Use or Recommended

The difference between a Location Referencing System and Method were defined by NCHRP: Synthesis of Highway Practices 21[1] as:

System - Set of procedures that include a referencing method.

Methods include such things as mileposts, stations, milepoints, etc.

Idaho, Pennsylvania, Vermont, North Carolina, and Delaware have all implemented referencing systems.

Pennsylvania:

Schema - County identifier (2 digits), state route (4 digits), segment identifier (4 digits), and offset (4 digits).

Segments are approximately ½ mile long.
Offset are in feet from segment begin point.

Does not cover municipal roads.

Segments correspond to field marker sign locations.

LRS history not readily accessible.

Delaware:

Schema - maintenance road number, county code (1 digit), milepoint direction, milepoint (Offset)

LRS not implemented for suburban development streets or for municipal streets.

Vermont:

Interstate Schema - Route, directional code, milepoint.

Other federal-aid highways - Route, town name or code number, milepoint.
LRS not implemented for local roads.

System based upon route logs (i.e. straight line diagrams) maintained in a spreadsheet.

Information on the above states was taken from slides from a AASHTO GIS-T Symposium pre-conference workshop held April 10, 1994, in Norfolk, Virginia.

North Carolina[10,31]:

Schema - County (2 digit), begin node (5 digit), end node (5 digit), length (? digits), and route (6 digit alphanumeric).

LRS not implemented for local or municipal roads.

Idaho[22]:

Schema - Segment code (6 digits), milepoint, effective date and expiration date.

Currently, only roadways are a part of Idaho's LRS (MACS/ROSE).

What are the implementation requirements?

North Carolina noted that the process to come to an agreement was painful, but that a standardized coding and LRS are required for a department-wide relational database.

North Carolina considered 3 systems: county/route/milepoint (history problems), link node, and station post (too costly).

North Carolina also noted that a directive from upper management was required because of resistance to change in the organization for a number of reasons.

North Carolina’s conclusion was that the benefits of conversion far outweighed the cost. They listed the following benefits from a unified referencing system:

Data can be shared throughout enterprise.

Data redundancy will be reduced.

Data can be accurately tracked over time.

HPMS reports can be generated from database with updated information.

GIS requires a standard reference system.

Models requiring information from various tables can be accomplished.

System allows for computerized updating of all tables when nodes are added or deleted.

Idaho noted:

> "The purpose of a LRS is identifying facilities temporally and spatially for geo-historical analysis"... "'real world' geo-historical analysis requires 'real world' references fixed both in time and space. Both must be measured offsets in reference to or *anchored* to some already known point, they must be application independent, they must be independent of each other, and they must lie at the same fundamental level of abstraction."[22]

At ITD (Idaho Transportation Department), the lowest common denominator is the segment code identifying an anchor section.

Beginning and ending milepoints are spatial anchors. Effective and expiration dates are temporal anchors.

The following items were found in a report from the Idaho Department of Transportation:

> "If route numbers, which change over time, are used as database keys, then it will be very 'difficult to maintain over time because of the dynamic nature of" these designations; not the dynamic nature of "field locations'".[34]

> *"Because linear referencing extends beyond GIS: and because both GIS and linear referencing extend beyond transportation, when properly combined, a LRS and a GIS are much more than just GIS-T."*[34]

<u>Federal Geographic Data Committee Ground Transportation Subcommittee recommendations and Observations:</u>

"It is the position of the FGDC Ground Transportation Subcommittee that a linear reference system is an essential component of transportation network spatial databases."[21]

"Establishment of this standard LRS data structure will require consideration of the specific software requirements of key GIS software and development of a software neutral data format."[21]

> Linear Referencing Systems
>
> 1. A standard LRS data structure, together with the key attribute fields required to support such a data structure, should be included as part of any Transportation Network Profile established under the Spatial Data Transfer Standard (SDTS).
>
> 2. Any transportation network databases developed as part of the National Spatial Data Infrastructure (NSDI) framework should include as part of their core data all key LRS attribute fields.

Recommended key features Route ID, beginning and ending reference points.

"While the creation of standards to simplify data exchange is viewed favorable, there seems to be little interest in establishing a standard map projection for national transportation networks. Different projections are appropriate under different situations. More over, most GIS software have the capabilities of converting from one map projection to another given the necessary control parameters. There is support, however, for establishing a common coordinate reference system (i.e. latitude/longitude) in order to avoid the propagation of errors introduced by the successive conversion of data from one referencing system to another."[23]

The FGDC also went on to say that national transportation networks should be geographically compatible with other spatial databases.

"It was generally agreed, however, that data based content referenced to latitude and longitude will make the combining of data sets, such as population data, boundary files and other model networks derived from various graphic and digital database sources, more straightforward. For this reason, it is recommended that absolute latitude and longitude be adopted as the most useful standard for linking databases to support national level ground transportation networking."[23]

Location Referencing Systems for Intelligent Transportation Systems (ITS)

"The ITS Datum is an essential component underlying many if not all LRMS profiles and format records. An ITS Datum generally is a regional or national standard network of accurately located ground control points, typically located at road intersections, that will anchor spatial references between databases of different kinds."[32] Location Reference Message Specification (LRMS).

"Location is the key to access, but there is no common access method or means of integrating methods."[9]

"The need for location referencing does not imply a common national or non-proprietary methods."[9]

"<u>The real key to sharing data between two different data sets is thus the specification of geographic coordinates for sufficient network nodes to effectively "tie" the network to earth</u>."[33]

"Rapid adoption of differential GPS makes coordinates attractive as a key component of common national methods for ITS."[9]

"Latitude/longitude with road ID may be the best single method for national interoperability."[9]

"As part of the tailoring process we recommend that the complete NHPN network be run with differential GPS-equipped vehicles in order to accomplish the following goals:"

improve the geographic coordinate accuracy of network nodes to the 3-5 meter range to support future ITS requirements for high-accuracy spatial data references; and

measure link ground distances accurately to support federal, state and local linear referencing system interoperability requirements.[33]

Five Location Reference Methods have been identified as fit for use in ITS:[28]

spatial coordinate pairs

"intelligent coordinate snapping"

cross street offset matching

Linear Reference Method (LRM)/Dynamic Assignment of Network Attributes (DANA)

link identification

Intelligent coordinate snapping involves using a coordinate pair (x,y) or triplet (x,y,z) and a road ID. The road ID is used to "snap" the data to a map vector.

Cross street offset matching identifies an intersection and then moves an offset toward another intersection.

Use of degrees/minutes and seconds to 2 decimals equates to centimeter level accuracy.

A proposal prepared for New Mexico in 1989 noted the following[5]:

"Locationally related information existing in one area of the department could be of use to another area, but that information is not used because either its existence is not common knowledge or the information is in a form which is not readily used by others."

"In fact, there is a system that is universally recognized as a means of clearly identifying the exact location of features on the Earth: geographic coordinates."

"A GIS is more than just an independent collection of electronic maps and data sets with some spatial component. Linkages between the attributes and base maps are provided, as well as software analysis tools that interpret the intelligent structure of the map, provide for input and output, and allow the data to be combined in meaningful spatial analyses that a knowledgeable human being can use to answer a question or solve a problem."

"This is not to say that the department should scrap all of its current referencing systems except those that are geographic. The other systems are well established and have evolved to meet specific needs. They must be retained. It is to say, however, that the department should recognize the significant benefits of having geographics as the underlying foundation of all of its location information. Without a common geographic reference, the efficient flow of information both within and outside of the department will continue to be hampered."

The report also noted that a DOT is somewhat unique in the scope (how large and small) of what is considered.

The report recommended Using UTM and NAD83 as the reference base.

Results: Linear Referencing Workshop NCHRP 20-27:

"Any generic data model for GIS-T must include linear referencing components. Linear referencing systems must be linked to higher dimensional systems, including those that model time."[2]

"Given all these activities and interests in data sharing and integration, the need for a common generic data model for linear referencing is compelling."[26]

Other Relevant Observations/Recommendations:

"To avoid the problems caused by inappropriate segmentation and still support accurate modeling, network segments should be fragmented at actual intersections and at very few, if any, additional locations. Network segments, and or links, should connect actual intersections and should be as long as possible. This will support efficient modeling and foster sharable link data."[29]

Dueker and Butler recommended the following:[36]

The endpoints of a transportation feature must be tied to anchor points if the feature is to be located within a geographic datum. To be valid, a datum must be tied to physical real world locations that are unambiguously defined. This would seem to eliminate such field references as county lines and other jurisdictional boundaries tied to monumentation since the monuments (signs) may not be properly and/or consistently placed. However, the linear LRS will work best if its origin is the beginning point of the road in the jurisdiction. The reconciliation of the these two needs is to reference the jurisdictional boundary to an anchor point that is unambiguously defined; i.e., make the location of the transportation feature origin 0.000 at the jurisdictional boundary, but locate the boundary (and origin) as an offset (plus or minus) from an anchor point. The transportation feature is thus unambiguously tied to a datum-compatible location.

"One possible option that eliminates many of the issues associated with proper names and other real world external IDs is the use of a numbering scheme for creating the named road value. Such an option could follow an approach similar to that used for Internet addresses, with numeric codes for state, county, jurisdiction or other important naming elements."[23b]

The following observations come from the Proceedings of the Management System Integration Committee Meetings in Washington DC:[3a]

1. Common Referencing (CR) is required to integrate management information systems.

2. CR is not driven by technology, but by the business needs of the agency.

3. More than one referencing system will need to be supported, but consolidation should take place when possible.

4. With multiple referencing systems, an agency should construct an enterprise referencing system.

5. The needs of the agency need to be carefully considered.

6. Common referencing is not just a GIS Issue.

7. To be successful, a CR needs a sponsor and champion.

8. Consult current research before making decisions about a CR.

Education/Training

"Any referencing scheme is only as good as the people who use it or the procedures for using it."[4]

Utah[8] recommended:

- Developing a manual
- A formal course
- Policy designating one office to maintain system
- Freezing system for one year
- Developing a formal computerized and manual system to cover all aspects of location referencing
- Procedures to cascade changes to historical files
- Procedures to make location as easy as possible in field
- Strategy to implement metric notation

Inventory of Current Location Referencing Methods

Current Methods

The following location referencing methods (techniques to identify specific points or segments of highway) have been identified.

Linear Referencing Methods

Linear systems use distance from a reference point along a route to reference information. Linear reference methods include mileposts, reference posts, milepoints and stations. The milepost and reference post methods use physical markers or pavement stamps in the field.

Control Point Methods:

Mileposts (Offices using this method are Design, Bridges & Structures, Materials, Construction, Maintenance Division, Driver Services and Motor Carrier Services.)

Mileposts are physical markers posted on the side of all primary roads at approximately one-mile intervals. Mileposts begin from zero at the state line, or the beginning of the route and increase from south to north, and west to east in the state.

Iowa uses decimal mileposts, and does not usually move all mileposts after a change in the system. Iowa, therefore, does not have a true milepost system because some posts are not one mile apart. The physical post is marked as an integer but the database reflects actual locations which are no more than 1.04 miles apart. The decimal milepost system used in Iowa has at times in the past been used incorrectly due to confusion about the ability to subtract one decimal mile post from another. The Iowa posting would more accurately be referred to as a reference post system.

Mileposts Advantages
1. easily learned
2. easiest to use in the field
3. fairly uniform spacing of signs
4. numerical sequence provides easy orientation in field
5. runs entire length of a route
6. always close to a reference point; approximately one-half mile

Mileposts Disadvantages
1. changes in length after initial placement result in signs not representing true milepoints
2. maintenance of signs
3. metrication
4. must be tied to another system
5. can be inconsistently applied
6. problems with temporary routes,

7. motoring public can use to assess progress and locate features
8. exit numbers are correlated to the mileposts numbers on four lane roads

bypasses and duplicate routes
7. human error in data collection
8. complex when route is adjusted
9. data stored in the attribute tables would not be stable over time
10. historical data is almost impossible to track

Reference Posts

Using reference posts is a more general method than mileposts. The reference posts are not necessarily a set distance apart. The posts could be placed at recognizable features such as intersections or bridges, or at jurisdictional boundaries (e.g., county or state lines). Records are used to keep track of the distance between reference posts, and the actual mileage from the beginning of the route (or some other starting point). The distance and direction to a location are recorded with a sign reference number. Milepoints may or may not be maintained for posts.

The Iowa DOT doesn't recognize that it uses a reference post system however, the system used is a combination of a reference post system and a milepost system. Whenever possible, an attempt is made to keep mileposts at one-mile intervals. Sometimes the posts are not moved after construction and are not maintained a mile apart, making it more appropriately defined as a reference post system.

Reference Post Advantages

1. changes in length caused by route length changes do not affect sign placement or validity of their numbers
2. can use existing monuments or features
3. spacing is frequent enough to easily locate position
4. similar to mileposts
5. can be "invisible" using transponders

Reference Post Disadvantages

1. possibly of little use to motoring public
2. maintenance of signs
3. no sense of distance
4. similar to mileposts
5. reference posts are difficult to see in towns
6. data stored in the attribute tables would not be stable over time
7. historical data is almost impossible to track

Base Point (Offset) Method:

Milepoint(Meterpoint) (Offices using this method are Transportation Data and Driver Services.)

A milepoint is the linear offset from the beginning of the route or the county line (depending on which method is used), measured in miles. Milepoints increase from south to north and west to east. There are no physical markers for this reference method. Milepoint is the reference scheme used in the highway inventory (base records) database. Milepoint alone does not constitute a unique reference; other key fields needed for unique record access are the county, system, route and segment sequence (system of sequentially numbered segments on the route).

Milepoint Advantages
1. no posts required
2. easily understandable
3. uses "actual" distances
4. distances between two locations can be calculated easily

Milepoint Disadvantages
1. users in field must measure from beginning of route
2. location is unstable because milepoints change when road length change (e.g.,alignment changes)
3. historical data is almost impossible to track
4. changes in route designation
5. concurrent routes
6. control point not well defined
7. points sometimes do not match roads as driven
8. errors accumulate

Base Point Method:

Stationing (Offices using this method are Design, Bridges & Structures, Materials, Construction, Traffic Engineering and Maintenance Division.)

Stations are points at multiples of 100 feet or 100 meters. Intermediate points are designated by the full station plus the number of feet or meters from the nearest full station. Station zero for a project is arbitrarily selected and the stationing becomes a reference system for only that project. Stationing can, however, be related to some real world coordinate system such as GPS. Stations are used in construction and are physically indicated on most highways (every five stations or 500 feet) by either a stamp in the pavement (concrete) or a post with a placard (asphalt). Stations are often used as an informal reference scheme, but are not used for reporting by offices. The Iowa DOT has begun collecting GPS readings for the beginning and ending of projects.

Stationing Advantages
1. easily understandable in field
2. highly accurate (survey quality)
3. good for small projects
4. can do a physical tie to project

Stationing Disadvantage
1. only useful for individual projects
2. difficult to tie into other linear reference methods/base maps
3. initial points not well known
4. stationing equations

Reference Points (Offices using this method are Transportation Data and Driver Services.)

Reference numbers are assigned to easily identifiable physical features such as intersections or some already known point. The distance and direction to a location or linear offset from a feature are recorded with the reference number. Milepoints may or may not be maintained for reference points. This method is used for accident locations and base record segments.

Reference Point Advantages
1. no signs required
2. apply to concurrent routes
3. can be applied to different level systems
4. allows for variation of the number of points
5. more permanent
6. alignment change may affect locations
7. may need to continuously update

Reference Point Disadvantages
1. cumbersome to use in field
2. spacing may be impractical
3. of no use to motorists
4. numbering may not be intuitive
5. difficult to find points/nodes
6. potential for misinterpretation

Spatial Referencing Methods (Offices using this method are Design [design sections and cartography], Right Of Way, Materials, Construction and Development Support [environmental].)

Spatial methods reference information in two or three dimensions using coordinates to identify location. Spatial methods can be classified as geographic or projected (e.g., State Plane) and include longitude and latitude, nodes, political designation and x-y coordinates.

Spatial Referencing Advantages

1. universal system
2. no physical markings necessary
3. geographic coordinates obtained from GPS
4. location information is "permanent"
5. automatically displays on an electronic map
6. data outside of ROW can be collected
7. all locations can be related back to spatial coordinates
8. well-defined spheroid
9. easy to map data
10. ability to link all location reference systems together
11. ability to use for history
12. coordinate with other agencies

Spatial Referencing Disadvantages

1. difficult to detect measurement errors in field
2. difficult to communicate location without map, linear referencing method or GPS
3. of no use to motoring public (may be usable with ITS)
4. calculation of distance between two points requires 3-D geometry
5. GPS receivers are required (to acquire geographic coordinates)
6. distortions of coordinate systems
7. accuracy requirements may be greater
8. problems using with legacy data
9. no obvious linear distance without right technology
10. datums, state plane coordinate systems differ

Latitude-Longitude (GPS) (Office using this method is Transportation Data.)

GPS is a common method used to determine the longitude and latitude of a location on the surface of the earth. GPS is a navigation and surveying system set up by the Department of Defense that utilizes a number of satellites to accurately locate objects on the earth. The Iowa DOT has applied GPS technology in highway design to establish initial survey and photo control information. In initial surveys, GPS information ties highway design projects to the National Geodetic Survey (NGS) State Plane Coordinate System using NGS control monuments. To establish photo control information, GPS has been combined with aerotriangulation techniques to establish control for photogrammetric mapping. For the environmental analysis, a temporary base station has been developed to utilize differential GPS to provide positional information needed to locate environmentally sensitive areas such as wetlands, native prairie, threatened plants and animals, archeological sites, landfills and hazardous waste sites. For video imagery, real-time GPS technology is used to integrate GPS into the videologging system. The entire primary highway network has been logged so we have a GPS latitude-longitude and altitude coordinate for every videolog frame on the primary road system, with readings every eight meters, and has been tied to the milepoint (meterpoint). The linking of GPS coordinates with visual information will create spatially based data that can be integrated to information in other data bases. In addition, the positional data can be displayed graphically to provide an automated method to update existing base maps. It is currently being used for bridge location, airport location, and is being tested for accident location. In order for it to be used with other reference methods it must be converted to a linear or segmental reference for data storage or retrieval.

Latitude-Longitude (GPS) Advantages

1. useful for locating features or events that happen at a point, or that can be defined by a boundary
2. GPS receivers are portable and can be integrated into a computer or a vehicle to locate any number of data collection activities in the field
3. the location of the nearest reference point or post does not need to be found
4. dynamic and highly precise

Latitude-Longitude (GPS) Disadvantages

1. if GPS was used as a key field in the data base, the same number of decimal degrees would have to be used every time
2. each time the data are collected, the coordinate could be different
3. seen as "new and fragile" technology and that control reference networks and base stations are needed to be reliable
4. certain reference points should be anchored to be control points for GPS

Link-Node Methods(Offices using this method are Transportation Data, Bridges & Structures and Driver Services.)

Nodes are points representing identifiable physical features or significant locations along the highway system. Most node systems define the segment of road between two nodes as links. This method is used in the Highway Performance Monitoring System, which is a federal system used to collect data from States on pavement condition, improvements (e.g., pavement overlay), geometrics (e.g., lane width), traffic/capacity (e.g., average annual daily traffic, percent trucks), and environment (e.g., climate zone, drainage adequacy). Nodes and links are currently used in Iowa to reference accident locations. There are nodes placed at significant road intersections or locations on primary, secondary and municipal roads throughout the state. The database fields necessary to access data in this reference scheme are county, township and a four digit 'pseudo-coordinate'. This numbering scheme provides unique numbers countywide and statewide. A reference node, a direction node, and a distance are recorded.

Link-Node Advantages

1. no signs required
2. apply to concurrent routes
3. fairly stable over time, not dependent on the route designation or a physical marker on the road
4. can be related to spatial coordinates, linking GIS with GPS technology
5. useful in urban areas (proximity)
6. great when precision is not needed
7. all data will continue to be associated with the section of highway to which it pertains

Link-Node Disadvantage

1. spacing may be impractical
2. no use to motorists
3. nodes dependent on milepoint system
4. node maps can be large, detailed and confusing
5. mistakes can easily be made
6. difficult to use in a complex environment; cumbersome to use in field w/o GIS
7. no embedded location reference system for links
8. cannot use for off-road features
9. complex numbering can be difficult to interpret
10. not a stable method

Jurisdictions and Public Land Survey System (Offices using this method are Transportation Data, Design, Bridges & Structures, Materials and Driver Services.)

Jurisdictions include state, county and incorporated areas. The Public Land Survey System (PLSS) is defined by the U.S. Department of Interior, Bureau of Land Management and includes, township, range and section. The secondary road (roads maintained by the counties) base record system currently uses a reference method including county, township, range, section and road number. The road number follows the following rules. If the road runs east/west across the section and starts in the northwest corner of the section it is labeled as a number one road. If the road runs north/south through the section and starts in the northwest corner of the section, it is labeled a number two road. If the road runs east/west and does not start in the northwest corner, it is labeled with an odd number starting with three. Similarly, if the road runs north/south and does not start in the northwest corner it is labeled with an even number starting with four. As stated earlier, the accident node system for Iowa also uses county and township as part of the reference.

X-Y Cartesian Coordinates (Office using this method is Design [Photogrammetry].)

There are many x-y coordinate systems that are available for use as a location reference method. Some examples are Universal Transverse Mercator (UTM) projection coordinates, Lambert Conformal projection coordinates, State Plane coordinates, and many other coordinate systems from projection or from an arbitrary origin and unit of measure. The Cartography Section of the IDOT uses a Lambert Conformal projection with two standard parallels (33 and 45 degrees) for all of the maps produced. The coordinates from this system are then transferred to the primary road base records and are used as the link between the graphics and the inventory information. The link is used to import the graphics with attribute attachments into a geographic information system (GIS) for analysis. Iowa has the capability to translate the information referenced to the Lambert coordinate system to almost any other coordinate system.

Segmental Referencing Methods (Offices using this method are Transportation Data, Pavement Management.)

There are two general categories of segmentation methods, fixed-length and variable length segments. In a fix-length segmentation scheme, highway routes are broken at a fixed interval, small enough intervals so that the attributes for a segment may be considered mostly homogeneous. The variable-length scheme changes to a new segment any time there is a significant change in the attribute values. The most widely referenced scheme within the Iowa DOT is segmental. The segmental reference schemes are record-oriented and not necessarily related to geography. Segmental reference schemes include the "control section and aliases" within the base records, accident case numbers within the accident records, maintenance section identification, etc. The Iowa base record is the DOT's most disaggregate data base. All other systems comprise a whole number of base record sections. Segmentation can be static or dynamic. In dynamic segmentation the attribute data is stored in several RDMS tables and segments can be generated automatically.

Fixed Length Static Advantages

1. conceptually simple
2. segment begin and end locations are uniquely determined by count of segment from origin
3. segment definition is not sensitive to attribute change

Fixed Length Static Disadvantages

1. last segment likely different length
2. many attributes are average/approximation over segment, limits accuracy
3. data redundancy, attributes not changing over several segments
4. changing in route geometry require begin/endpoints to be recalibrated

Variable Length Static Advantages
1. attribute data in one table
2. better data accuracy (breaks determined by attribute values)
3. less data redundancy (than fixed length)
4. individual segments more adaptable to geometry changes

Variable Length Static Disadvantages
1. segment definition is sensitive to change in attributes
2. considerable data redundancy remains
3. requires secondary system to calculate distances
4. large number of segments required

Dynamic Segmentation Advantages
1. use of data normalization practices to minimize storage
2. more flexible data management
3. segments can be generated in real time
4. spatial data need not replicate attribute segments

Dynamic Segmentation Disadvantages
1. relational database management system required
2. changes in route geometry may require updating many tables
3. computationally intensive

Cross-Reference Methods (Offices using this method are Transportation Data and Pavement Management)

A cross-reference system is designed to use multiple referencing methods in the same system. An example is the cross-reference needed between a milepoint and a nominal milepost method. The relationship between methods is maintained in a table. Cross-referencing has enabled referencing between pavement management data and base record data. This relationship allows for GIS analyses that encompass both systems.

The milepost-milepoint-segmental cross reference scheme should be used to determine the distance between two mileposts rather than subtracting fractional mileposts. To determine the relationship between the milepost and milepoint system, the laser disc images of the state Primary road system from Iowa’s videolog van are used. The videolog software displays the mileage along a route for each image. This mileage can then be related to the milepost locations as seen in the video.

Coordination Issues

“To manage location referencing, a highway agency must have one, and only one, location reference system” (Deighton & Blake, 1994). The Iowa DOT’s goal should be to develop an integrated reference system, not redundant, stable over time, and provides for the efficient exchange of information among all systems.

The department’s location reference system must incorporate all existing systems. It may require multiple reference methods to be used within the common reference system. The method used to collect the data in the field does not have to be the same method used to store, maintain and retrieve the data in the database. “To accommodate the varied needs of data collectors, the system allows location to be identified using any valid addresses. However, to ensure easy communication with all users and uniformity, the system converts input addresses to a standard address that is stored, retrieved, manipulated and used for all reporting” (Deighton & Blake, 1994). There must be a defined cross-reference system. To enable the Iowa DOT to make data-based decisions, we need to be able to analyze information as it occurs along the road network. Therefore, the location reference system should contain a linear reference method. If a spatial reference method is used, it should be as attributes in the system. It will be necessary to correlate linear and spatial reference methods in the system. It is desirable “for an agency to either use one location reference method or provide a location reference system that can accommodate many methods at once” (Deighton & Blake, 1994).

The system decided upon needs to ensure stability over time, allowing for roadway alignment and route number changes. Any reference system should use anchored (fixed in space through time) points to ensure stability. It should not use the signed route name as part of the reference system. If the route designation is changed, historical data for the road are difficult to maintain. Many current systems (milepost, milepoint and reference post) use the route as part of the reference description. If a route number is used as part of the reference system, it should be independent of the system used in the field. It has been recommended by many sources that the actual route number of the highway should not be part of the internal address for the reference system.

The reference system, once established, should allow for the referencing needs of all business systems in the Iowa DOT. To make the change to one integrated reference system, each area of the agency affected should be involved in making the decision of what reference system is going to be adopted. The referencing system chosen must support many DOT activities: geographic information system, pavement management system, management information system, other ISTEA management systems, accident reporting and analysis, maintenance management system, permit routing and others.

With the coordinate translation capabilities of GIS, data from two different reference systems can be integrated without the use of formal cross-reference system. This would allow for spatial integration of the data. However, to analyze information that was not directly associated with the linear network, data would need to be integrated into the network (network integration).

Dynamic segmentation used within a GIS can allow for network integration of roadway data. A routing package requires these special referencing needs: continuous routes, a system defined to deal with duplicate routes, split roads, cul-de-sacs and ramps (Petzold, 1994). For the permit routing process to be fully functional, it is important to have a real-time database in place, and maintained.

The reference system must address the needs of all users and their accuracy requirements should be evaluated. The existing systems and data in the state should be considered in the selection of the reference system. This is also true for reference systems for the roads that are under the jurisdiction of other agencies.

There may be a need in Iowa to make modifications to the existing primary road reference system to make sure that all data from the new management systems that should be correlated by location can be. The system could be supplemented by locating the mileposts with GPS so it could eventually replace other methods.

When the reference system for the secondary and municipal roads is established, an inventory of existing reference systems for these roads should be done. Also, representatives from these jurisdictions should be a part of the reference system decision for these roads.

"The [Iowa] DOT must commit to a comprehensive reference system, timely and regulated updates to the reference system, correlation of all route segmentation, complete coordination of geographically based data, and a firm interagency working relationship" (Mangum, 1990a). After a system is chosen, and the agency has agreed to use it as the only reference system, the responsibility of managing, operating and maintaining the location reference system must be assigned. The system should be nearly transparent to the user, and all employees adequately trained. All users will need to know how to use the new reference system, and also how their old system will be affected.

References

Knight, Peggi, “Evaluation of Reference Systems for the Iowa Department of Transportation,” Iowa State University Creative Component, November 1994.

Center for Transportation Research and Education, “Iowa DOT Location Referencing Workshop,” October 11, 1996.

Deighton, R.A., and D.G. Blake, “Improvements to Utah’s Location Referencing System To Allow Data Integration,” Third International Conference on Managing Pavements, San Antonio, Texas, May 22-26, 1994, pp. 97-107.

Petzold, R., and Simon Lewis, “Linear Referencing Systems and Dynamic Segmentation” a Pre-conference Workshop of the AASHTO GIS-T Symposium, Norfolk, VA, April, 1994.

Mangum, G., and L.G. Walker, Final Report of the Highway Location Reference Procedure Project, June 1990.

Investigation of Specific Referencing Needs

The third step in the work plan was to identify the needs of the Department for Location reference methods and needed accuracy for those reference methods. A survey was developed and distributed to the Offices, Transportation Centers, and Divisions that were interviewed in 1994 as part of the Department's Geographic Information System (GIS) Strategic Plan. The distribution of the survey was intended to ensure that all appropriate areas of the Department were considered during the project.

Five items were sought from the survey. They were:

1. What features or events need referencing?
2. Is the feature or event currently in use?
3. What reference method is used or desired?
4. Who or what is the source of the data?
5. What level of accuracy is used or needed?

Offices, Transportation Centers, and Divisions were first asked to identify the spatial data sets that are currently used, or may potentially be used, for applications within their areas. The spatial data sets were defined as features, or events, which may occur on, along, or near transportation infrastructure and may be described by multiple attributes, or data sets. Based on the 1994 interview responses, a list of initial features/events was developed and included on each survey. Respondents were asked to remove any inappropriate features/events and include features/events that had been omitted. Respondents were then asked to identify the features/events they were currently using and the source of these data, if known.

Next, the respondents were asked to identify the method(s) used to reference the location of the features/events currently being used. Respondents also identified any other method(S) they would like to use to reference both these features/events and those not currently being used. Several referencing methods were provided for the respondents to identify. The list of methods, which included milepost, milepoint, link-node, spatial coordinates, stationing, and literal description, was based on an earlier review (1994) of the location referencing methods used within the Iowa Department of Transportation.

Finally, respondents were asked to identify the level of accuracy of the features/events currently being used, a preferred (desired) level of accuracy for these features/events, and a preferred level of accuracy for the features/events not currently in use. Six different accuracy ranges were provided, each representing the expected errors of different global positioning system (GPS) collection and processing mechanisms. Respondents were asked to consider that the higher levels of accuracy will be more costly to obtain. (A copy of the letter and a sample survey sheet are in Appendix G).

The survey responses are summarized in Appendix H (Tables 1 through 3). Table 1 presents the referencing methods by Division. The most frequently listed reference method was coordinates. Much of the need for location referencing using coordinate data was for desired applications (features) rather than current applications. Stationing, literal description, and milepost reference methods were all identified for approximately the same number of features (60 to 70). Milepoint and link-node were identified as used or needed for 41 and 23 features, respectively. Both of these reference methods have fairly specific uses and are not suited for widespread usage within the Department.

Table 2 presents the survey results by feature (event) type, as identified by the Offices, Transportation Centers, and Divisions. There are several applications (features) where survey accuracy is used or desired, but the most common accuracy needs are in the 5 to 100 meter accuracy range.

Table 3 presents the measured accuracy needed or desired for the features/events identified by the Offices, Transportation Centers, and Divisions.

VOLUME II

APPENDIX A

TEAM REVIEWS OF RELATED LITERATURE

TERMS AND DEFINITIONS

Appendix A
Terms and Definitions

1. Address: Sequence of numbers and characters to represent the location of a point, specific to a location reference method.

2. 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 which provides the information necessary for determining and recovering the anchor point's position in the field. Forms of location descriptions can vary and can be quantitative or descriptive or both. Example values include: the intersection of the centerlines of Oak Street and Maple Street; and 1.2 miles south of the Post Office on Route 9.

3. 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 which is the length of the anchor section measured on the ground. Values are expressed in units of linear distance measure (e.g., kilometers).

4. Area: A two-dimensional object, including its boundary.

5. 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.

6. Chain: A directed nonbranching sequence of non-intersecting line segments and (or) arcs bounded by nodes, not necessarily distinct, at each end.

7. CSOM: Cross street offset matching.

8. DANA: Dynamic assignment of network attributes.

9. Datum: The context within which real world locations are referenced.

10. FIPS: Federal information process standard.
11. Geographic Point: A zero dimensional object carrying the coordinate

location (e.g. latitude/longitude/elevation) of a given data item.

12. Geometric point: The internal address reference for map cartography.

13. ITS: Intelligent Transportation System.

14. Line: "A generic term for a one-dimensional object." (SDTS, 1992) 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. According to SDTS, a line segment is a direct line between two points, a string is a connected nonbranching sequence of line segments, an arc is a locus of points that forms a curve that is defined by a mathematical expression, and a chain is a directed nonbranching sequence of nonintersecting line segments and (or) arcs bounded by nodes, not necessarily distinct, at each end. Shape and position are provided either by the x,y,z coordinates of points associated with line segments or by the mathematical expressions associated with arcs. Possibilities for types of coordinate values include Cartesian and geographic (lat/long/elev). Possibilities for mathematical expressions include splines and polynomials.

15. Line Segment: A direct line between two points.

16. Linear Datum: The collection of objects which serve as the basis for locating the linear referencing system in the real world (see Figure 3). The datum relates the database representation to the real world and provides the domain for transformations among linear referencing methods and 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 datums.

17. Linear Event: A one-dimensional phenomenon that occurs along a traversal and is described in terms of its attributes in the extended database (see Figure 8). Examples of linear events include pavement types, speed zones and construction projects. Each linear event in the linear referencing system data model 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. Linear events

will typically have additional attributes in the extended database.

18. Linear Referencing Method: A mechanism for finding and stating the location of an unknown point along a network by referencing it to a known point. Note: This is a modification of the definition provided by Deighton and Blake (1993). There are many kinds of linear referencing methods (e.g., milepoint, reference post, and engineering stationing). All linear referencing methods consists of traversals and associated traversal reference points, that together provide a set of known points, a metric, and a direction for referencing the locations of unknown points(see Figures 6 and 7). No attributes are assigned to linear referencing methods.

19. Link: A topological connection between two ordered nodes. Note: This is a modification of the definition provided by the Spatial Data Transfer Standard. 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.

20. Link: Highway between adjacent nodes.

21. Link ID: Reference table and digital base map.

22. Location: Particular position on a route, identified by address(es).

    Locate: A location of a point in the field by reference.

23. Location Reference Methods: Set of procedures used in the field to identify the address for any point.

24. Location Reference Systems: Set of procedures used in an agency to manage all aspects of location referencing.

25. MACS/Rose: Milepost and coded segment/road segment.

26. Mile Point: Distance in miles from the beginning of the road in the primary direction.

27. Milepost: Post placed along the road, with a number representing the milepoint of the post.

28. Negative Direction: Opposite to the positive direction.

29. Network: A graph 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 a modification of the definition provided by the Spatial Data Transfer Standard. Modification is necessary to exclude chains. 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 (see Figure 5). The network component of the model provides the basis for analytical operations such as pathfinding and flow. No attributes are assigned to networks.

30. 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 the Spatial Data Transfer Standard. 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.

31. Offset: Linear distance along the route to relate a point to a known point.

32. Place: Translation of data-base into real world location.

33. Point Event: A zero-dimensional phenomenon that occurs along a traversal and is described in terms of its attributes in the extended database (see Figure 8). Examples of point events include signs and accidents. Each point event in the linear referencing system data model has an "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 the traversal. Point events will typically have additional attributes in the extended database.

34. Polygon: Represents a location with area coverage.

35. Position: Translation of real-world into data-base location.

36. Positive Direction: Undivided highways: the primary direction highways: the direction of travel on each side.

37. Primary Direction: The direction in which a route is said to "run".

38. Referencing Method: Is seen by the user in the field as a way to identify a single location i.e., to reference a specific position with respect to a known point. A referencing system can encompass one or more referencing methods.

39. Reference Post: Post placed along the road, with an identification number.

40. Reference Point: Point on the road which can be easily identified and whose identification number and location is known.

41. Reference System: Is the set of procedures used to relate all locations to each other. It includes techniques for storing, maintaining and retrieving location information.

42. Regional: Road data base.

43. Road Segment: A portion of the road itself.

44. Road View Segment: The particular data about the road a person needs to do work.

45. Route: Composite spatial object composed of a directed nonbranching sequence of links and/or network chains.

46. Route: A combination of segments.

47. Segment: Simple spatial object, equivalent to a link or network chain.

48. SDTS: Spatial Data Transfer Standard.

49. Spatial: Object type codes.

50. Spatial Coordinate Datum: Format and precision.
51. Street: Naming conventions.

52. String: A connected nonbranching sequence of line segments specified as the ordered sequence of points defining the line segments. A string may intersect itself or other strings.

53. Thematic maps: Maps whose primary purpose is to display the locations of a single attribute or the relationships among several selected attributes.

54. Topology: The mathematically explicit rules defining the linkages of geographical elements. Relationship between features.

55. Transform: Conversion between: Dif. linear reference methods
Dif. cartographic representation
Methods and representations

56. Transportation feature: Usually a portion of the roadway system that is defined by a unique identifier, or name.

57. Transversal: Ordered and directed, but not necessarily connected, set of whole links.

58. Transversal Segment: Part of a traversal; traversal segments are the result of joining linear events with links that form a path through the transportation network.

VOLUME II

APPENDIX B

TEAM REVIEWS OF RELATED LITERATURE

(LISTED BY BIBLIOGRAPHY REFERENCE NUMBER)

Appendix B
Relevant

Number 1:

Material: FGDC Ground Transportation Subcommittee Position and Recommendation on Linear Referencing Systems

Objective: To recommend nationwide standards for a linear referencing system for all roads on the national highway system.

Contact Person(s):

Number 2:

Material: On the Results of a Workshop on Generic Data Model for Linear Referencing Systems

Objective: To prepare a draft consensus conceptual data model, at the entity-relationship level, for linear referencing systems.

Contact Person(s): Alan Vonderohe, Principal Investigator supported by the National Cooperative Highway Research Program Project, University of Wisconsin, Madison; Peggi Knight, Iowa DOT; and Bill McCall, CTRE/ISU.

Number 3:

Material: Evaluation of Referencing Systems for the Iowa Department of Transportation

Objective: To emphasize the distinction between a referencing system and a referencing method; present the referencing system solutions of other state DOTs and compare them to what has been done in Iowa; outline the requirements of a reference system to support various DOT systems; evaluate each reference method with respect to these requirements and their past success or failure; and to make recommendations on the essential elements of a successful reference system.

Contact Person(s): Peggi Knight, Iowa DOT.

Number 4:

Material: "Linear Referencing Systems & Dynamic Segmentation" (Preconference workshop of the April 10, 1994, AASHTO GIS-T Symposium in Norfolk, VA.)

Objective: Workshop on Linear Referencing Systems and Dynamic

Segmentation.
Session A - Introduction to Spatial Data and Location Referencing Systems
Session B - Linear Referencing Systems (LRS)
Session C - Top-Level Review of GIS-T
Session D - Concepts and Techniques of Dynamic Segmentation (DS)
Session E - Comparison of Three DOT Alternatives
Session F - Work at FHWA in LRS/DS
Session G - Upcoming Development in DS

Contact Person(s): Roger Petzold, FHWA & Simon Lewis, GIS/Trans. Ltd.

Number 5:

Material: Position Paper: A Proposal for the Acquisition, Use, and Maintenance of Geographically Related Info in the New Mexico State Highway & Transportation Dept.

Objective: To show the current state of data in the NMSHTD and recommend strategies for achieving common geographic environment.

Contact Person(s): Thomas Henderson, P.E., R.L.S.; Geometronics Unit Manager Computer Aided Engineering Sect. Information Systems Bureau.

Number 6:

Material: Integration of GPS and GIS for Highway Inventory Data Capture

Objective: To evaluate the use of GPS technology and a means of collecting roadway data.

Contact Person(s): David K. Loukes, P.E., Geoplan Consultants Inc., Fredericton, NB Canada.

Number 7:

Material: NCHRP 20-27(2) Location Data Modeling Workshop

Objective: To prepare a draft consensus conceptual data model at the entity-relationship level, for linear referencing systems.

Contact Person(s):

Number 8:

Material: Improvements to Utah's Location Referencing System to Allow Data Integration

Objective: To present issues UDOT addressed when it selected its approach to location referencing.

Contact Person(s):

Number 9:

Material: Location Referencing for Intelligent Transportation Systems

Objective: Integrate multiple methods.

Contact Person(s): Stephen R. Gordon, Oak Ridge National Laboratory.

Number 10:

Material: Establishing a Link/Node Referencing System in North Carolina

Objective: To determine a uniform relational database for NCDOT.

Contact Person(s): Mary Opperman Shie-Shin Wu, NCDOT.

Number 11:

Material: Highway Location Reference Procedure Project

Objective: Establish a highway network locational reference process that will allow for proper correlation of pavement management data and provide the basis for other existing and future database integration and GIS.

Contact Person(s): Gene Mangum, Larry G. Walker (C.W. Beilfuss & Associates, Inc.)

Number 12:

Material: Evaluation of GIS done for DOT in 1989

Objective: Updating current information in data base to create better system beneficial to different departments.

Contact Person(s): Keystone Management Systems State College, PA.

Number 13:

Material: Improvements to Utah's Locating Reference System

Objective: Pros and cons of each system. Spatial-Linear, etc.

Contact Person(s): Richard A. Deighton - David G. Blake.

Number 14:

Material: Iowa DOT - Highway Location Reference Procedure Project

Objective: To establish a locational referencing process that will allow correlation of pavement management data and relate DOT data to that of other agencies and allow graphical map displays.

Contact Person(s): Charles W. Beilfuss.

Number 15:

Material: Transportation Location Reference Systems: Problem Definition and Current Topics

Objective: Linear reference methods - overview of elements, description of various methods, challenges, alternative storage methods (fixed-length static) (variable-length static) (dynamic segmentation), advantages/weaknesses, and evaluation criteria.

Contact Person(s): Simon Lewis, GIS/Trans., Ltd.

Number 18:

Material: Dimensionality of Referencing Systems: Integration of GPS and Linear Referencing

Objective: Create a model for the integration of ld and 2d/3d data.

Contact Person(s): TRB.

Number 19:

Material: Optimal Data Model for a Transportation Locational Data Acquisition and Management System

Objective: To define an optimal data model and institutional framework for collecting and managing field derived locational data in support of transportation systems.

Contact Person(s): TRB.

Number 20:

Material: Workshop on a Generic Data Model for Linear Referencing Systems.

Objective: Preparation of a draft consensus conceptual data model for linear referencing systems that can be extended to meet specific needs of various application areas.

Contact Person(s): NCHRP 20-27(2).

Number 21:
Material: FGDC Ground Trans. Subcommittee epg. Position and Recommendations on LRS.

Objective: To provide a consistent framework for incorporating LRS within a network data structure.

Contact Person(s): FHWA.

Number 22:
Material: Theory & Practice: Linear Referencing at the Idaho Transportation Department

Objective: To evaluate Idaho Transportation Department's LRS as compared to Vonderohe's Model.

Contact Person(s): Randolph C. Powell, Idaho Transportation Department.

Number 23:
Material: Federal Agency Needs for Ground Transportation Networks and Network Attributes, September 1993

Objective: Initial step in development of an overall requirements document for spatial data related to ground transportation.

Contact Person(s): Federal Geographic Data Committee, Ground Transportation Subcommittee.

Number 24:
Material: GIS-T '94: GIS and Spatial Data Needs for Urban Transportation Applications

Objective: To suggest needed enhancements to current GIS software to allow use of GIS in urban environments.

Contact Person(s): Bruce D. Spear, U.S. DOT, Volpe National Transportation System Center.

Number 25:

Material: Method For Determining STD Linear Referencing Systems

Objective: Method for determining STD linear referencing systems.

Contact Person(s): Paul Scarponuni, GDSC, Engelwood, Co. 8011.

Number 26:

Material: Linear Referencing Systems Workshop

Objective: Prepare a conceptual data model, at the entity relationship level, for linear referencing systems.

Contact Person(s): Alan Vonderohe, University of Wisconsin, Madison.

Number 27:

Material: Data Structure and Information Coding For Its Location Reference Messages

Objective: 1) To create a data model and structure suitable for loc ref info exchange. 2) Provide strategies to encode loc. ref compactly.

Contact Person(s): Demin, Xiong Oak Ridge Lab, TN37831.

Number 28:

Material: Loc. Ref. Method for ITS.

Objective: Study 5 Loc Ref. Methods and Extract the common components as the basis for a set of standards for a loc. ref. system for its users.

Contact Person(s): Paula Okunieff, Viggen Corp, Boston, MA.

Number 29:

Material: Feature-Based Data Models

Objective: Overview of each referencing system.

Contact Person(s): Charles E. Hickman - Rolla, MO.

Number 30:

Material: Location Translation Within a GIS

Objective: Although many of the off-the-shelf GIS systems allow conversion among a wide variety of planar or spherical referencing systems, few accommodate linear referencing systems, and none provide the capability of translating among linear referencing systems or between planar or spherical and linear systems. The Utah Department of Transportation (UDOT) desired the capability to translate spatial references within the context of their existing GIS-T. This paper discusses some of the issues that arise in the development of location translation systems. A description of the data model and database requirements of the system designed for UDOT is included.

Contact Person(s): Wende A. O'Neill, Elizabeth Harper.

Number 31:

Material: The North Carolina DOT Engineer Database & GIS Project: L.R.S. Review and Recommendation

Objective: 1) Attribute identification and standardization; 2) Database design, processing and development; 3) data management utility tool development.

Contact Person(s): Ed Shuller N.C. DOT and Don Kiel Geo Decisions.

Number 32:

Material: Location Reference Messages Specification - Revision A

Objective: Specification for ITS Location Referencing Worldwide.

Contact Person(s): Cecil Goodwin.

Number 33:

Material: Review Draft Recommendation for Location Referencing For ITS Needs

Objective: The key is to find a common frame of reference for the spatial data. There are two kinds of existing frameworks: topological networks-nodes and links; coordinate systems

Contact Person(s) Cecil W. H. Goodwin, David Siegel, Stephen R. Gordon, Demin Xiong.

Number 34:

Material: Solving Problems: Rethinking the Relationship between Linear Referencing Geographic Referencing

Objective: Discussion on why LRS and GIS are separate issues.

Contact Person(s): Randolph C. Rowell, Idaho Dept. of Transportation.

Number 35:

Material: Linear Referencing: A Theoretical Model

Objective: Analyze a good LRS Model.

Contact Person(s): Randolph C. Rowell, Idaho Dept. of Transportation.

Number 36:

Material: GIS-T Enterprise Data Model with Suggested Implementation Choices

Objective: This paper examines issues of sharing digital road map databases and proposes a data model with suggested implementation choices that can accommodate a range of applications. The proposal is best characterized as a GIS-T enterprise linear data model, suitable for organizations responsible for maintaining roadways.

Contact Person(s): Kenneth J. Dueker, J. Allison Butler, Center for Urban Studies, School of Urban and Public Affairs, Portland, Oregon.

Number 37:

Material: The Case For A Unified Linear Reference System

Objective:

Contact Person(s): David Fletcher, Steve, Gordon, John Espinoza, Bruce Spear, Alan Vonderohe.

Number 38:

Material: A Methodology for Design of a Linear Referencing System for Surface Transportation.

Objective: Develop a methodology for design of a linear datum based on the accuracy requirements of users. A datum design consists of specs for locating anchor points measuring anchor.

Contact Person(s): Alan Vonderohe.

Fairly Relevant

Number 1b:FR

Material: Transportation Location Reference Systems: Problem Definition and Current Topics - GPS

Object: Global Positioning System (GPS) Application - Overview of GPS Applications.

Contact Person(s): William E. Strange, Chief Geodesist - NGS.

Number 2b:FR

Material: Transportation Location Reference Systems: Problem Definition and Current Topics - Appendix 2

Objective: Appendix 2: Comparison of three DOT alternatives Pennsylvania, Delaware, Vermont.

Contact Person(s):

Number 3b:FR

Material: Management Systems Integration Committee Meetings Paper - Common Reference Systems - Page 25

Objective: Role of common referencing systems and data transformation under management systems.

Contact Person(s):

Number 4b:FR

Material: Recommendations for Supporting and Developing Automated Translations Among Location Referenced Systems.

Objective: Create an "infrastructure" to support the development of GIS applications through translation of datum from one location method to another.

Contact Person(s): Location Data Server Task Force - Minnesota DOT.

Number 5b:FR

Material: Recommendation for Location Reference Systems (Executive Summary Only)

Objective: Develop standards for describing the locations of roads, bridges, vehicles, traffic accidents, land use, natural resources and other locatable features.

Contact Person(s): Location Data Standards Group - Minnesota DOT.

Number 6b:FR

Material: Location Referencing Rules

Objective: Identifies methods for specifying places and positions in traffic and travel information messages (DIFACT and RBDS-TMC). Intended to facilitate future extension of the rules to other traffic/travel messaging systems.

Contact Person(s): ENTERPRISE Program ITIS Task Force.

Number 7b:FR

Material: Location Referencing Systems: Analysis of Current Methods Applied to IVHS User Services

Objective: All known LRS will be examined and evaluated for compatibility with a set of desirable criteria formulated by the IVHS community. The criteria are: unambiguous, public domain, automated, machine processable, extractable, multimodal, versatile, flexible, compact, efficient, and compatible.

Contact Person(s): Steve Gordon, Oak Ridge National Lab.

Number 8b:FR

Material: From Map-Based To GIS-Based, A Technical Review of ALISS Migration

Objective: To describe the process Arizona DOT used to convert existing ALISS Technology to state-of-the-art GIS technology.

Contact Person(s): Bo Guo, Joe Breyer; Lee Engineering, Phoenix, AZ; Wayne Rich, Loretta Barcus, Rosemary Hobsett, ADOT.

Number 9b:FR

Material: Automated Collection of Sign Inventory Info - by Integrated GPS with Videologging Data Collection Activities

Objective:

Contact Person(s): John Whited.

Number 10b:FR

Material: Potential for GIS in Transportation Planning and Highway Infrastructure Management (TRB Record 1261)

Objective: None - the report covers five existing GIS projects around the country.

Contact Person(s): Petzold & Freund.

Number 11b:FR

Material: Location Referencing and GPS/GIS for the Information Technology Age

Objective:

Contact Person(s): David Fletcher & Jack Springer FHA Geographic Paradigm Computing.

Number 12b:FR

Material: Research Results Digest Implementation of GIS in State DOTs.

Objective:

Contact Person(s):

Number 13b:FR

Material: Integrated Transportation Information Systems for Managers Handbook page 8

Objective:

Contact Person(s):

Number 14b:FR

Material: GTS Office of Geographic Information Services

Objective:

Contact Person(s):

Number 15b:FR

Material: Hampshire County Council

Objective:

Contact Person(s):Johanna Lusmore.

Number 16b:FR

Material: Michigan DOT

Objective:

Contact Person(s): David Doyle.

Number 17b:FR

Material: Federal Geographic Data Committee - Ground Transportation Subcommittee - Meeting Minutes 4/13/96

Objective: Discussion of committee activities and future direction for the committee. Information discussed was very general in nature.

Contact Person(s):

Number 18b:FR

Material: Integrating CPS into Dynamic Segmentation Linear Referencing Systems - (Proceedings GIS-T '93)

Objective: Discussion of how to integrate attribute data recorded in terms of geographic coordinates with other linear referencing systems.

Contact Person(s):

Number 19b:FR

Material: On the Results of a workshop on Generic Data Model For Linear Referencing Systems

Objective: To establish a generic data model for LRS.

Contact Person(s):

Number 20b:FR

Material: FGDC Ground Transportation Subcommittee Position and Recommendation on Linear Referencing Systems

Objective: To establish a national highway performance monitoring system using state linear referencing systems.

Contact Person(s):

Number 21b:FR

Material: Design Requirements for Location as a Foundation for Transportation Information Systems - GIS-T '93 Proceedings

Objective: Paper describing a Wisconsin DOT analysis of an information strategy plan business area called Location Control Management.

Contact Person(s):

Number 22b:FR

Material: Frameworks for Describing and Evaluating Linear Referencing Systems and Linear Data Models

Objective: To aid in classification of the issues involving Location Referencing Systems and Linear Data Models.

Contact Person(s):

Number 23b:FR

Material: GIS-T Enterprise Data Model with Suggested Implementation Choices

Objective: Propose a data model to share digital road map databases.

Contact Person(s): Kenneth Dueker.

Number 24b:FR

Material: Minnesota DOT Location Data Modeling Effort: Final Report

Objective: Develop a model that defines the objects necessary for describing locations to the relationship between objects.

Contact Person(s):

Number 25b:FR

Material: TRB 1261 - PMS Applications of GIS

Objective: Evaluate feasibility of using GIS technology to satisfy the requirements of the TX SDHPT for the production of maps identifying deficient pavement sections.

Contact Person(s): Paredes, Fernando, Scallion.

Number 26b:FR

Material: TRB 1261 - Automated Conversion of Milepoint data to Intersection/Link Network

Objective: Describes theoretical and practical issues related to conversion from one network data structure to another.

Contact Person(s): O'Neal and Akandi.

Number 27b:FR

Material: TRB 1261 - Using GIS Technology to Enhance PMS

Objective: Use GIS as a framework for data integration data collected under various reference systems.

Contact Person(s): Howard Simkowitz.

Number 28b:FR

Material: An Alternative Approach: Coordinate Snapping

Objective: To establish and explain a LRS that uses existing data and can be implemented with little infrastructure.

Contact Person(s): Viggen Corporation, Boston, MA.

Number 29b:FR

Material: Standard Location Referencing (SLR) System: Road Name ID Scheme

Objective: In this paper the authors discuss various initiatives under way at the International Standards Organization (ISO), the Federal Highway Administration (FHWA) and the Society of Automotive Engineers (SAE) that will have a direct impact on achieving a consensus on an SLR method. A road name ID scheme -- a method that assigns a unique ID to each base name, is proposed and reviewed with the other methods currently under consideration, such as latitude/longitude position scheme, link ID assignments and ordered pair segments and their tradeoffs.

Contact Person(s): Ramesh Ramakrishnan, Clay Collier, Dave Behr - SEI Information Technology - IVHS Group.

Number 30b:FR

Material: A New Location Coding Scheme For Intelligent Transportation Systems

Objective: Many ITS applications require some form of location information. Examine several coding schemes and propose a new location coding scheme based on 1st 3 digits of the zip & local information.

Contact Person(s): Zhihui Huang and Kang G. Shin.

Number 31b:FR

Material: Location Control Management Manual/WI DOT

Objective: To understand divisions information needs - make analysis and integrate current methods into data bases and process data.

Contact Person(s): Julie Crego, WI DOT; Tom Ries WI DOT.

Number 32b:FR

Material: An Expert System to Integrate Highway Maintenance Systems W/GIS

Objective: Explains a system of matching incompatible data sets by breaking down one data sets narrative description of roadways to update GIS data set making highway maintenance data sets usable in a GIS environment.

Contact Person(s): Marsh, P.J. and Kerali, H.R., University of Birmingham, UK.

Number 33b:FR

Material: Geographic Information System Activities

Objective:

Contact Person(s): James Gruver, FHWA.

Number 34b:FR

Material: Transportation Spatial Data Dictionary

Objective: Develop a dictionary as an initial step to standardize definitions and spatial object presentations for transportation features.

Contact Person(s): Federal Geographic Data Committee and Ground Transportation Subcommittee Matthew Rabkin/Sarah Maccalous U.S. Department of Transportation Research and Special Programs Administration.

VOLUME II

APPENDIX C

TEAM REVIEWS OF RELATED LITERATURE

LOCATION REFERENCING SYSTEMS

COLUMN 1 NUMBERS REFERENCE RELEVANT ARTICLES REVIEWED

AND

COLUMN 3 NUMBERS REFERENCE FAIRLY RELEVANT ARTICLES REVIEWED

Appendix C
Location Referencing Systems

System & Number of Report Where Referenced	Relevant	Fairly Relevant	Not Relevant
Linear Referencing 1, 3, 7, 8, 11, 23, 28, 29, 36	lllllll ll	llll 11, 18, 22, 31	
Four-dimensional - 3	l		
County, Route, Segment Number and offset - 4	l		
County, Route, Forward and Reverse Milepoint - 4, 5, 14, 11,	llll		
Route, Direction and Milepoint - 4, 22	ll	ll 20, 26	
GPS - 5, 6, 12	lll		
Coordinates - 3, 9, 23	lll		
Street Addresses - 9	l	ll 20, 30	
Link/Node - 9, 10, 31	ll		
County, Route, Mile Post 10, 31	ll	l 27	
Base Record Sequence Number - 11, 14	ll		
Post Number and Displacement - 3, 10, 11, 14	llll		
Fixed-Length Static - 15	l		
Vonderohe's Model - 22	l		
ITD's LRS - 22	l		
Anchor Segments - 25	l		

Spacial Coordinate Pairs - 28	l		
Intelligent Coordinate Snapping - 28	l	l 28	
Cross-street offset matching - 28, 31	ll		
Link identification using a link reference base map - 28	l		
Pennsylvania, Delaware Vermont		l 2	
Interchange Ramp		l 3	
NAD83 - 38	l	l 5	
Pre-defined primary location extent		l 6	
Pre-defined primary & secondary location		l 6	
Distance Markers (Primary location extent)		l 6	
Coordinates and distance		l 6	
Coordinates (Geometrical)		l 6	
Coordinates (Primary & secondary		l 6	
Proprietary ref. systems		l 6	
Geocoding/Address Matching		l 7	
Highway Performance Monitoring System (HPMS)		l 7	

Cartesian Coordinate System (Long & Lat)		l l 7, 28	
ITS Location Coding Enterprise		l l 7, 30	
Master Table of Unique Street Names		l 7	
ALISS		l 8	
A.T.I.S.		l 8	
Latitude/Longitude		l l 9, 10	
Geodetic		l l 11, 31	
Geographic - 36	l	l l 11, 31	
Framework		l 13	
Generic Data Model for LRS - 38	l	l l 14, 19	
CHALIST		l 15	
Location Control Management		l 21	
Named Road Value		l 23	
Digitized nodes with arcs		l 25	
Intersection/Link		l 26	
Digitizing USGS Maps		l 26	

Reference Post		l 27	
Efficiency		l 29	
Cost		l 29	
Extractable		l 29	
Unique Location		l 29	
Expandable		l 29	
Multi-modal		l 29	
Does not favor particular vendors		l 29	
Non-language dependent		l 29	
Commercial viability		l 29	
Architecture non-sensitive		l 29	
State Plane Lat/Long		l 27	
UDOT's crash reporting system - 30	l		
Datum Nodes - 32, 38	ll		
Milepoint Offset - 36	l		
Lateral Displacement - 36	l		
Variable-Length Static - 15	l		

VOLUME II

APPENDIX D

TEAM REVIEWS OF RELATED LITERATURE

LOCATION REFERENCING METHODS

COLUMN 1 NUMBERS REFERENCE RELEVANT ARTICLES REVIEWED

AND

COLUMN 3 NUMBERS REFERENCE FAIRLY RELEVANT ARTICLES REVIEWED

Appendix D
Location Referencing Methods

Method & Number of Report Where Referenced	Relevant	Fairly Relevant	Not Relevant
Mileposts - 1, 3, 4, 11, 23	lllll	1 34	
Segment Number & Offset - 4	l		
Reference Post - 3, 4, 8, 13, 30	lllll		
Reference Point (Miles, Kilometers) - 3, 4, 11, 22	llll	ll1 6, 12, 34	
Control Section and Control Segments - 3	l		
Stations - 3, 11, 10	lll		
Link/nodes - 3, 4, 9, 10, 11, 31	llllll	lll 11, 31, 32	
Public Land Survey (PLSS) -3	l	l 5	
GPS - 5, 6, 9, 11, 12,	lllll	l 30	
Street Addresses - 1, 4, 9, 23, 30, 31	llllll		
County/Route/Milepost - 10 30, 31	lll	l 12	
Political Subdivision - 11	l		
X-Y Cartesian Coordinates - 11, 31	ll		
Milepost/Milepoint/Segmen-tal Cross Reference - 11	l	l 34	
Dynamic Segmentation - 15	l	ll 7, 12	
Spatial/Linear/Segmental Cross Reference - 11	l		

Fixed-Length Static - 15	l		
Map coordinates - 30	l		
Vonderohe Model - 22	l		
Coordinates		l 5	
Linear Referencing		lll 5, 33, 34	
Location Names		ll 6, 30	
Latitude/longitude - 31	l	llll 6, 7, 10, 23	
Rectangular grid		l 6	
ITIS, ENTERPRISE		l 7	
Master Table of Unique Street Names		l 7	
A.T.I.S.		l 8	
Generic Data Model for LRS		l 19	
Coordinate Snapping		l 28	
WGS-94 Datum - 32	l		
Nodes (Datum Nodes) - 32	l		
Alert C		l 30	
Narrative Description		l 32	
Variable-Length Static - 15	l		

VOLUME II

APPENDIX E

TEAM REVIEWS OF RELATED LITERATURE

OTHER RELEVANT OVERALL SYSTEM ISSUES

(LISTED BY BIBLIOGRAPHICAL REFERENCE NUMBER)

Appendix E

Other Relevant Overall System Issues (accuracy, maintenance):

1. Standards are being suggested to promote nationwide consistency.

2. Any generic data model for GIS-T must include linear referencing components.

   Linear referencing systems must be linked to higher-dimensional systems, including those that model time.

   Changes in the datum, caused by changes in alignment, generate a cascade of changes in the database (for mappings between the datum and cartographic representations, for mappings between the datum and networks, for specification of traversals, and for offsets of traversal reference points and events).

   The model must be able to handle very large databases.

   What are the rules for establishing linear referencing method starting and ending points?

   What is the best method for referencing ramps?

   The location of any unknown point along a linear feature can be determined by specifying the direction and distance from any known point to the unknown point. All linear referencing methods are based on this.

   The data model must support certain fundamental operations: establishment of the location of an unknown point in the field by reference to objects in the "real world"; translation of a real-world location into a database location; translation of a database location into a real-world location; conversion between various linear referencing methods (represented by database locations) and between various cartographic representations.

3. Peggi Knight notes that C.W. Beilfuss recommended that for the most accurate location referencing, use milepost markers (which are actually reference posts). We abandon the fractional/decimal milepost system and instead use reference post +/- offset distance (e.g. US 30, eastbound, RP 148 + 0.69 km). The reviewer agrees this should be the way we reference to our mileposts whenever high accuracy is required.

GPS could be used to determine and maintain the location of reference posts. (Reviewer's note: this is exactly what we intend to do, beginning this year!)

The Cartography Section of the IDOT uses a Lambert Conformal projection with two standard parallels (33 and 45 degrees) for all of the maps produced.

4. About 60 percent of the data in a DOT has location as a principal reference.

   GPS will provide an accurate place and time stamp for data collection activities.

5. Accuracy - must be unambiguous.

6. Accuracy - needs improving (possibly using differential methods)

7. Model will support multiple into graphic representation and multiple methods and multiple linear referencing methods.

8. Ease of conversion to metric units. Standard address format will be used. Ease of maintenance.

9. Nothing

10. Maintenance by many offices (some reluctant to change).

    Accuracies will improve as GPS coordinates are used to locate nodes.

11. The system must be comprehensive. Maintain system with timely and regulated updates. Established procedures must be communicated throughout the DOT. Provide a common and precise location scheme for data located along or on the road network. The location reference must be unique and unconditionally repeatable despite collection procedures or network changes. (See attached page II-l.) Need a complete geographic description of each route. (See attached pages II-6, V-4, V-5).

12. Nothing

13. Nothing

14. Comprehensive systems, timely and regulated updates, timely route revision notifications, correlation of route segmentations, correlation of geographically based data, firm interagency working relationship.

15. Nothing

18. Nothing

19. Nothing

20. Nothing

21. Nothing

22. Parsimony - Economy of explanation; simplicity - (Occam's Razor); utility - usefulness

23. Accuracy, basemap scale, establishing a standard map projection, attributes to include in the basic national transportation network.

24. This paper explained a series of suggestions for improving existing GIS software applications.

25. Did not require a change in data input methods- so may give wrong results., i.e., traffic volumes are "directed" while accident data is "laned".

26. Use standard (unambiguous) definitions for data base items. Very accurate.

27. Nothing

28. Nothing

29. Nothing

30. Nothing

31. Nothing

32. Nothing

33. Nothing

34. Nothing

35. The LRS to be effectively used by any application, must be independent from all applications. In this LRS, however, the number and type of attribute data tables is determined by the organization needs and allows unlimited expansion with utility and stability.

36. In order to serve the database registration function, an anchor point must be present in all databases. Anchor points could be placed at prominent bridges and intersections, for example. Anchor points must be defined at least for the beginning and ending locations of anchor sections. Anchor points have only a real-world identifier, such as the name of an intersection. The real-world location (address) of an anchor point is given by a geographic point.

Location referencing systems (LRSs) include two-coordinate methods such as latitude/longitude, three-coordinate methods that also include altitude, and one-coordinate methods that show where an object is located in reference to a known point. The last type is called a linear location referencing system.

Under no circumstances should the name of a transportation feature be something that may change, such as its route number.

The physical location of a point event on a transportation feature is found using a linear LRS, typically a milepoint offset (analogous to an x-coordinate) from the transportation feature's point of origin. If a point even is laterally offset from a road, as in the case of a roadside sign, then the feature location is also found by applying a lateral offset value (analogous to a y-coordinate).

Many transportation databases include data elements that are lane-specific or side-specific. For example, traffic volumes may be recorded by lane, while pavement type may be stored by side of road for divided highways. Lateral offsets may be needed to locate point events adjacent to a transportation feature position.

Fairly Relevant Overall Issues

1. Nothing

2. Nothing

3. This report looks more at the administrative functions and problems relating to developing a common reference system.

4. Task force recommends against developing a "grand" location translation server. Instead, focus attention on improving the accessibility and support of existing translation methods.

   Executive summary was all that was included for review. Full report may be more relevant.

5. Only the executive summary was included for review. The full report may have additional useful information.

6. All three methods can be supported by traffic/travel messages using look-up tables to convert between methods.

   Pre-defined locations are referenced by their location number (tabular address). These should correspond to digital map features whenever practical.

   Hierarchical tables help to make location referencing simple and unambiguous providing automated sorting and selection of information.

   Location types and subtypes are required for language independence and to tell the system what data fields to expect.

   Primary and secondary locations are used to indicate extremities of sections.

   To avoid ambiguity, a rule must be adopted that both the primary and secondary locations lie on the same route.

7. Use a relational database (p. 25).

8. Nothing

9. Chapter 6 gives information of test results using GPS in different modes.

May be useful when we establish system accuracy.

10. General accuracy of 0.01 mi (50') will often be sufficient.

11. Nothing

12. Base map maintenance mixing data of varying quality and scale with base map results in difficulties.

13. Nothing

14. Nothing

15. Nothing

16. Nothing

17. Area to share information - GTS home page maintained by the Bureau of Transportation Statistics.

18. Dynamic Segmentation - How to get all data into a common form so dynamic segmentation will function.

19. Terms/Definitions, scope, schema constructs, transformation, multi-dimensionality, methods/coding, data integrity.

20. Accuracy - system must contain route IDs and beginning/ending reference points for each segment.

21. Accuracy and extent of coverage, ability its support multiple linear reference system.

22. Development of other referencing systems and ease of transformation among systems.

23. Spatial data transfer standards (SDTS).

24. Nothing

25. Used county highway maps to digitize nodes.

26. Tiger files or USGS 7.5 min. guad. maps.

27. Tiger files & USGS 1:100,000 scale.

28. Unambiguous/identifier, cost-effective, flexible, compact.

29. Type: type of information being transmitted (delay, turn impedance, etc.)

On: Road Name ID of the road of travel

FROM: Road Name ID of the "from" crossroad

TO: Road Name ID of the "to" crossroad (if necessary)

CITY: to distinguish between ambiguity (if necessary)

DATA: traffic flow or incident data

VOLUME II

APPENDIX F

TEAM REVIEWS OF RELATED LITERATURE

CONCLUSIONS AND RECOMMENDATIONS

OF TEAM LITERATURE REVIEWS

FOR RELEVANT ARTICLES/REPORTS

(LISTED BY BIBLIOGRAPHY REFERENCE NUMBER)

Appendix F
Conclusions & Recommendations

1. This is a recommendation only. The goal is to encourage states to adopt more standardized linear referencing systems that will satisfy FHWA's Highway Performance Monitoring System's requirements.

2. A need for extension of the data model to include particulars for specific application areas should be expected. Potential application areas include infrastructure management, transit, freight, intelligent transportation systems, urban planning, waterway navigation, and seismological testing.

   The most significant unresolved point of contention has to do with the nature of traversals and the associations among linear referencing methods, networks and the datum. Some participants believe that traversals (at least the ones containing traversal reference points) should be associated with the datum and not with networks. The contrary position is that linear referencing is inherently network-based.

3. Develop a single referencing system for the DOT.

   Involve the whole department in choosing and developing the single referencing system.

   To provide effective involvement and coordination, develop a department-wide committee for transportation information systems. The role of this committee will be to represent divisions in important decision-related to developing a single referencing system.

   Provide staff for the Transportation Information Systems Committee. In order to provide the resources and authority, time should be allocated as part of a job description rather than a "voluntary" activity on the part of a committee member.

   Eliminate one or more redundant referencing methods.

   (Interim) It will take some time to implement each of the recommendations made above. In the interim, it will be important to develop and improve cross-referencing techniques between the systems in use.

REVIEWER RECOMMENDS THAT THIS PAPER BE READ BY ALL MEMBERS OF THE LRS COMMITTEE.

4. Existing LRS usage in most DOTs is "well-institutionalized." We must review new spatial data processing technologies and must ask ourselves "Do the existing systems work?" We need to pay special attention to GPS and GIS developments. Above all, we need to look at the "big picture" and make suer our present and future activities will fit into the overall information technology, GIS strategic, and implementation plans.

5. The New Mexico State Highway & Transportation Department recommends:

   The NAD83 mathematical reference framework be adopted as the underlying reference for data.

   All field surveys for projects be tied to New Mexico GPS reference network pending requisition of receivers/network completion.

   Department should support research into expanded GPS applications.

   Department should acquire as much existing non-redundant digital map data as is available to constitute an initial statewide geographic database.

   Pursue ways to update the acquired digital map data to a current level and plan for long term methodical updating.

   The department should acquire a GIS, load all data into system, and develop a practical pilot project, and proceed with full implementation pending success of the pilot.

   Maintain a graphical project database through the CADD design process which preserves linkages to geographic position.

6. The system demonstrated an ability to facilitate the collection of road inventory features at a reasonable cost. Software limitations (editing capability at time of entry) and accuracy limitations can be improved through use of newer technology (i.e. differential).

7. This report is relevant to the project but very difficult to read and understand.

8. Well-written report that provides good information on the process UDOT

used in developing its location reference system.

9. No need for common or even non-proprietary method - combination of multiple methods.

   Use National Highway Planning Network (NHPN) as basis for link/node IDs. Use multiple methods for locations not on NHPN (lat/long combined with street ID) standard interface for transfer of location info via multiple methods.

10. None

11. Prepare, distribute and maintain an instructional document, explaining the reference system. It should describe accuracy of the linear and spatial reference systems, how to use the reference systems, and which system is not relevant for a specific purpose.

12. None

13. Use reference post method.

14. (Immediate Action) Assign overall data management coordination responsibilities, create a "clearing house" for data.

    Revise milepost reference system to reflect milepost number and positive/negative displacement. Redesignate duplicate mileposts to eliminate duplicity.

    Enhance milepost/milepoint cross-ref scheme to accommodate plus/minus nomenclature and to take into account milepoint discontinuities.

    Align pavement management sections/test sections by milepost with base record breaks. Include P.M. segment designator on the base records and P.M. sections.

    Increase P.M. sections/test sections by milepost to include all pavement type changes and age of pavement changes.
    - would allow exact correlation of 18 kip esals

    Take age of data into account when calculating PCRs.

    Establish historical requirement criteria for P.M. data. Priorities data sets for processing.

(Near term action) Implement a geographic node and shape description data base as precursor to a DOT GIS. Include linear/spatial conversion utility routines.

Define user, application and system requirements for DOT GIS.

Improve correlation of construction history records to P.M. records.

Begin processing high priority P.M. data to reflect historical significance.

Convert manual/PC-only P.M. data to mainframe.

Hasten implementation of automatic truck weight and classification system.

Implement data base for P.M. data include segment designator.

Prepare/distribute/maintain instructional document explaining ref. systems (linear and spatial).

(Long-term) Implement dynamic segmentation of P.M. sections.

Establish additional monuments along routes.

Continue processing P.M. data to reflect historical significance.

Implement DOT GIS.

15. Nothing

18. Nothing

19. Nothing

20. Nothing

21. A standard data structure, together with key attribute fields required to support such a data structure, be included as part of any transportation network profile established under the spatial data transfer standard.

Any transportation network databases developed as part of the National

Spatial Data Infrastructure (NSDI) framework include and populate, as part of their code data, all key LRS attribute fields.

22. IDOT's MACs/Rose follows the principles of Vonderohe's model but eliminates complications by avoiding the use of using attributes to reference attributes.

23. This report presents a summary of federal agency needs for grown transportation networks and network attributes. It will lead to the development of a document that will present overall requirements for spatial data for transportation.

24. Develop a TNP (transportation network profile) that allows incorporation of non-planar networks (i.e. over/underpasses), link directionality attributes, an adequate LRS, node impedances, route/trip spatial objects, and matrix handling capabilities.

    The software should have temporal (time) dimension display capabilities. It should have "near-real time" capability, store time-sensitive network attributes (i.e. have reversible lanes, peak/off peak traffic volumes), and have an internal clock to synchronize movements through a network.

    The ability to create and display multi-dimensional displays depicting changes over time.

25. Nothing

26. Let us review this in detail.

27. Unambiguous location information representation.

    Compactness for efficient info transfer.

    Flexibility.

28. These five sets are capable of supporting multiple methods under a single system.

29. Nothing.

30. The prototype application which was developed using these algorithms has shown that multiple linear referencing can be accomplished using desktop GIS capabilities. The application is practical to implement and could be

used to support additional analysis capabilities which rely on multiple location referencing and spatial analysis. The biggest constraint to implementation is the development of an accurate and complete database. Additional locational referencing methods such as GPS, grid parcel address, and intersection offset are methods which will be explored and added to the application in the future.

31. Attached. Worth reading. It would be worthwhile to get the full report from North Carolina DOT.

32. Nothing.

33.
1. Adopt a common frame of reference (datum)
   Specify a standard internal interface format for the datum

2. Adopt the National Highway Planning System Network (NHPN) as the data set for the ITS datum because it:

   - Already exists;
   - contains all roads;
   - is public domain;
   - has geographic coordinates of nodes, and in sufficient density to support coordinate based referencing;
   - contains network topology to serve as datum for linear and link based referencing; and
   - is easy to maintain.

3. Survey the NHPN with differential GPS to:

   - Improve the accuracy to 3-5 M
   - Measure link ground distances accurately

4. Adopt a national standard interoperability protocol

5. Adopt a standard data presentation format

34. Linear Referencing Systems and Geographic Referencing are different creatures and need to be evaluated independently.

35. Randy describes an LRS to perfection in a very clear, concise and precise manual. He makes emphasis on age (time) as a basic coordinate in a location system.

36. The endpoints of a transportation feature must be tied to anchor points if the feature is to be located within a geographic datum. To be valid, a datum must be tied to physical, real- world locations that are unambiguously defined. This would seem to eliminate such field references as county lines and other jurisdictional boundaries tied to monumentation since the monuments (signs) may not be properly and/or consistently placed. However, the linear LRS will work best if its origin is the beginning point of the road in the jurisdiction. The reconciliation of these two needs is to reference the jurisdictional boundary to an anchor point that is unambiguously defined; i.e. make the location of the transportation feature origin 0.000 at the jurisdictional boundary, but locate the boundary (and origin) as an offset (plus or minus) from an anchor point. The transportation feature is thus unambiguously tied to a datum-compatible location.

The strength of the proposed model is compartmentalizing graphic, attribute (using linear referencing), and network components, whereas other data models have overly integrated them. However, the key is a flexible data model to enable integrating the components for specific applications.

VOLUME II

APPENDIX G

LOCATION REFERENCE SURVEY

LETTER AND FORM

Appendix G

IOWA DEPARTMENT OF TRANSPORTATION

TO OFFICE: DATE: December 9, 1997

ATTENTION: REF. NO.: 300

FROM: Location Reference Process Improvement Team

OFFICE:

SUBJECT: Location Referencing Process Improvement Project

A group representing several of the Divisions of the Department has been formed to investigate and recommend a location reference system for the Department. The reference system will initially be used in the redesign of the "Base Record" data base maintained by the Office of Transportation Data. Ultimately, the system will support the integration of data from the different offices and divisions. We are requesting your assistance with the project as we work through the investigation phase. The reference system recommended should be one that will support the needs of the different offices and divisions.

To make sure that all the needs of the Department are considered, we are asking your help to identify the needs of your office. Attached is a list of features and events that were identified by your office during a Geographic Information System (GIS) study conducted by Iowa State University for the agency in 1994. Please provide the information needed and add any applications that you feel should also be considered. If you have any questions or comments, the people representing the divisions are:

John Nervig	1428	Engineering
Jaime Reyes	1077	Engineering
Francis Todey	1398	Maintenance
Richard Rothert	237-3073	Motor Vehicle
Dave Oesper	1038	Operations and Finance
Steve Kadolph (Co-chair)	1677	Planning and Programming
Ralph Crawford	1615	Planning and Programming
Peggy Knight	1380	Planning and Programming
Annette Jeffers (Co-chair)	1079	Project Development
Alice Welch	1041	Project Development
Kevin Jones	1232	Project Development

Thank you for your assistance with this project.

Location Referencing Process Improvement Project Survey

Division:	**Office:**	**Original information provided by:**
Engineering	Safety	John Nervig, Fred Walker (Engineering, Safety)
Field Services		Bob Younie (CEIATC); Jim Nelson, John Sommers, Ken Stark, Roger Workman, Richard Peterson, Newman Abuissa, Keith Norris (NEIATC); David Ellis (SEIATC); Mr. Burr (ECIATC); Jim Andersen (NWITC); Jon Singelstad (S
Maintenance		Duane Smith, John Selmer (Maintenance)
Maintenance	Bridge Management	Bridge Management Technical Committee, Chair: Bruce Brakke (Maintenance, Bridge Management)
Motor Vehicle	Motor Carrier	Carol Crouse, Gerry Ambroson, Ruth Skluzacek (Motor Vehicle, Motor Carrier Services)
Motor Vehicle	Driver Services	Terry Dillinger (Motor Vehicle, Driver Services)
Old Air/Transit		Harry Miller (District Planners, Old Air and Transit)
Old Rail/Water		Peggy Baer, Dennis Burkheimer (Program Management, Maintenance - Programs; Old Rail and Water)
Planning and Programming	Planning Services	Tom Jackson, Marlee Walton, Ruth Vander Shaaf (Program Management, Planning Services)
Planning and Programming	Project Planning	Harry Budd, Marty Sankey (Planning and Programming, Project Planning)
Planning and Programming	Program Management	Jerry Solbeck, Gene Jones, Carol McDaniel, Rynie Foss (Planning and Programming, Program Management)
Planning and Programming	Systems Planning	Lorne Wazny, Craig Markley (Planning and Programming, Systems Planning)
Planning and Programming	Traffic Survey	Gordon Peterson, Ron Bunting, Sam Basu (Planning and Programming, Traffic Survey)
Planning and Programming	Base Records	Karen Carroll, Ken Hawly, Bill Hall, Carol Becvar, Neil Tarman, Sheri Anderson, Scott Burklund, Bill Lutz, Leroy Hamilton, Bill Samuell (Planning and Programming, Base Records)
Planning and Programming	Cartography	Randy Patterson, Brenda Leerhoff, Judy Allen, Denny Sills, Tom Olsen (Planning and Programming, Cartography)
Project Development	ROW	Jim Olson, Fred Cirksena (Project Development, ROW)
Project Development	Road Design	Mel Nutt, Tracy Fultz (Project Development, Road Design)
Project Development	Materials	Kevin Jones (Project Development, Materials)
Project Development	Construction	John Smythe, Donna Buchwald, Jim Rost (Project Development, Construction)
Project Development	Bridge Design	Bill Lundquist, Dean Bierwagen (Project Development, Bridge Design)
Project Development	Contracts	Roger Bierbaum (Project Development, Contracts)

Please return to:
Steve Kadolph, Planning Services, 239-1677, by May 16, 1997

Directions:
In 1994, your office participated in a survey in which potential applications of geographic information systems (GIS) were identified. Based on your responses, the following list of data features/events was developed.
Features/events may occur on, along, or near transportation infrastructure and may be described by multiple attributes, or data sets.

(1) Please review the list and add any additional, relevant features/events and remove those which do not apply.
(2) If a feature is currently used by your office, please mark "Yes" and identify how the location of the feature is referenced with a "U" for in use. (More than one method may be identified.)
Please also note how your office would like to reference the feature with a "D" for desired, if different from the method currently used. (More than one method may be identified.)
If a feature is currently not used by your office, and it is a feature you plan to use, please note how your office would like to reference the feature with a "D" for desired. (More than one method may be identified.)
(3) If your office is, or will be, the source (collector or provider) of the feature related data, or a portion of it, mark "Your Office".
If another office(s) will provide the data entirely, or provide a portion of the data, please list them under "Other Offices".
If you do not know which office(s) may provide the data, please enter a "?" under "Other Offices".
(4) If a feature is currently used by your office, please identify the existing level of accuracy (if known) with a "U" for in use. (More than one method may be identified.)
Please also note a reasonable, desired accuracy level with a "D" for desired, if different from the accuracy level currently used. (Please identify only one.)
If a feature is currently not used by your office, please note the desired, reasonable accuracy level with a "D" for desired. (Please identify only one.)
Note: Please realize that higher levels of accuracy will be more costly to obtain.

Feature/Event*	Currently in Use		Referencing Method: U (in use); D (desired, if different)							Data Sources		in use); D (desired, if different)					
(to be location referenced)	Yes	No	Milepost	Milepoint (kmpoint)	Link-node	Coordinates (e.g. GPS)	Stationing	Literal Desc.	Other (Please list)	Your Office	Other Office(s) (Please List)	10-100m	5-20m	1-10m	.1-5m	1-50cm	<1cm
accidents (EXAMPLE from Safety)	X		U, D (Primary Sys)	U, D (Primary Sys)	U	D	D			No	Driver Services, Motor Vehicle Div	U,D (Rural)	D (Muni)				
guardrail, fences																	
projects																	
bridges																	
accidents																	
intersections																	
traffic																	
culverts																	
roadside obstacles																	
roadway features																	
railroad grade crossings																	
curves																	
safety improvements																	
watershed, drainage																	
adopt-a-highway																	
bridges																	
guardrails and pipes																	
pavement																	
ROW																	
parcels																	
accidents																	
detours																	
speed zones																	
no passing zones																	
land use																	
trails																	
hydrology																	
topography																	
railroads																	
traffic																	
utilities																	
sign inventory																	
lane/pavement markings																	
various routing (routes)																	
bridges, bridge maintenance																	
pavement sensors																	
speed zones																	
railroad crossings																	
mile post locations																	
const. site/detour signing																	
utilities																	
signs																	
pavement, maintenance man.																	
freeway ramps																	
culverts/other structures																	
lighted intersections																	
traffic																	
guardrails																	
bridges																	
bridge																	
traffic																	
truck routes																	
speed limits																	
accidents																	
road closures, embargoes																	
population																	
projects																	
vertical clearances																	
intersections																	
accidents																	
airports																	

accidents																	
obstructions																	
railroads																	
accidents																	
traffic																	
projects																	
traffic generators																	
truck routes																	
hazardous waste sites																	
recreational trails																	
cemeteries																	
endangered species																	
material pits																	
demographic (pop. & employ.)																	
accidents																	
topography																	
prehistoric/national register sites																	
utilities																	
pavement																	
projects																	
ROW																	
flood plains																	
property																	
environmentally sensitive areas																	
wetlands																	
railroads (and crossings)																	
rivers																	
river ports																	
intermodal facilities																	
airports																	
census transportation planning package																	
access																	
alternative transportation networks																	
traffic																	
river terminals																	
railroads																	
transp. improvement programs																	
airports																	
RISE project sites																	
demographic																	
pipelines																	
intersections																	
bike paths																	
airports																	
traffic																	
ATR locations																	
speed limits																	
weigh-in-motion																	
pavement																	
ROW																	
signs																	
hospitals																	
misc. mapping																	
projects																	
ROW																	
property																	
lakes, streams																	
wetlands																	
utilities																	
Federal lands																	
survey																	
soils																	
railroad data (crossings)																	
property																	
wetlands																	
accidents																	
pavement, PMIS, history																	
vertical clearances																	
traffic																	
projects																	
bridges																	
pavement, PMIS, test																	
projects, material location																	
utilities																	
site and construction management																	
ROW																	
wetlands																	
culverts																	
soils																	
survey																	
property																	
underground storage tanks																	
bridges, bridge management																	
project (begin/end lat/long)																	

* Based on the expected errors of the following global positioning system (GPS)

collection and processing mechanisms:

Standard positioning system with selective availability	100m
Standard positioning system without selective availability	10-30m
Precision positioning system	5-20m
Wide area differential GPS	1-10m
Local area code differential	.1-5m
Dynamic survey	1-50cm
Static survey	<1cm

VOLUME II

APPENDIX H

SUMMARY AND RESULTS

OF

LOCATION REFERENCE SURVEY

Table 1 Summary of Referencing Methods

(a) Mile Posts

Division	Desired	Used	Total
Air/Transit			0
Engineering	3	4	7
Maintenance		1	1
Motor Vehicle	4	1	5
NEITC	15	3	18
Planning		5	5
Project Development	1	12	13
Rail/Water		2	2
SEITC	2	4	6
SWITC	2	4	6
Total	**27**	**36**	**63**

(b) Mile Point

Division	Desired	Used	Total
Air/Transit			0
Engineering	3	4	7
Maintenance			0
Motor Vehicle	4	1	5
NEITC	10		10
Planning		5	5
Project Development		6	6
Rail/Water			0
SEITC	1	3	4
SWITC	3	1	4
Total	**21**	**20**	**41**

(c) Link Node

Division	Desired	Used	Total
Air/Transit			0
Engineering		5	5
Maintenance			0
Motor Vehicle		1	1
NEITC	2	1	3
Planning	1	6	7
Project Development		3	3
Rail/Water			0
SEITC		3	3
SWITC		1	1
Total	**3**	**20**	**23**

(d) Coordinates

Division	Desired	Used	Total
Air/Transit		1	1
Engineering	14		14
Maintenance		1	1
Motor Vehicle	1		1
NEITC	12		12
Planning	29	13	42
Project Development	14	11	25
Rail/Water	2		2
SEITC	8		8
SWITC	12	2	14
Total	**92**	**28**	**120**

(e) Stationing

Division	Desired	Used	Total
Air/Transit			0
Engineering		1	1
Maintenance			0
Motor Vehicle			0
NEITC	9	1	10
Planning	1	9	10
Project Development	1	21	22
Rail/Water			0
SEITC	6		6
SWITC	2	26	28
Total	**19**	**58**	**77**

(f) Literal Descriptions

Division	Desired	Used	Total
Air/Transit		1	1
Engineering	2		2
Maintenance			0
Motor Vehicle		6	6
NEITC	6		6
Planning	4	22	26
Project Development		6	6
Rail/Water	2		2
SEITC	2	7	9
SWITC	1	7	8
Total	**17**	**49**	**66**

(g) Overall Summary of Methods

Division	Desired	Used	Total
Mile Posts	27	36	63
Mile Points	21	20	41
Link Nodes	3	20	23
Coordinates	92	28	120
Stationing	19	58	77
Literal Description	17	49	66

Table 2 Referencing Accuracies

(a) 10 to 100 Meter Accuracy

Division	Desired	Used	Total
Air/Transit			0
Engineering	1	5	6
Maintenance		1	1
Motor Vehicle		1	1
NEITC	6		6
Planning	2	20	22
Project Development		9	9
Rail/Water			0
SEITC	1	1	2
SWITC	1	3	4
Totals	**11**	**40**	**51**

(b) 5 to 20 Meter Accuracy

Division	Desired	Used	Total
Air/Transit			0
Engineering	8		8
Maintenance			0
Motor Vehicle	5		5
NEITC	1		1
Planning	10	16	26
Project Development		5	5
Rail/Water			0
SEITC	4		4
SWITC	1	1	2
Totals	**29**	**22**	**51**

(c) 1 to 10 Meter Accuracy

Division	Desired	Used	Total
Air/Transit			0
Engineering	3		3
Maintenance			0
Motor Vehicle			0
NEITC	8		8
Planning	7	4	11
Project Development	4	3	7
Rail/Water	1		1
SEITC			0
SWITC	2		2
Totals	**25**	**7**	**32**

(d) 1 to 50 Centimeter Accuracy

Division	Desired	Used	Total
Air/Transit			0
Engineering	2		2
Maintenance			0
Motor Vehicle			0
NEITC	7		7
Planning			0
Project Development		3	3
Rail/Water			0
SEITC			0
SWITC	11	8	19
Totals	**20**	**11**	**31**

(e) Less than 1 Centimeter

Division	Desired	Used	Total
Air/Transit			0
Engineering			0
Maintenance			0
Motor Vehicle	1		1
NEITC			0
Planning			0
Project Development		5	5
Rail/Water			0
SEITC			0
SWITC	3	10	13
Totals	**4**	**15**	**19**

(f) Summary Data

Division	Desired	Used	Total
10 to 100 Meter	11	40	**51**
5 to 20 Meter	29	22	**51**
1 to 10 Meter	25	7	**32**
1 to 50 Centimeter	20	11	**31**
<1 Centimeter	4	15	**19**
Total	**89**	**95**	**184**

VOLUME II

APPENDIX I

SURVEY SUMMARY

	USED			MPST		MPNT		LINK		CRD		STA		LIT		10-100M		5-20M		5-10M		0.1-5M		1-50CM		<1CM	
FEATURE	YES	NO	BLANK	USED	DES	USED	DES	USED	DES	USED	DES	USED	DES	USED	DES	USED	DES	USED	DES	USED	DES	USED	DES	USED	DES	USED	DES
Access	1	1		1	(1)		1				2	2	(1)			1					1						
Access Points			1		1						1										1						
Accidents	8	1	2	8	(3)	5	(2)	7			9		3	2	1	5	(2)		3		1	1	1				
Adopt-a-Highway		2		1	(1)									1							1						
Aerial Photography	1										1					1											
Aggregate Product Location	1															1											
Airports	6									4	2			2	1	2		1	1				1				
Runway Features	1										1												1				
'Alternative Transportation Networks	1							1			1			1		1											
ATR Locations			1			1								1						1							
Bridges	10	1		4	1	3	1	3		4	3	4	1	3	1	3	(1)	2	2		2	2	1			1	
Cemetaries	1										1								1								
Census Transportation Planning Package	1									1						1											
Construction Placement History	1				1							1						1									
Crossing Locations			1								1												1				
Culture	1									1								1									
Culverts	3		2	1	1	1	1	1		2	2	3		2		1		1			2			1			1
Guardrails and Pipes		2	1				2				2												2				
Curves	1										1								1								
Demographic (Pop. & Emp.)	2	1								1	1	1		2		1	(1)	1									
Detours		1	1		1										1		1										
Employees in Vehicles		1			1		1								1		1										
Endangered Species/Habitat	1										1	1		1				1			1						
Environementally Sens. Areas	1										1	1		1		1			1								
Federal Lands	1										1		1														
Flood Plains	1										1			1		1	(1)										
Geodetic Control	1									1																1	
GPS Coordinates	1									1										1							
Hazardous Waste Site	1										1			1				1	(1)								
Hospitals	1									1																	
Hydrology	3	1	1							1	1	1			1		1	1			1						
Intermodal Facilities	2		1								3				2		1		2								
Intersections	3				1		1	2			2			2	1	1			2								
Land Use		1	1		2						1		1		2		2										
Mapping features	2									2						1		2			1						
Material Pits	1										1	1		1		1			1								
Navigation Aids			1								1												1				
No Passing Zones		1	1		1																						
NRHP Historic/Achitectural Sites	1										1	1		1				1			1						
Roadside obstacles		1	1		1		1				2								1								
Pavement	10			8 (1)	1 (2)	2	2		1		2	3	1	2		3		2	2			1	1				
Patch Locations		1			1		1						1										1				
Pipelines			1								1			1		1											
Projects	7		2	2	1 (1)	2	1			2	2	6		2		2			2			2		1		2	
Projects, Material Location	2									1	(1)	1		1		1	(1)			1							
Property	5	1	2	1	1						3	5	1	1		1			1					1	1	3	
Railroads (including crossings)	7	1	4	1	1	1	1	2			8	2	2	1	1	3	1	1	1		3		2			1	
Trails, Bike Paths	3	1			1						2			3	1	1	1	1									
Rest Areas/Parks	1											1															
Rise Projects			1																								
River ports, terminals	2		1								3			1	1	1			1				1				
River Gauge Stations			1																								
Road Closures/Embargos	1				1		1							1					1								
Roadway Features			1			1					1								1								
Roadway Safety Features		1			1		1				1		1								1		1				
ROW	3	2	2		1						2	3	1	1										1	1	1	1
Safety Improvements	1			1	(1)	1	(1)				1					1			1								
Sign Inventory		2	2		1		1				2		1										2				
Sign Trusses	1			1		1					1		1	1				1			1						
Site and Construction Management	2			1						1		2												1	1		1
Soils																											
Speed Limits, Zones	2		2		1		1				1		1						1								
State Parks/Institutions	1									1								1									
Survey	4									1	1		4	1												4	
Switches			1								1												1				
Topography	1	1	1												1		1	1			1						
Traffic	6	2		3	1 (1)			4	1		3		1	3	1	2	2			1							
Traffic Striping		1			1		1						1								1		1				
'Trans. Improvement Programs	1								1		1			1		1											
Truck Routes		1																									
Underground Storage Tanks	2										1	2										2					
Utilities	5	1		1	1		1				3	2	1	1					1		1	1	1		1		
Vertical Clearence	3			1	1		1							1										1			1
Videolog Van	1			1		1					1	1								1							
Water Locks/Dams			1								1										1						
Watershed, Drainage	1	1			1		1				2			1	1				1		1						
Weigh in Motion	1					1								1						1							
Wetlands	6									1	2	6		2		1			1	1	1		1			2	

VOLUME II

APPENDIX J

BIBLIOGRAPHY

Relevant Bibliography

1. "FGDC Ground Transportation Subcommittee Position and Recommendation on Linear Referencing Systems" July 21, 1994

2. Conducted by University of Wisconsin-Madison with Support from the National Cooperative Highway Research Program "NCHRP 20-27(2) Location Data Modeling Workshop" August 5-6, 1994

3. Knight, Peggi "Evaluation of Referencing Systems for the Iowa Department of Transportation" November 28, 1994

4. Petzold, Roger, FHWA; Lewis, Simon, GIS/Trans, Ltd. Pre-conference Workshop "Linear Referencing Systems & Dynamic Segmentation" April 10, 1994

5. Henderson, Thomas, P.E., R.L.S. Geometronics Unit Manager Computer Aided Engineering Section Information Systems Bureau Position Paper "A Comprehensive Proposal For The Acquisition, Use, and Maintenance of Geographically Related Information in the New Mexico State Highway and Transportation Department" January 19, 1989

6. Loukes, David K., P.Eng., Geoplan Consultants Inc., Wayne J. P. Walsh, P.Eng., New Brunswick Department of Transportation "Integration of GPS and GIS For Highway Inventory Data Capture" GIS-T Proceedings 1996

7. Vonderohe, Alan; Chou, Chih-Lin; Sun, Forest; and Adams, Teresa, Department of Civil and Environmental Engineering, The University of Wisconsin-Madison. The digest was prepared by Kenneth S. Opieda, Ph.D., P.E., NCHRP Senori Program Officer, from the contractor's interim report. "A Generic Data Model for Linear Referencing Systems" August 4, 1994

8. Deighton, Richard A., P.Eng., Deighton Associates Limited; David G. Blake, P.E., Utah Department of Transportation "Improvements to Utah's Location Referencing System To allow Data Integration" September 1993

9. Gordon, Stephen R., Oak Ridge National Laboratory "Location Referencing for Intelligent Transportation Systems" December 1994

10. Oppermann, Mary C. and Wu, Shie-Shin, North Carolina Department of Transportation "Establishing a Link/Node Referencing System in North Carolina TRB-TRIS 1994

11. Mangum, Gene, Walker, Larry G., C. W. Beilfuss & Associates, Inc. "Iowa

Department of Transportation Highway Location Reference Procedure Project” June 28, 1990

12. Coudriet, Daren L., Brown, Paula A., Luhr, David R., Keystone Management Systems, Inc. State College, Pennsylvania “Systems Application Study: An Evaluation of Geographic Information Systems for the Iowa Department of Transportation” March 17, 1989

13. Deighton, Richard, Deighton Associates Limited; David G. Blake, Utah Department of Transportation “Improvements to Utah’s Location Referencing System To Allow Data Integration” TRB-TRIS 1994

14. Beilfuss, Charles W., Walker, Larry G., Mangum, Gene, C. W. Beilfuss & Associates, Inc. “Iowa Department of Transportation Highway Location Reference Procedure Project Final Recommendations” June 1, 1990

15. Lewis, Simon, GIS/Trans., Ltd., Petzold, Roger, FHWA “Transportation Location Reference Systems: Problem Definition and Current Topics” Pre-conference Workshop AASHTO GIS-T Symposium ‘95 April 2, 1995

18. Vonderohe, Alan, University of Wisconsin “Dimensionality of Referencing Systems: Integration of GPS and Linear Referencing April 7, 1997

19. Huff, David, South Dakota “Optimal Data Model for a Transportation Locational Data Acquisition and Management System April 7, 1997

20. Transportation Research Board NCHRP 20-17(2) “Workshop on a Generic Data Model for Linear Referencing Systems” August 5-6, 1994

21. Federal Highway Administration “FGDC Ground Transportation Subcommittee Position and Recommendations on Linear Referencing Systems” October 1, 1994

22. Rowell, Randolph C., Idaho Transportation Department “Theory and Practice: Linear Referencing at the Idaho Transportation Department” 1996

23. Federal Geographic Data Committee, Ground Transportation Subcommittee “Federal Agency Needs for Ground Transportation Networks and Network Attributes” September 1993

24. Spear, Bruce, U.S. Department of Transportation “GIS-T ‘94: GIS and Spatial Data Needs For Urban Transportation Applications” April 11-13, 1994

25. Scarponcini, Paul, GDSC, Englewood, Co., “Method For Determining

Standard Linear Reference System" GIS-T 1995

26. Vonderohe, Alan, University of Wisconsin, Madison, "Linear Referencing Systems Workshop" GIS-T 1995

27. Xiong, Demin, Oak Ridge Lab "Data Structure and Info Coding for ITS Location Ref. Messages GIS-T Conference 1995

28. Okonieff, Paula, Viggen Corp, Boston, MA "Study 5 Loc. Ref. Methods and Extract the Common Components as the Basis for a Set of Standards for a Loc. Ref. System for ITS Users GIS-T Conference 1995

29. Hickman, Charles E., U.S. Geological Survey, Feature-Based Data Models and Linear Referencing Systems" April 3, 1995

30. O'Neil, Wende A., Utah State University; Harper, Elizabeth, Massachusetts Highway Department, "Location Translation Within a GIS" January 12-16, 1997

31. Shuller, Ed, North Carolina DOT, Kiel, Don, Geo Decisions Methods "The North Carolina DOT Engr. Database and GIS Project: L.R.S. Review and Recommendation, Presentation Slides GIS-T-1997

32. Goodwin, Cecil, Siegel, David; Viggen Corporation; Gordon, Stephen R., Oak Ridge National Laboratory "Location Reference Message Specification Revision A" September 18, 1996

33. Goodwin, Cecil, University of Tennessee; Siegel, David, Viggen Corporation; Gordon, Stephen R., Xiong, Demin Oak Ridge National Laboratory; "Review Draft Recommendation for Location Referencing for ITS Needs" Executive Summary June 30, 1995

34. Rowell, M.A., Idaho Department of Transportation "Solving Problems: Rethinking the Relationship Between Linear Referencing and Geographic Referencing" Presentation and Slides GIS-T 1997

35. Rowell, Randolph, Idaho Transportation Department, "Linear Referencing: A Theoretical Model" AASHTO GIS-T '97

36. Dueker, Kenneth J.; Butler, J. Allison, Portland State University "GIS-T Enterprise Data Model with Suggested Implementation Choices March 1997

37. Fletcher, David, Alliance for Transportation; Espinoza, John, Mackoy,

R.D., Sandia National Laboratories; Gordon, Steve, Oak Ridge National Laboratory; Spear, Bruce, U.S. DOT; Vonderohe, Alan, University of Wisconsin-Madison "The Case for a Unified Linear Reference System" July 26-27, 1996

38. Vonderohe, Alan, Hepworth, Todd; University of Wisconsin "A Methodology For Design of a Linear Referencing System for Surface Transportation" December 1996

Fairly Relevant Bibliography

1b. Strenge, William, NGS “Transportation Location Reference Systems: Problem Definition and Current Topics” AASHTO GIS-T Symposium Pre-conference Workshop April 10, 1994

2b. Pennsylvania DOT, “Transportation Location Reference Systems: Problem Definition and Current Topics” AASHTO GIS-T Symposium Pre-conference Workshop April 10, 1994

3b. Management systems Integration Committee “Proceedings from the Management Systems Integration Committee Meetings” January 12-13, 1996 and May 3-4, 1996

4b. Location Data Standards Group, Minnesota Dept. Of Transportation, “Recommendations for Location Reference Systems” May 21, 1992

5b. Location Data Standards Group, Minnesota Dept. Of Transportation, “Recommendations for Location Reference Systems Executive Summary” May 21, 1992

6b. ENTERPRISE Program ITIS Task Force “Location Referencing Rules”

7b. Gordon, Steve, Oak Ridge National Lab “Location Referencing Systems: Analysis of Current Methods Applied to IVHS User Services” February 17, 1994

8b. Guo, Bo; Breyer, Joe; Lee Engineer, Inc; Rich, Wayne; Barcus, Loretta; Hogsett, Rosemary, Arizona Dept. Of Transportation; Girard, Peter, Environmental Systems Research Institute “From Map-Based to GIS-Based, A Technical Review of ALISS Migration” March 31 - April 4, 1996

9b. Whited, John, Iowa Dept. Of Transportation “Automated Collection of Sign Inventory Information by Integrating Global Positioning System (GPS) With Videologging Data Collection Activities” January 1995

10b. Petzold, Roger G., Freund, Deborah M., FHWA “Potential for Geographic Information Systems in Transportation Planning and Highway Infrastructure Management (TR Record No. 1261) January 29, 1997

11b. Fletcher, David R., Geographic Paradigm Computing; Springer, Jack H. FHWA “Location Referencing and Global Positioning Systems/Geographic

Information Systems for the Information Technology Age” (Workshop Session 6)

12b. NCHRP “Research Results Digest” Number 180 August, 1997

13b. FHWA, Publication No. FHWA-SA-96-024 “Integrated Transportation Information Systems: A Managers Handbook” June 1995

14b. FHWA, “Geographic Information System Activities” December 12, 1996

15b. Lusmore, Johanna “Hampshire County Council” September 19, 1996

16b. Doyle, David, Michigan Dept. Of Transportation “Michigan Dept. Of Transportation” January 1997

17b. Federal Geographic Data Committee, Ground Transportation Subcommittee “Meeting Minutes from Open Meeting at GIS-T Symposium, Kansas City, MO” April 3, 1996

18b. Graziadio, Bradley, Intergraph Corporation “Integrating GPS Into Dynamic Segmentation Linear Referencing Systems” Proceedings GIS-T ‘93

19b. Workshop Participants and Vonderohe, Alan “On The Results of a Workshop on Generic Data Model for Linear Referencing Systems”

20b. FGDC Ground Transpiration Subcommittee “Position and Recommendations on Linear Referencing Systems” October 1, 1994

21b. Reis, Tom, Wisconsin Dept. Of Transportation “Design Requirements for Location as a Foundation for Transportation Information Systems” Proceedings of GIS-T ‘93

22b. Nyerges, Tim, University of Washington “Frameworks for Describing and Evaluating Linear Referencing Systems and Linear Data Models” July 15, 94

23b. Dueker, Kenneth J., Butler, J. Allison, Portland State University “GIS-T Enterprise Data Model with Suggested Implementation Choices” November 1996

24b. Scarponcini, Paul, Graphic Data Systems Corporation “Location Data Modeling Effort Final Report” June 1994

25b. Paredes, Miguel;; Fernando, Emmanuel; Scullion T. Transportation Research Record 1261 “Pavement Management Applications of GIS: A Case Study

26b. O'Neil, Wende A.; Akundi, Balakrishna Virginia Polytechnic Institute and State University "Automated Conversion of Milepoint Data to Intersection/Link Network Structure: An Application of GIS in Transportation" Transportation Research Record 1261

27b. Simkowitz, Howard J., Caliper Corporation " Using Geographic Information System Technology to Enhance the Pavement Management Process" Transportation Research Record 1261

28b. Viggen Corporation "White Paper - FHWA Location Referencing System for IVHS User Services An Alternative Approach: Coordinate Snapping" December 1, 1994

29b. Ramakrishnan, Ramesh; Collier, Clay; Behr, Dave SEI Information Technology - IVHS Group "Standard Location Referencing (SLR) System: Road Navme ID Scheme"

30b. Huang, Zhibui and Shin, Kang, University of Michigan "A New Location Coding Scheme For Intelligent Transportation Systems" ITS Journal, 1996

31b. Crego, Julie, Ries, Tom Wisconsin DOT "Location Control Management Manual/Wisconsin DOT"

32b. Marsh, P.J., Kerali, H.R. University of Birmingham, UK Paper on "An Expert System to Integrate Highway Maintenance Systems with GIS"

33b. Gruver, James, FHWA "Geographic Information System Activities"

34b. Rabkin, Matthew and Maccalous, Sarah U.S. DOT "Transportation Spatial Data Dictionary" March 25, 1997