Summary of
Best practices in
Linear Referencing Systems (LRS)

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Philadelphia Regional ESRI GIS Transportation Special Interest Group

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Chester County
Morning Agenda

- 9:00: Coffee and Introductions: Cathy Sbarbaro and Simon Lewis
- 9:45: Overview of GIS at Chester County: Stacey Howe
- 10:00: Transportation LRS Use: Stacey Howe & Gerry Kelly
  - History
  - Current RDCL design and use
  - LRS overview/data structure
  - Demo of GIS-T apps
- 11:00: Uses of the LRS and GIS-T: Cathy Sbarbaro & Randy Waltermyer
- Chester County Planning Commission
  - How the tools are used
  - Bus routes, etc
  - Transportation improvement inventory
- 11:30: Mercer County GIS, NJ – Expansion Plans Matthew Lawson
  - Land Use & Transportation Asset Management
- 12:00: Morning wrap-up
Afternoon Agenda

• **12:00:** Lunch  *There is a cafeteria on the 3rd floor and maps will be distributed of local eateries*

• **Afternoon:**
  • **1:15:** Technical Interactive Demo of how and why our LRS was created
    – Chester County system and how it was built and the reasoning behind it: *Gerry Kelly*
    – Relation to Best Practices/Theory with Gerry's Demo: *Simon Lewis*
  • Status from other counties on where they are with their LRS efforts
  • Input from other agencies and individuals
Overview:
Linear Referencing System (LRS)

1. \((very\ short!\)\) Introduction to LRS
   - What it is
   - Key features

2. LRS Best practices:
   - General
   - Ten technical best practice factors
Section 1

Introduction to LRS
Goal: Recording Linear Infrastructure

- Linear Features Length (Mi)
  - Curbs: 2,223
  - Dividers: 151
  - Guardrails: 28
  - Number of Lanes: 6141
  - One Way Streets: 71
  - Pavement Markings: 3,655
  - Road Width/Area: 38,844,698
  - School Zones: 31
  - Shoulders: 3,222
  - Sidewalks: 1,874
  - Sidewalk Handrails: 9
  - Speed Limit Zone: 2,798

- Total Linear Features: 157,288
Absolute Location vs. Relative Location

Absolute Location (location ref)
- Uses one of several independent pieces of information to locate “things” as separate, identifiable entities (e.g., roadways, railways, waterways in time and space)
- Enables integration of over 80% of all transportation data
- Basis for Linear Referencing

Relative Location (linear ref)
- Uses interdependent pieces of information to locate entities to their relative geographic position.
- Enables graphic display and analysis of attribute data
- Basis for Geographic Information Systems and GIS-T
Linear Referencing Model

- A set of procedures and method for specifying a location as a distance, or offset, along a linear feature, from a point with known location
- The basis or core of many GIS-T applications
- Three common elements of linear referencing methods
  - known point
    - transport system
    - traversal
    - traversal reference point
  - direction from known point
  - distance from known point
LRS Elements

- Linear reference method
  - Fundamental means of identifying specific locations on a network

- Route organization scheme
  - Convention for organizing and identifying basic highway units, called "routes"

- Data storage method
  - Strategy for organizing the tabular attribute data pertaining to highway units and relation to attribute data
LRS: The Application Integrator

- **Spatial Data (Network)**
  - Infrastructure Management Application
  - Safety Application
  - Public Transit Application

- **LRS**
  - Methods
  - Procedures

- **Attribute Data**
  - Accident
  - Pavement Condition
  - Traffic Counts
  - Transit Stops
  - Bridge Condition
LRS Framework

• Four Levels of Information
  – Events
  – LRM
  – Datum
  – Geometry
LRS Layers

Event Layer

Datum Layer

Geometry Layer
## Typical Current DOT Situation

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Responsible Entity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Event</td>
<td>Entity to be located by the LRS (e.g. guard rail, striping, crash data, permit, parcel, etc.)</td>
<td>Division maintaining the asset information</td>
</tr>
<tr>
<td>LRM</td>
<td>Measurement metric of linearly referenced data. (e.g. Intersection/Offset, County Cum, Route Cum, Milepost/Offset…etc)</td>
<td>Roadway Systems, other Divisions</td>
</tr>
<tr>
<td>Datum</td>
<td>Underlying known baseline definition of roadway</td>
<td>Roadway Systems</td>
</tr>
<tr>
<td>Geometry</td>
<td>Spatial location of roadway alignments</td>
<td>Location Division</td>
</tr>
</tbody>
</table>
Dyn Seg: Example

Task / Step 3: Assign attributes along a route

Reference point

Road attribute tables based on milepost measurement:

<table>
<thead>
<tr>
<th>30. width</th>
<th>30. condition</th>
<th>30.class</th>
<th>30.surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fr  To  Val</td>
<td>Fr  To  Val</td>
<td>Fr  To  Val</td>
<td>Fr  To  Val</td>
</tr>
<tr>
<td>0.0  0.5   20</td>
<td>0.0  0.2   A</td>
<td>0.0  3.0   A</td>
<td>0.0  1.4   C1</td>
</tr>
<tr>
<td>0.5  1.9   25</td>
<td>0.2  0.7   B</td>
<td>1.4  1.7   A2</td>
<td></td>
</tr>
<tr>
<td>1.9  2.0   20</td>
<td>0.7  0.8   A</td>
<td>1.7  2.1   C2</td>
<td></td>
</tr>
<tr>
<td>2.0  3.0   22</td>
<td>0.8  1.7   C</td>
<td>2.1  3.0   A1</td>
<td></td>
</tr>
<tr>
<td>1.7  2.5   B</td>
<td>2.5  3.0   A</td>
<td>Fr = From</td>
<td></td>
</tr>
<tr>
<td>30.accident</td>
<td>30.</td>
<td>30.</td>
<td>Fr  To  Val</td>
</tr>
<tr>
<td>Fr  To  Val</td>
<td>Val</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6  0.6   2</td>
<td>Val</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Dyn Seg: Example

Step 4: Software performs intersection between tables

“Show me the section of roadway where:
road condition = A or surface type = A2”

Selected records where COND = A or ST = A2

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Cond</th>
<th>ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.2</td>
<td>A</td>
<td>C1</td>
</tr>
<tr>
<td>0.7</td>
<td>0.6</td>
<td>A</td>
<td>C1</td>
</tr>
<tr>
<td>1.4</td>
<td>1.7</td>
<td>C</td>
<td>A2</td>
</tr>
<tr>
<td>2.5</td>
<td>3</td>
<td>A</td>
<td>A1</td>
</tr>
</tbody>
</table>
SECTION 2: LRS BEST PRACTICES

• General
• Ten best practice technical features
LRS Requirements

- LRS should:
  - promote efficient storage of roadway attribute data
  - not require redefinition of non-geometric roadway attribute changes (or vice-versa)
  - be supported through robust, off-the-shelf, software tools (e.g., dynamic segmentation)
  - promote efficient computation of performance of roadway data analysis
  - be compatible with prevailing organizational/institutional factors at DOT (e.g., conform to jurisdictional or maintenance district boundaries)
Criteria for LRS Selection

• Practical, easy to use method for specifying event locations
• Spatial accuracy
• Meet specific usage requirements
• Efficient storage of location information
• Supported by GIS platforms
Criteria for LRS Selection (cont.)

- Efficient display and analysis of referenced data
- Easy maintenance of the system
- Provide suitable ways for addressing special cases for network pathologies
- Conversion of data between different LRSs
Challenges to Establishing a Standard LRS

- Roadway alignments and associated milepoint references evolve over time
- Multiple location reference schemes may have come into existence for different applications, users, and districts
- User may have to learn the new LRS and its “view” of the DOT highway network
Section II: Ten LRS Best practices

1. Link to agency transportation data model
2. Link to NCHRP 20-27-2
3. Network topologies supported
4. Bi-directional traversals
5. Traversal identifiers
6. Ramps
7. Overlapping traversals and Non contiguous traversals
8. Local roads
9. Historical / temporal
10. Documentation

Others: a) Support of Dynamic Segmentation, b) sideways traversals, c) support MLS, … etc.
1. Link to agency transportation data model

Enterprise-level Business Goals & Objectives

Organization
- Who?

Applications
- Planning
- Engineering
- Fiscal
- Maintenance
- Construction

Process/Work Methods
- How?

Technology
- What/Where?

Data
- What?

Lewis-Delcan LRS Best practices - summary
WHAT IS GDF?

DATA DICTIONARY- 10 FEATURE THEMES:

- Settlements and Named Areas
- Roads and Ferries
- Administrative Area
- Waterways
- Railways
- Public Transport
- Services
- Land cover and use
- Brunnels
- Road Furniture
GDF Data Model
2. NCHRP 20-27(2) - Object Model

![Diagram of Linear Referencing System Object Model](image)

NCHRP Linear Referencing System Object Model
(from Vonderohe, et al, 1995)
Figure 2.
3. Network Topologies: Hierarchy of Network Elements

1. Piece of highway

2. Highway or Maintenance Section

3. Highway or Maintenance Route

4. State Route
Special Cases of Network Topology

1: Discontinuous
2: Dog-leg
3: Split road
4: Cul-de-sac
5: Ramps
Other Special Cases for Network Representation

- **Tiered Roadways**: treat as divided (separate traversal for each travel direction)
- **Service Roads**: separate, one-way traversals
- **Rest Areas**: separate traversals for each road
- **Rotaries**: account for all links
- **Cul-de-sacs**: clockwise or counterclockwise
4. Bi-directional Traversals

- Most often used for divided highways and one-way pairs (differ in length, location)
- Enable event storage by travel direction (‘right shoulder width’, ‘northbound crash’, etc.)
- Agree with geographic representation
- Simplify data collection in ‘non-mainline’ direction
Bi-directional Traversals: Problems

- Development / maintenance costs
- Change in established practice
- Complicates data entry in some cases
- 2 milepoints at each location (non-divided hwys)
- Conversion between ‘directional’ milepoints
- Complicates data analysis
Bi-directional Traversals: Case Studies

- MoDOT: all travelways (with separate lengths)
- WSDOT: certain road types and ramps
- PennDOT: divided highways, one-way pairs
- Idaho TD: not used, except where extreme difference in length
- Best practice: divided highways and one-way pairs at a minimum
5. Traversal Identifiers

- Main options:
  - Code based on route name / number (‘50SR0011’)
  - Random code, generally control sections (‘01834’)
- WSDOT, PennDOT: route names / numbers
- ITD, MoDOT: random code for storage, but named routes available for input/output
- **Best practice**: use of ‘stable’ identifiers, providing ‘named routes’ for end users
6: Ramps: Route Definition: Option I

- Ramps appear as part of higher numbered route
Route Definition: Ramps Option II

- Ramps appear in separate ramp file, attached by both routes
Route Definition: Ramps Option III

- Ramps are stored in the higher numbered route as it appears at the end of the route.
Ramp Numbering: Option I

- Start (say) north-east corner, go (say) clock-wise (e.g. 1, 2, 3, 4)
Ramp Numbering: Option II

• Number from (say) the higher numbered route.

• Procedure
  – North-West
  – North-East
  – South-West
  – South-East
# Ramps and Approaches

<table>
<thead>
<tr>
<th>Ramp traversal definition</th>
<th>Washington State DOT</th>
<th>Idaho Trans. Department</th>
<th>Pennsylvania DOT</th>
<th>Missouri DOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separate traversal</td>
<td>Separate traversal</td>
<td>Separate traversal</td>
<td>Separate traversal (‘9000’ series Segments)</td>
<td>Separate traversal for each ramp, travel direction</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ramp end points</th>
<th>Point of taper</th>
<th>At painted gore point</th>
<th>Physical gore point</th>
<th>Physical gore if discernible, otherwise painted gore</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Acceleration/ deceleration lanes</th>
<th>Part of the ramp</th>
<th>Part of ramp, to end of painted line</th>
<th>Part of the roadway, not the ramp</th>
<th>Not part of ramp, lanes are a travelway attribute</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Implemented in GIS</th>
<th>Yes</th>
<th>No</th>
<th>Only ramps in the GIS data</th>
<th>Yes</th>
</tr>
</thead>
</table>
Ramps and Approaches

**Best Practice**
- Use separate traversals for each ramp / approach
- Enable routes on ‘ramps’
7. Traversals: Non-contiguous

- Case studies: all use continuous traversals
- Problem: milepoint on Rte 5 where meets Rte 27?
- **Best Practice**: Avoid non-contiguous traversals, let ‘route’ milepoints correspond to real world
Traversals: Overlapping

- **Best Practice**
  - Increasing milepoints on overlapping traversal
  - Enable unlimited overlapping traversals to meet special needs
  - Store data by ‘primary’ traversal
  - Systematic rule for establishing the ‘primary’ traversal

One of the overlapping traversals may be ‘primary’, for example, the lowest numbered.
Mileage Equations

- ITD, WSDOT: use mileage equations, complex over time
- PennDOT: short control sections avoided these
- MoDOT: no mileage equations
- **Best Practice**: avoid mileage equations (FGDC Ground Trans. Subcommittee recommendation)
8: Local Roads - Incorporating

• Justification:
  – Traffic modeling
  – Recording locations of crashes, other events
  – Public transportation data
  – (mostly) SafetyLU requires
• MoDOT: all public roads incorporated
• ITD, WSDOT, PennDOT: (previously) few or none
• Important to ‘comprehensive’ Trans. Mgmt. System
• Substantial development / maintenance costs
9. Support Temporality

- The LRS should support storing and analyzing information over time
- Safety needs to look at up to 10 years of accident data
- R/W needs to look at as much of 50 years of road life history
Temporal Changes - Transportation Experience

- Design/Construction
- Inspection/Monitoring
- Maintenance/Rehabilitation Treatment
- Abandon/Transfer
- Demolition
Historical Data Management: Agency experience

• Idaho Trans. Department:
  – Control sections identified by effective / expiration dates
  – On-line event data are date stamped
  – Off-line event data generally not date stamped
  – Control sections become highly fragmented
  – No coding of historical control sections in GIS data

• Issue whether to do at the database, GIS or other application level?
10. Documentation

• GIS was supposed to be a data integrator, but it (technology, institution, people) have often become another “island”
• Documentation one part of issue
• Often given lip-service, but ignored
• LRS is a fundamental agency data schema, so it needs to be available and understood -- agency wide
• Need quality documentation
LRS Other “Shoulds”

- Multiple LRM.s
- Multiple Cartographic Representations

Marker Tables

LRS DATUM

Associated via Dynamic Segmentation

Geometry 1

Geometry 2

Geometry N

Linear Reference Methods

Cartographic Representations

Event 1/1
Event 1/2
Event 1/n
Event 2/1
Event 2/2
Event 2/n
Event N/1
Event N/2
Event N/n

Associated via Dynamic Segmentation

Event Data
LRS: Conclusions

1. Linear referencing presents some data anomalies that are difficult to manage
2. Modern data management systems can be successfully applied to LRSs
3. Need procedures to abet proper functioning of the system
4. Mostly needs to be part of wider transportation data strategy
LRS: "The People Perspective"

1. Institutional support is essential to successful management of location control and spatial data

2. Any referencing schema only "as good as the people who use it" (and, their training)

3. Train, evaluate, train!