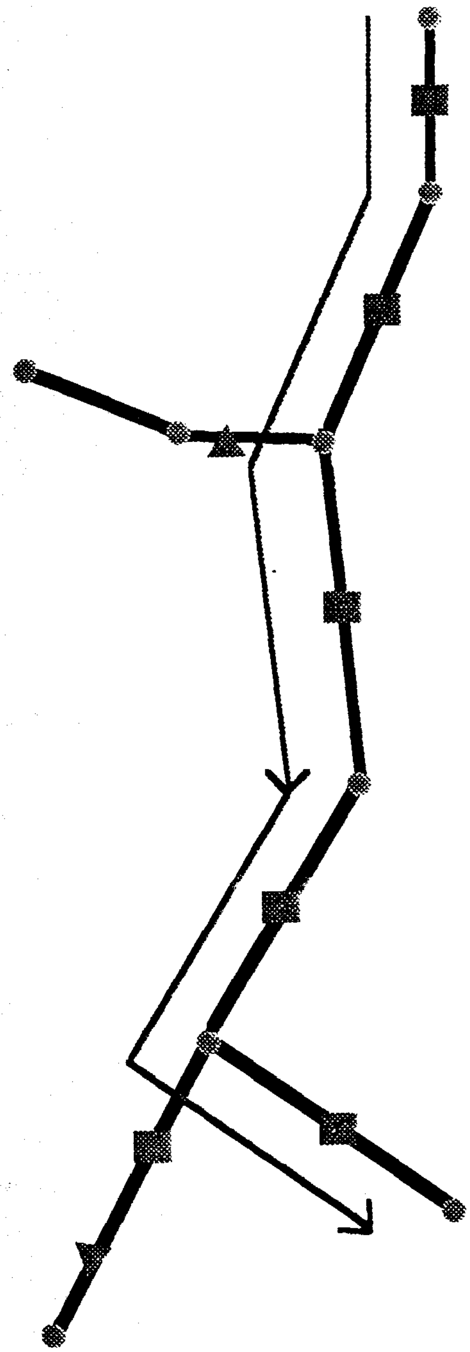
A Primer for Geographic Information Systems for Transportation



Volume 1:

A Review of Linear Referencing Systems

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PREFACE

This series has been compiled by GIS/Trans in the course of its work designing, developing and implementing GIS solutions for transportation. GIS/Trans has produced this series because no similar material is currently available in texts offered in this new and growing field. We provide it as a general introduction to the subject.

Current volumes available in the GIS/Trans "A Primer for Geographic Information Systems for Transportation" Series are:

Volume 1: A Review of Linear Referencing Systems

Volume 2: Dynamic Segmentation of Network Data

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A Primer for Geographic Information Systems for Transportation

Volume 1:

A Review of Linear Referencing Schemes for Geographic Information Systems

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1.

INTRODUCTION

Departments of Transportation and other public agencies are currently reviewing their use of linearly stored data as part of their general review of database management and the spatial referencing of data. In this book, we describe the range of possible linear reference schemes, and the location reference methods upon which they are based, that are commonly employed by state DOTs in the USA. However, the nomenclature and referencing schema are applicable wherever network analysis is being performed in a GIS (Geographic Information System). The following definitions come from the Highway Research Board document, *Highway Location Reference Methods*:[1]

> A *linear reference system* is a set of office and field procedures ... for determining and retaining a record of specific points along a highway ... that includes a highway *location reference method*. The latter is a way to identify a specific location with respect to a known point. The primary objective of any highway location reference method is to provide a means for designating and recording the geographic positions of specific locations on a highway and for using the designations as a key to stored information about the locations.

The purpose of an LRS, in short, is to provide an efficient, logical, easy-to-use means of tying together two forms of data describing highways — network spatial elements and tabular attributes.

The terms location reference scheme and linear reference scheme are often used interchangeably. While this is a common practice, it is useful to draw a distinction between location referencing, which refers to x, y, z coordinate systems, and linear referencing, which is measured as some offset distance from a base point. The subtle distinctions are elaborated further below.

1.1 History of Use

Linear referencing methods had their first use as an aid for highway travelers in indicating the distance from or to a major place. Milestones have been used at least since the time of the Roman Empire, perhaps borrowed from even earlier uses in

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1 Highway Research Board. *Highway Location Reference Methods*, National Cooperative Highway Research Program Synthesis of Highway Practice No. 21. Washington, DC: 1974. This is a detailed, though somewhat dated, review of highway location reference methods.

Asia. The first American use of highway markers was Benjamin Franklin's implementation of them on the Boston Post Road in 1763. Widespread use did not begin until concrete mile posts were installed on the roads of a few states in the early 1920s. The realignment and abandonment of roads, together with the construction of many new highways, beginning about 1916, made many of the old mileage signs virtually useless and they were gradually replaced by signs displaying point-to-point distances and route numbers based on the uniform highway numbering system.

The use of mileposts took on new significance when the 1956 Highway Act and the Highway Act of 1966 required their use as a basic element in the planning, construction, and administration of the national highway system, including the accurate identification of accident locations. This contrasts markedly with their earlier use as a device primarily for the convenience of travelers. Today, in addition to the Interstate System, most states use some type of milepost method.

1.2 Location Reference Schemes and GIS

The advent of GIS has given an added dimension to the use of location referencing schema on networks, often referred to as *linear referencing systems.* GIS allow many layers of data to be spatially referenced to road geometries and the utilization of linear referencing systems is therefore growing. Many applications in pavement management, bridge management, sign management and other management systems now employ linear reference methods. Most of these employ traditional milepost-based measurement but the use of more accurate geodetic techniques such as global positioning by satellite (GPS) is also growing. This promises to improve the positional accuracy of point data locations and of those linear reference systems which measure between control points so determined.

Linear reference systems are a core component of the extension of GIS to transportation, or GIS-T as it is known in abbreviated form. Traditionally GIS was developed as a *polygon processing* system. The extension into transportation has meant refocusing on network features and network analysis capabilities. Fundamental to using GIS-T is the ability to measure network features, link attributes to networks, merge networks (referred to as network conflation) or build applications for vehicle routing or other transportation operations.

The extension of location in GIS to location in GIS-T can be understood by reference to the "real estate model," so called because of the maxim that the three factors that determine popularity, price and potential are "location, location, and location." In geography, these assets have more precise meaning as depicted in Figures 1.1 - 1.3. Geodetic location is the position on the earth's sphere in latitude, longitude and elevation (Figure 1.1); geographic location is less precise and uses x, y coordinates (Figure 1.2); while linear referencing schemes use measurement from fixed points (Figure 1.3). Ultimately, all locations are related back to geodetic position – in GIS this is accomplished by reprojection from one projection to another where necessary to ensure consistency. Given the volumes of transportation-related data, it is unrealistic to locate everything geodetically "on the fly."

1.3 Summary of Alternative Approaches

A typology of linear reference schemes includes the following elements:

(1) Linear reference method;
(2) Route organization scheme; and
(3) Data storage method.

A *linear reference method* is the fundamental means of identifying specific locations on the highway network, whereas a *route organization scheme* refers to a convention for organizing and identifying the basic highway units, often called "routes." The *data storage method* refers to the strategy for organizing the tabular attribute data pertaining to the highway units, as well as relational linkage data. All three elements are important components to successfully building a GIS-T application. The following sections discuss their use in more detail.

Fig. 1.1 Location Reference Systems

Location Reference Methods

- Geodetic

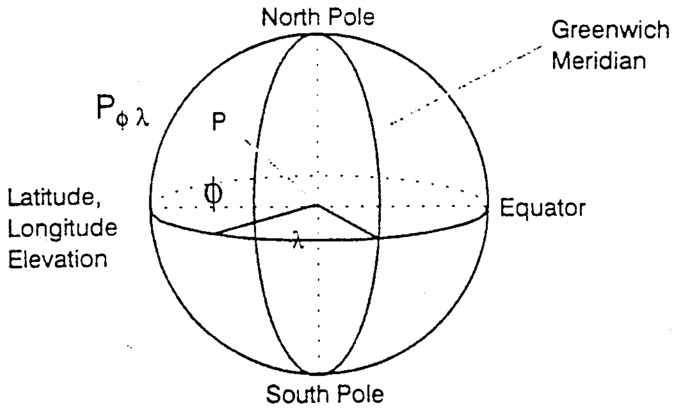


Fig. 1.2 Location Reference Systems

Location Reference Methods

- Geodetic
- Geographic

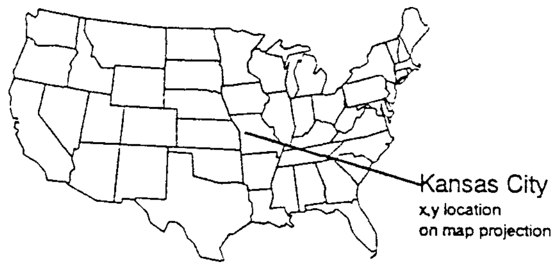
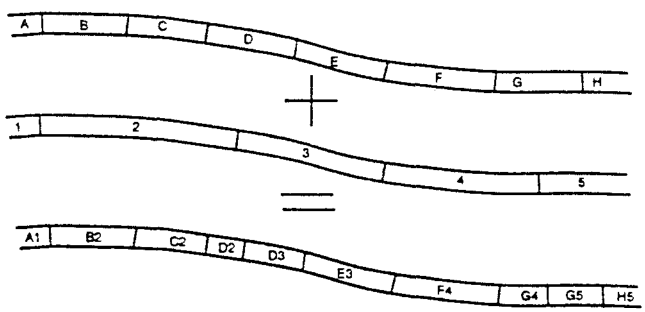


Fig. 1.3 Network Overlay



Traditional overlay of static segments creates a new topological division.

2.

LINEAR REFERENCE METHODS

The three elements common to all linear reference methods are:

(1) Identification of a known point;
(2) A measurement from the known point; and
(3) A direction of measurement.

There are two standard systems by which these elements are employed. The first one, known as the base offset method, is depicted in Figure 2.1. In this case, measurement along a road is determined from a single base point, and the offset may be an absolute or interpolated distance. The second approach is to utilize a series of control points along the road as illustrated in Figure 2.2. Measurement is made to or from these points, which may be local landmarks or known points with x, y values. These different approaches are important in GIS for they affect the ability to query network data by static or dynamic segmentation techniques. To give an example, an accident located 50 feet from an intersection may fall in a segment where traffic flow is high but because the segment is one mile long, it only contains one value which over the whole length is low. How do we account for this in the GIS? Some solutions are presented later (and the reader is referred to the second volume in this series, "Dynamic Segmentation") but as a clue, the answer is to either reorganize the section data in new segments or devise a dynamic segmentation query system which is able to locate from control points as well as base points. This is not as straightforward as may first appear and has exercised the minds of many GIS-T experts for several years. The issue is further complicated by network geometry considerations and complex routing structures (such as multiple transit routes over a network of routes) and especially what happens when route geometry changes (e.g., a change of bus route or new road bypass). In coping with these types of situations, the choice of LRS can be crucial.

Linear reference methods may be broken down as follows:

(1) *Sign-oriented methods* involve placement of physical signs along roadways. There are two subcategories:

   (a) The *milepost method* employs signs which indicate the actual milepoints or approximate mileages of the locations from some zero reference point, usually a route beginning, or state or county boundary.

Fig. 2.1 Linear Referencing Methods

Base Offset Method

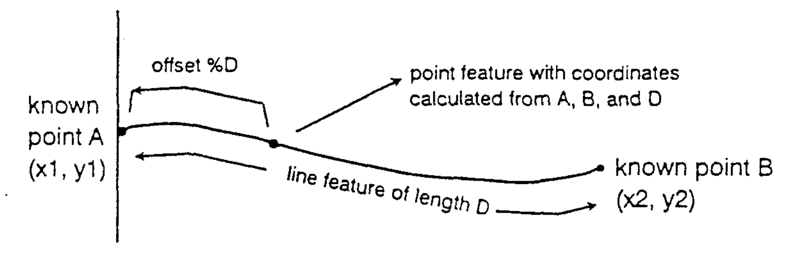
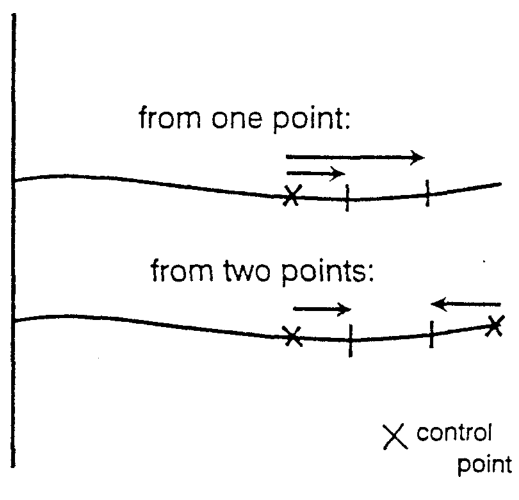


Fig. 2.2 Linear Referencing Methods

Local Control Point Methods



(b) The *reference post or landmark method* is a more general method in which the signs themselves do not necessarily indicate known distance from a fixed point. The signs may be placed at a variety of recognizable features (e.g., intersections, jurisdictional boundaries) or at some fixed interval. Central office records are used to equate unique reference post IDs (which do not necessarily follow any logical sequencing) with actual mileages.

(2) So-called *document-oriented methods* avoid the costs of installing and maintaining signs in the field. There are two subcategories considered in the reference:

(a) The first type of document-oriented method uses a log, strip map, or other diagram (*straight-line diagrams*, or SLDs, is a pertinent example) to associate identifiable roadway features — intersections, bridges, railroad crossings — with their milepoint or reference point numbers.

(b) Another method employs street maps to locate incidents or attributes on the highway system.

It should be obvious that whatever method is employed, the measurement of distance from the base point, local control point or other landmark is critical.

3.

ROUTE ORGANIZATION SCHEMES

Three *route organization schemes* are defined in an *ITE Journal* article by Nyerges, and are noted therein as being in use at many state DOTs today.[2] Note that Nyerges' term, "locational reference scheme," has been replaced here by the more precise "route organization scheme" to indicate that this is but a component of the more broadly defined LRS. The three schemes are:

(1) The *route and milepoint* scheme employs a road naming convention (as a standard procedure for assigning names to highways and streets) and linear offsets (e.g., measured in miles) from the beginning of the route. A common variation of this methodology breaks routes having a common posted name within the state into county-specific segments or "districts." The route and county identifiers are often referred to as, respectively, the primary and secondary keys of the route units.

(2) The *control section*, or *control segment*, method breaks highways (usually within a named route) into units such that the key attribute data may be considered as homogeneous in value over the length of each unit. To account for the fact that different classes of highway attributes (e.g., traffic volume, pavement quality, roadway width) may change in value at different points along the highway, multiple sets of control sections may be maintained.

(3) The *A-node, B-node*, or *link and node*, scheme defines route units based on the link-node topology of the highway system. The route unit identifier often incorporates the identifiers assigned to the two end nodes, hence the name "A-node, B-node."

Measurement along the route is made from either a control point (base point or local control point) or a reference point. In a GIS the distinction is important. A control point is a point on the network with a known position. The control point fits in with the topology of the network and does not create any new topological divisions. A reference point (such as a local landmark) may not be on the network, and measurement is more problematic and imprecise. Further, in order to measure

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2 T.L. Nyerges. "Locational Referencing and Highway Segmentation in a Geographic Information System," *ITE Journal*, March 1990.

accurately from a reference point along a route, an artificial node may be required, thus creating topological divisions. Problems arise in both measurement systems when the route geometry is changed, such as when a road is straightened or a new bypass added. Some GIS provide the capability to recalibrate the distance from control points automatically. In some cases, only a local recalibration between control points is necessary. Updating routes working from reference points involves more manual effort or program development. To apply dynamic segmentation to route organization schemes requires the use of control points (or the conversion of reference points to local control points).

An example of a route scheme utilizing the base offset method is illustrated in Table 3.1. This example, from Caltrans, measures the route distance from where the actual route begins or at the county boundary. Thus, where a route runs across the county line, the measurement begins again from O.O (e.g.: Route 9, Santa Cruz County / Santa Clara County boundary). Notice also the use of control points or reference points where traffic counts are made. These could be intersections or bridges. So long as they can be referenced to the milepoint system, they can be utilized in a GIS, which is the case in Caltrans.

An example of a reference point method based on the link-node scheme is the TINIS (Transportation Integrated Network Information System) file in use in Maine DOT. The advantage of this route scheme is that changes in route geometry are automatically represented in the TINIS file. This was developed several years ago prior to GIS being adopted. Figure 3.1 shows an example of the inventory node map which is not a topological map and therefore requires conversion for use with the Maine DOT GIS. Point records, such as accidents or bridges, can be measured to the TINIS reference points, but these may be geographically imprecise. Linear data, such as pavement condition, is predefined by categories. This static database file, and the form of the route organization strucutre, make it difficult to configure with GIS. Conversion to a format compatible with GIS requires the use of correspondence table and recalibration to a GIS-based route system.

Table 3.1 Caltrans Point Mile Linear Referencing System

RTE 9, SCr Co

Mile-post	Description	Peak Hour	ADT Pk. Mo.	ADT Annual
8.11	Ben Lomond, Glen Arbor Road			
		1,750	14,500	12,500
9.71	Ben Lomond, San Lorenzo River Bridge	1,600	13,400	11,600
		1,600	13,300	11,600
		1,150	8,700	7,600
11.30	Brookdale, Alameda Ave.			
		1,450	10,900	9,600
13.04	Boulder Creek, Junction Route 236 West	1,650	13,200	11,700
		1,650	13,500	11,900
13.24	Bear Creek Road			
		1,150	9,100	7,900
		1,000	6,500	5,600
15.34	Kings Creek Road			
		870	5,700	4,850
		690	4,050	3,450
20.83	Waterman Switch Jct. Route 236 Southwest	770	4,100	3,450
27.09 =0.00	Santa Cruz County, Santa Clara County Jct. Route 35	840	4,300	3,650
		960	4,650	3,950
		880	4,150	3,550
4.89	Sanborn Road			
		1,100	5,100	4,450
		1,150	5,300	4,650
5.71	Saratoga, Pierce Road			
		1,250	5,600	4,950
		1,900	8,600	7,600
7.09	Saratoga, Sixth St.			
		1,500	8,800	7,800
		2,150	18,100	16,200
7.40	Saratoga, Jct. Route 85 North			
		3,960	36,500	33,000
		3,700	33,500	30,500
8.84	Saratoga, Fruitvale Ave.			
		4,400	40,000	36,500
		4,250	38,500	35,500
9.88	Quito Road			
		4,850	43,000	40,000
11.06	Los Gatos Santa Cruz Ave.	5,200	46,000	43,000
		4,450	39,500	37,000
11.45	Los Gatos, Jct. Rte. 17			

RTE 10, LA Co.

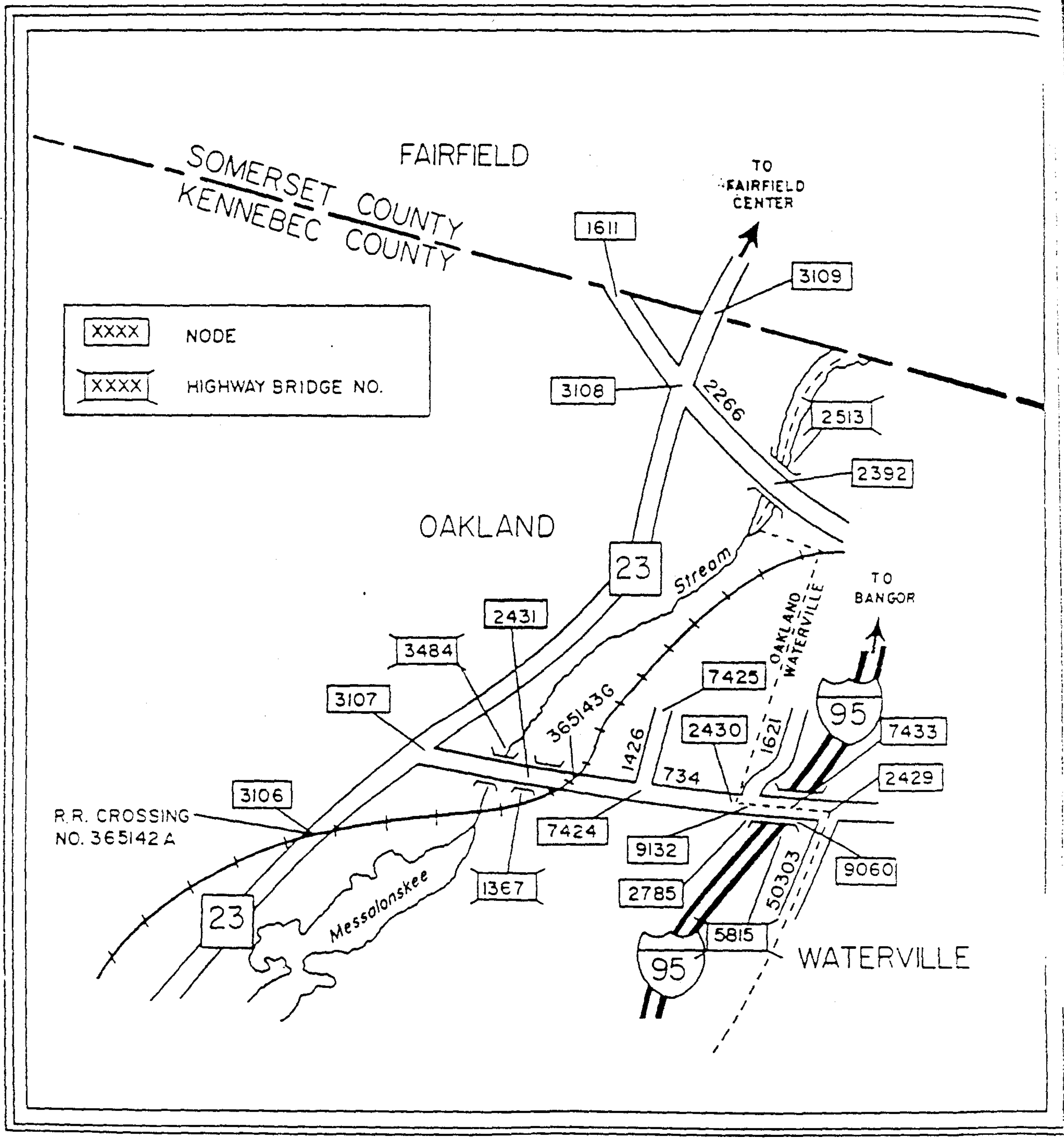
Route 10 — **Routes 1 and 2 in Santa Monica to Arizona State Line Via Blythe**

District 7

Los Angeles County

Mile-post	Description	Peak Hour	ADT Pk. Mo.	ADT Annual
R2.16	Santa Monica, Jct. Rtes. 1 and 2, Lincoln Blvd. Interchange, Via Santa Monica Freeway			
R3.21	Santa Monica, 20th St. Cloverfield Blvd. Interchange	11,100	144,000	139,000
R4.24	Santa Monica, Centinela Ave.-Pico Blvd. Interchange	14,500	189,000	183,000
R4.51	West Los Angeles, Bundy Drive Interchange	13,700	181,000	176,000
R5.45	West Los Angeles, Jct. Route 405, San Diego Freeway	16,600	224,000	218,000
R6.40	West Los Angeles, Overland Ave. Interchange	18,000	270,000	263,000
R7.21	West Los Angeles, National Blvd. Interchange	18,000	262,000	256,000
R7.92	Los Angeles, Robertson Blvd. Interchange	18,000	282,000	276,000
R8.97	Los Angeles, Venice-Washington Blvd. Interchange, Jct. Rte. 187	16,000	274,000	269,000
R10.43	Los Angeles, La Brea Ave. Interchange	16,000	295,000	290,000
R11.39	Los Angeles, Crenshaw Blvd. Interchange	20,000	318,000	313,000
R12.32	Los Angeles, Arlington Ave. Interchange	20,000	331,000	326,000
R12.82	Los Angeles, Western Ave. Interchange	24,000	339,000	334,000
R13.30	Los Angeles, Normandie Ave. Interchange	24,000	349,000	344,000
R13.80	Los Angeles, Vermont Ave. Interchange	24,000	353,000	348,000
14.25	Los Angeles, Hoover St. Interchange	24,000	351,000	346,000
14.84	Los Angeles, Jct. Rte. 110, Harbor Freeway	24,000	343,000	338,000
15.91	Los Angeles, Los Angeles Street Connections	20,000	260,000	255,000
16.90	Los Angeles, San Pedro St.-Central Avenue Interchange	20,000	274,000	269,000
17.35	Los Angeles, Alameda St. Connections	20,000	293,000	287,000
17.71	Los Angeles, Santa Fe Ave. Connections	20,000	296,000	290,000

Figure 3.1 Inventory Node Map, TINIS, Maine DOT



Excerpted from Maine Department of Transportation, *Transportation Integrated Network Information System*, Vol. 1, "System Overview," Revised Version, June 1990

Figure 3.2 Link and Route Log Updating, TINIS, Maine DOT

Tinis Link Record

CO	LOW NODE	HIGH NODE		PRIMARY ROUTE		LINK LENGTH		ALTERNATE ROUTES			
11	1712	7240	...	0003x	...	0.41	...	0009x	0202x		...
11	7240	7364	...	0003x	...	0.20	...	0009x	0202x		...
11	7241	7364	...	0003x	...	0.45	...	0009x	0202x		...
11	7241	7242	...	0003x	...	0.69	...	0009x	0202x		...
11	7242	7243	...	0003x	...	0.65	...	0009x	0202x		...
11	7243	7245	...	0003x	...	0.97	...	0009x	0202x		...
11	7245	7367	...	0003x	...	0.22	...	0009x	0202x		...
11	7367	7368	...	0003x	...	0.15	...	0009x	0202x		...
11	7368	7369	...	0003x	...	0.05	...	0009x	0202x		...
11	7369	7370	...	0003x	...	0.12	...	0009x	0202x		...
11	7370	7371	...	0003x	...	0.41	...	0009x	0202x		...
11	7246	7371	...	0003x	...	0.02	...	0009x	0202x		...
11	7246	7372	...	0003x	...	0.34	...	0009x	0202x		...
11	7372	7373	...	0003x	...	0.18	...	0009x	0202x		...
11	7247	7373	...	0003x	...	0.40	...	0009x	0202x		...
11	7247	7731	...	0003x	...	0.07	...	0009x	0032x	0202x	...
11	7248	7731	...	0003x	...	0.73	...	0009x	0032x	0202x	...
11	7248	7249	...	0003x	...	0.45	...	0009x	0032x	0202x	...
11	7249	7250	...	0003x	...	0.24	...	0009x	0202x		...
11	7250	7251	...	0003x	...	0.29	...	...	...		...
11	7251	7252	...	0003x	...	2.28	...	...	...		...
11	7252	7253	...	0003x	...	0.78	...	...	...		...

Route Log Mile Record

ROUTE	0003x	0009x	0032x
1712	4.90	133.54	
7240	5.31	133.95	
7364	5.51	134.15	
7241	5.96	134.60	
7242	6.65	135.29	
7243	7.30	135.94	
7245	8.27	136.91	
7367	8.49	137.13	
7368	8.64	137.28	
7369	8.69	137.33	
7370	8.81	137.45	
7371	9.22	137.86	
7246	9.24	137.88	
7372	9.58	138.22	
7373	9.77	138.41	
7247	10.17	138.81	47.50
7731	10.24	138.88	47.43
7248	10.97	139.61	46.70
7249	11.42	140.06	46.25
7250	11.66	140.30	
7251	11.95	140.39	
7252	14.23	140.56	

Whenever the LINK RECORDS are updated, the ROUTE LOG MILE file is also adjusted to reflect the change. This is an automated procedure which assures the user that the ROUTE LOG MILE file represents exactly what is in TINIS.

Excerpted from Maine Department of Transportation, *Transportation Integrated Network Information System*, Vol. 1, "System Overview," Revised Version, June 1990

Figure 3.3 Bridge Record Screen Display, TINIS, Maine DOT

BRIDGE RECORD SCREEN #1

DISPLAY: BRGINV DATE 08/04/92 BRIDGE NO: 3484 CNTY: 11 KENNEBEC
BRIDGE NAME MEMORIAL TOWN: 11020 AUGUSTA

TO RETURN TO PREVIOUS MENU — BRGMENU(PF4) — MAINMENU(PF5) — CLEAR TO EXIT

LOCATION:	.2 MI W 9	LOW NODE:	7066 HIGH NODE: 7067 DIST:
CUSTODIAN:	1 MDOT N N/A	OWNER	1 MDOT N N/A MAINT DIV:
		LAST FED AID PROJECT:	FIUI-389(2
EATURE ON:	100,201,202	FEATURE UNDER:	KENNEBEC RIVER + MCRR
ROUTE:	0017X	• ROUTE:	1006
JURIS:	1 ST HWY .00 0	• JURIS:	3 TWNWAY .00 0
URB/RUR:	2 URBAN .00 0	• URB/RUR:	2 URBAN .00 0
FAS:	P PRIMARY	• FAS:	1 URBAN
RESERV:	0 .00 0	• RESERV:	0 .00 0
FED FC:	3 OTHER PR ARTERIALS	• FED FC:	5 MAJOR COLLECTORS
STATE FC:	3 OP ART .00	• STATE FC:	5 COLL .00
LINK:	7066 7067 .00	• LINK:	3314 3318 .00
S.H. DESIG:	1	• S.H. DESIG:	
S.A. NO.:	000 .00 000	• S.A. NO.:	000 .00 000
ST. NAME:	MEM.BR.APPR	• ST. NAME:	ARSENAL ST
RAMP:	0 NO	• RAMP:	0 NO
URB. GROUP:	4 . 25-50T	• URB. GROUP:	4 25-50T
ACC. CTRL:	1 NONE .00 0	• ACC. CTRL:	1 NONE .00 0
ADDT ON:	28040	• ADDT UNDER:	04713

TO DISPLAY SCREEN #2 - PLEASE PRESS THE ENTER KEY SCREEN #1 OF 4

Excerpted from Maine Department of Transportation, *Transportation Integrated Network Information System*, Vol. 1, "System Overview," Revised Version, June 1990

4.

DATA STORAGE METHODS

In discussing options for the electronic storage of highway attribute data, there are two basic types of attributes to be considered:

(1) *Linear attributes*, denoting a characteristic about or feature on the highway itself, or along its wayside, that has constant properties over some finite length of the highway. Pavement material type and surrounding land use are two examples of linear attributes.

(2) *Point attributes*, denoting a feature or incident located on the highway, or along its wayside, which has no appreciable length. Traffic accidents and highway signs are two examples of point attributes.

Data storage options for linear attributes employ either *static* or *dynamic* methods of highway segmentation. Under static segmentation, a unique data record is maintained to store a set of attributes for a single highway segment of defined location and length. There are two principal sub-classes of static segments:

(1) *Fixed-length segments* are used by many transportation agencies. Highway routes are broken up into segments of an equal length small enough (e.g., 0.01 miles) so that they may be considered roughly homogeneous with respect to their attributes.

(2) *Variable-length segments* are defined on the route whenever at least one of a selected set of highway attributes changes in value. The actual number of segments for a given stretch of roadway depends on the attributes contained in the table and how often each such attribute changes in value.

Dynamic segmentation uses a variable segmentation created on demand to reference road attribute data.

For point attribute data, the storage options described above collapse, in practice, into a single alternative. By definition, attributes of these features are homogeneous over their (infinitesimal) length. A single database record is required for each point attribute feature.

4.1. Critique of Data Storage Methods

Among implementation options for linear referencing schemes, a trade-off exists between keeping the number of "zero" points (and associated measure systems) to maintain down to a minimum versus the adaptability of the referencing system in the face of changes to the highway geometry or the placement of reference points.

A comparison of advantages and disadvantages of the three data storage methods follows:

(1) Fixed-length static segmentation:

Strengths:

- Conceptually simple.
- Can store all attribute data in one table; minimizes record storage overhead.
- Begin and end of each segment is uniquely determined by the count of segments from the origin.
- Segment definition is not sensitive to changes in any of the attributes.

Weaknesses:

- At least one segment (i.e., the last) in each route will not have the standard length.
- Many attributes are an average or approximation of conditions over the length of a segment. To get a better approximation, smaller segments would be preferred, but this in turn drives up data storage requirements.
- If conditions are unchanged over consecutive segments, there is data redundancy (which might be avoided through alternative methods). See Figure 4.1.
- When the geometry of a route changes, fixed-length segments may only be maintained by recalibrating the begin and end points of the rest of the route from the point of geometry change to the end. This would entail a costly regeneration of the (average) attribute values for all of the newly-defined segments. This regeneration of attribute data could be avoided, but this would require the introduction of more segments of non-standard length.

Fig. 4.1 Linear Data Storage

Fixed Road Segment Lengths

Route with fixed road segment lengths, showing redundancy in attribute data

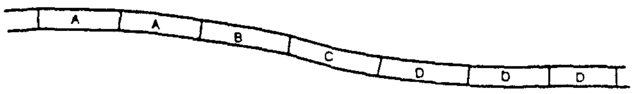
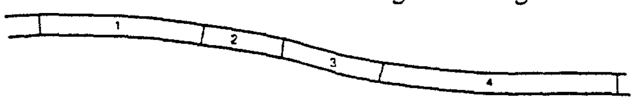


Fig. 4.2 Linear Data Storage

Variable Segment Length

Variable road segment lengths



Key Attributes

1	A	B	A				
2	B	B	A				
3	C	C	A				
4	A	C	A				

- Some transportation agencies create new segments when key attributes changes

(2) Variable-length static segments:

Strengths:

- All attribute data is kept in one place.
- Provides better data accuracy, since segments are defined by changes in attribute values.
- Less data redundancy generally results than for fixed-length segments.
- Individual segments are more adaptable in response to changes in highway geometry; begin-point and end-point mileage references are simply adjusted to the change in total route length. (See Figure 4.2, above.)

Weaknesses:

- Segment definition is sensitive to the change in any one or more attributes.
- There is still considerable data redundancy because many attributes may remain unchanged in value over segment breaks.

(3) Dynamic segmentation:

Strengths:

- Minimizes data storage requirements through the use of data normalization practices.
- Multiple, overlapping attributes may be stored and managed in independent tables, possibly on a variety of RDBMS platforms, without duplicating route geometry.
- Segments are generated "on the fly" to address more complex queries based on multiple attributes.
- Does not require spatial data to replicate the attribute segments.

Weaknesses:

- Requires use of relational DBMS technology.
- Measure system changes (as brought about, for example, by a change in the spatial network) require updating multiple attribute tables.

Dynamic Segmentation methods are the most robust and enable query of network data from databases "on the fly." These techniques represent the first true GIS-T methods and are gradually being introduced in the latest version of GIS by the vendors. A more detailed description of these methods is contained in Volume 2 of this series.

5.

EVALUATION OF LOCATION REFERENCING SCHEMES

5.1 *Evaluation Criteria*

The following are included as evaluation criteria for the alternative linear referencing system options:

- Efficiency in the number of required static or dynamic segmentation elements (e.g., number of routes, number of control points). This may affect performance, independent of specific vendor products.
- Storage efficiency.
- Maintainability with respect to geometry update.
- Maintainability with respect to attribute update.
- Availability of robust, off-the-shelf supporting software tools
- Ease of transition from the current data organization.
- Avoid reliance on supporting field signage infrastructure.
- Compatibility with current work organization (e.g., preserves relationship with current highway maintenance jurisdiction boundaries).

5.2 Exposition of Options

A total of six alternative linear referencing system options, including one which maintains the current organization of spatial and attribute data, are evaluated. The key characteristics of these options are summarized in Table 5.1. A brief review of the six options follows (See Figures 5.1 through 5.6):

(1) No change. Topological links represent fixed segments as defined in field. Multiple attribute tables exist, each containing multiple (not necessarily concurrent) attribute columns.

(2) Merge segment links. Highway segments are delineated instead by control points (or sections). Attribute data organization remains as under Option 1.

(3) Normalized attribute database; segment-based measures. Highway attribute data is normalized by creating a separate table for each primary attribute (and its set of related, concurrent attributes). Each such table is keyed by CO/SR/SEG (County/State Route/Segment) and offset values.

(4) Normalized database; county-based measures. The measure system is referenced as offsets from county lines. Attribute tables are keyed by CO/SR and offset. A fewer number of control points results.

(5) Normalized database; intersection-based measures. The measure system is referenced from fixed, recognizable features – State Route intersections, bridges, rail crossings, etc.

(6) Normalized database; state-based measures. The measure system is referenced from state lines or route origins within the County. Attribute tables are keyed by SR and offset.

Table 5.1 LRS Options

Option No.	Segment Delineation	Database Storage	Route Key*
1	Topological links	Existing	SR+DIR+CO+SEG
2	Control sections	Existing	SR+DIR+CO+SEG
3	Control sections	Normalized	SR+DIR+CO+SEG
4	Linear events	Normalized	SR+DIR+CO
5	Linear events	Normalized	SR+DIR+INT
6	Linear events	Normalized	SR+DIR

* Route key codes:

SR	State Route ID
DIR	Direction code (e.g., 1=undiv/NB/EB, 2=SB/WB)
CO	County ID
INT	Major intersection ID
SEG	Segment ID

Each option is also shown graphically in Figures 5.1 through 5.6.

Short-Term Options

Of the options described above, Options 1 and 2 may be considered as "short-term" options on the basis of not requiring a significant restructuring of key spatial attribute databases.

Fig. 5.1 Option 1 : "No Change"

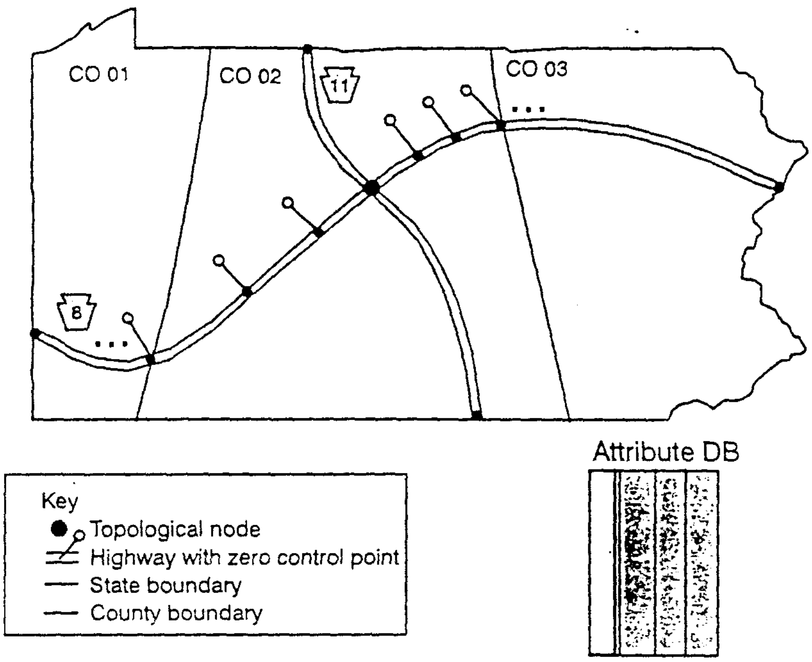


Fig. 5.2 Option 2 : Merge Segment Links

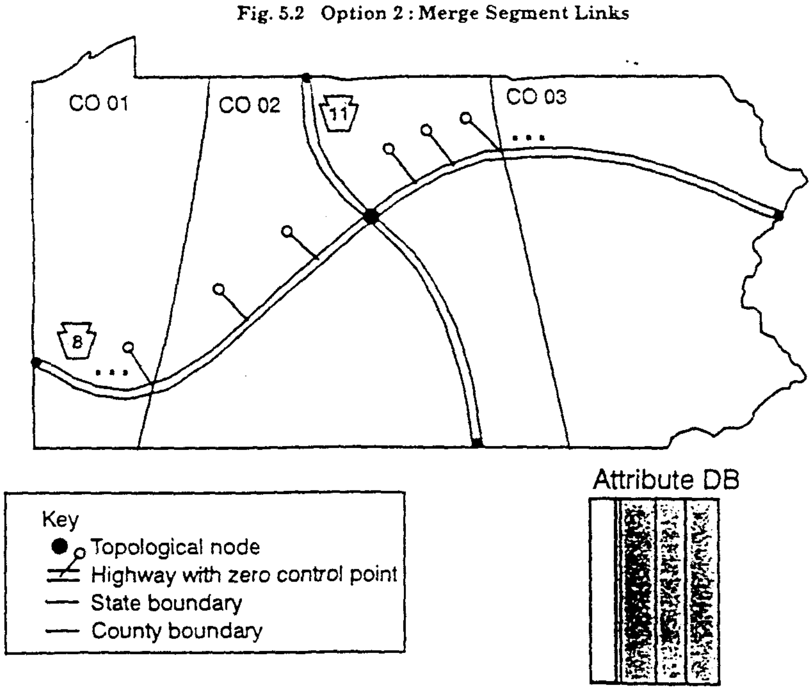


Fig. 5.3 Option 3 : Normalized Attribute Base; Segment-Based Measures

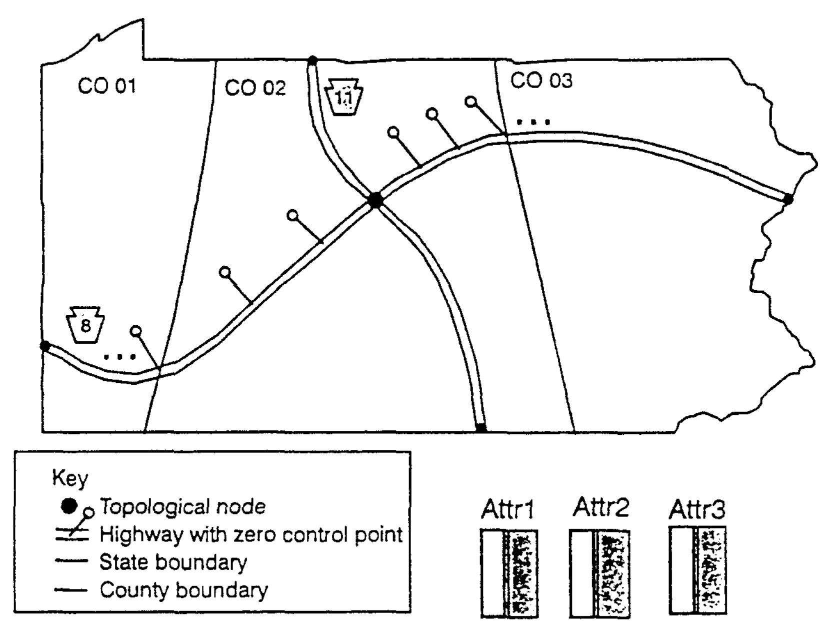


Fig. 5.4 Option 4 : Normalized Database; County-based Measures

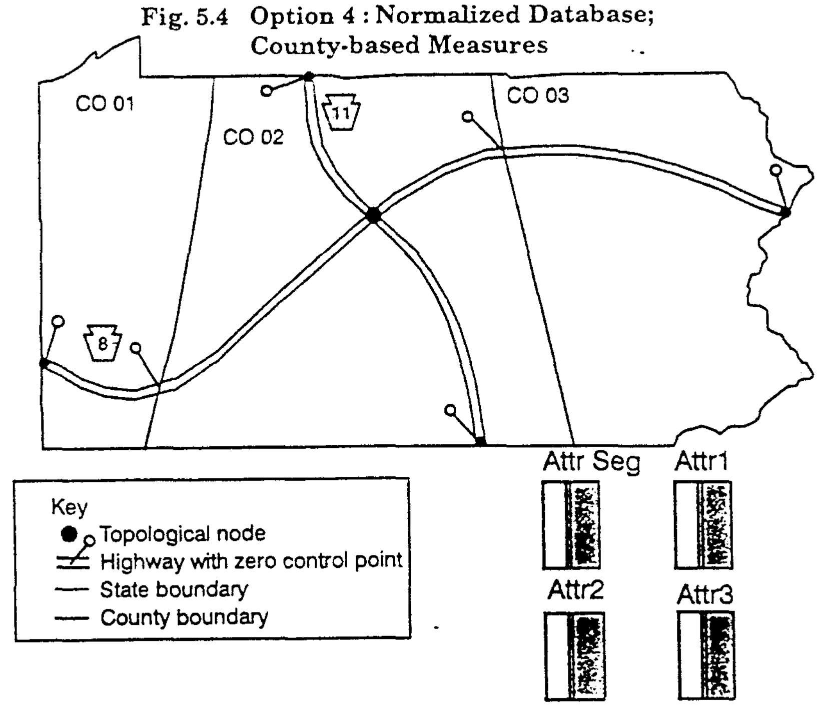


Fig. 5.5 Option 5 : Normalized Database; Intersection-based Measures

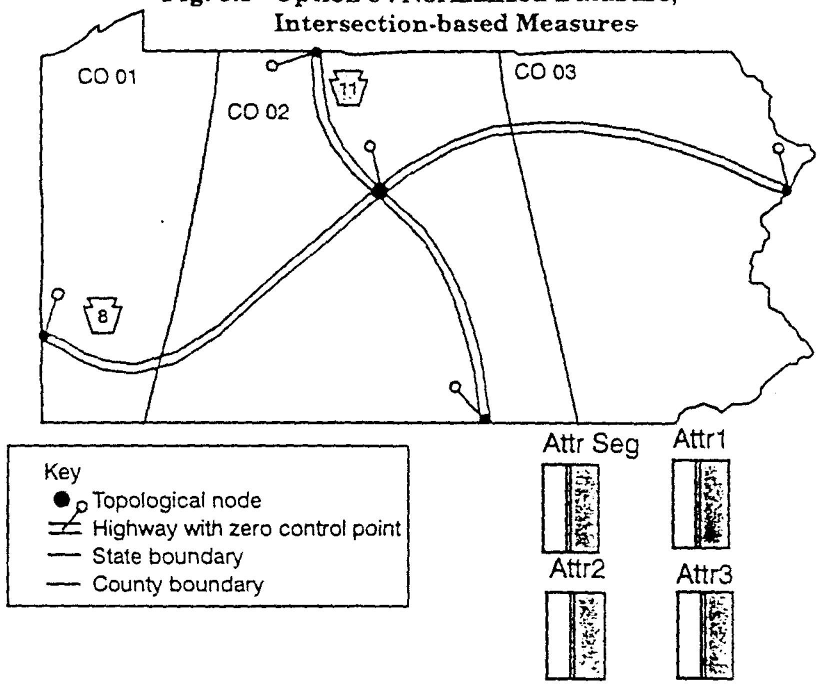
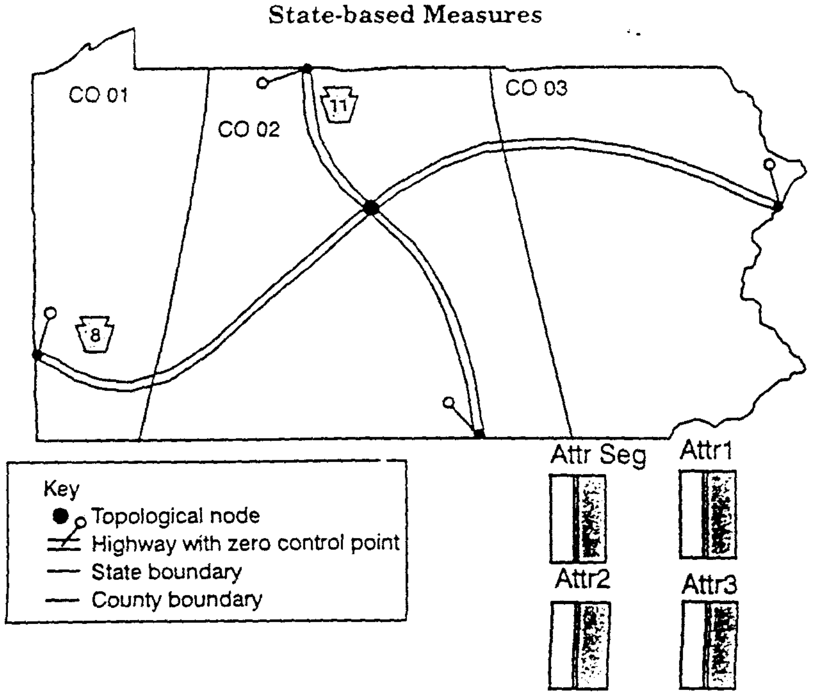


Fig. 5.6 Option 6 : Normalized Database; State-based Measures



Long-Term Options

Of the options described above, Options 3, 4, 5 and 6 may be considered as "longer-term" options which take advantage of dynamic segmentation technology by implementing a reorganization and normalization of existing attribute databases. Although a major effort is required to carry out this normalization task, it appears that the potential gains in terms of reduction of required storage space and maintainability of the attributes may be quite large.

Local Roads Option

In consideration of linear referencing options for local roads, the following remarks are appropriate:

- A numeric municipality identifier (Municipality ID) system should probably be established to differentiate between roads with the same name in different towns. Cases of duplicate street names within the same town will probably be small enough to be handled on an exceptional basis.

- A numeric street identifier (Street ID) system may be established as a more compact referencing item than using the street name itself. It may also serve to handle duplicate street names within a municipality.

- In all the options, measurement would follow the same general conventions as for State Routes (e.g., measures generally run from west to east, south to north, etc.).

The following appear to be the currently feasible options for a local roads linear referencing system:

(1) Organize streets into routes by County ID, Municipality ID, and street name (or Street ID). Use of County ID may facilitate extraction of information on a county basis.

(2) Organize streets by Municipality ID and street name (or Street ID).

(3) Organize streets into routes by County ID, Municipality ID, and street segment. The street segment is defined by the names of the street itself and the intersecting streets at the beginning and end of the segment. Alternatively, Street IDs may be used instead of names for the primary and intersecting streets.

(4) Organize streets by Municipality ID and street segment.

5.3 Evaluation of Options

The results of the evaluation process are summarized in Table 5.2. A brief review of each of the six options follows:

Table 5.2: Evaluation of LRS Options

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Characteristics						
Segment delineation	Topological links	Control sections	Control sections	Linear events	Linear events	Linear events
Database storage	Existing	Existing	Normalized	Normalized	Normalized	Normalized
Route key*	SR/DIR/CO/SEG	SR/DIR/CO/SEG	SR/DIR/CO/SEG	SR/DIR/CO	SR/DIR/INT	SR/DIR
Criteria						
Element efficiency	Poor	Fair	Fair	Good	Good	Excellent
Storage efficiency	Poor	Poor	Good	Excellent	Excellent	Excellent
Maintainability (geometry update)	Fair	Excellent	Excellent	Very Good	Very Good	Good
Maintainability (attribute update)	Fair	Fair	Good	Excellent	Excellent	Excellent
Use of robust, off-the-shelf tools	Fair	Fair	Good	Good	Good	Good
Easy transition from current LRS	Excellent	Very Good	Fair	Fair	Fair	Fair
Avoid field support infrastructure	Poor	Poor	Poor	Good	Good	Good
Organizational compatibility	Very Good	Very Good	Very Good	Very Good	Good	Good

* Route Key Codes:

SR State Route ID
DIR Direction Code (e.g., 1=undiv/NB/EB, 2=SB/WB)
CO County ID
INT Major Intersection ID
SEG Segment ID

(1) No change. This option offers no particular advantages except that it is easy to implement, considering that it is the model of several current "backdoor" GIS operations.

(2) Merge segment links. This option is readily implemented because it does not require major reorganization of attribute databases. It can operate directly off the official road centerline file, instead of segmenting this file.

(3) Normalized attribute database; segment-based measures. This option appears to offer improved attribute storage efficiency and maintainability. As with all following options, a significant, but one-time, work task would be required to carry out the reorganization of existing attribute tables into the normalized, attribute-specific tables.

(4) Normalized database; county-based measures. This option appears to offer even greater storage and attribute maintainability gains by going to significantly larger route units. Also, this option (as well as both of the options below) renders segment markers in the field superfluous and allows discontinuation of their maintenance over some timeframe.

(5) Normalized database; intersection-based measures. This implementation most closely resembles standard control section methods of linear referencing. The smaller segment size (meaning less roadway will need recalibration in the case of spatial changes) trades off against reduced compatibility with the existing segmenting system.

(6) Normalized database; state-based measures. This option offers the fewest number of routes, but the longest routes. Consequently, route geometry changes will result in the relatively large stretches of roadway requiring measure recalibration.

Short-Term Options

Of the two short-term options evaluated, Option 2 takes full advantage of dynamic segmentation to overlay a route-and-section system over the existing road centerline network, without altering the latter's topology. This means that the network used for highway attribute analysis does not necessarily need to be specialized from the base centerline file used for other GIS applications, thereby greatly improving maintainability of the spatial data. The reduction in number of line segment elements may also improve the performance of some GIS analysis functions.

In order to access any highway attribute data from the GIS, it must be formatted into some relational DBMS (e.g., DB2, Oracle).

Long-Term Options

All of the longer-term options discussed share the considerable advantage of working off of an efficient, normalized, more maintainable set of attribute tables. A prerequisite is either a wholesale conversion of the databases, or extraction of large portions of them, into a relational format.

The gain in storage efficiency and maintainability of this conversion and normalization (i.e., moving from Option 2 to Option 3) is very large.

There are further (though smaller) gains to be made by going from the SEG highway units of Option 3 to either County- or Intersection-based units of Options 4 and 5, respectively. This also eliminates the need for field markers to delineate the SEG units. The storage gains by proceeding from Option 4 to Option 6 appear relatively small.

Another key consideration between Options 4 through 6 may be how each option adapts to existing highway data collection practices. Using county-based measures (Option 4) may be more compatible with existing procedures than converting to intersection-based (Option 5) or state-route-based (Option 6) measures.

Local Roads Options

Linear referencing on local roads is made more complex by:

- The large number of streets and street names involved.
- No standard numbering system exists which includes all roads not currently on the state-maintained system.

Of the options for local roads, the primary issues are as follows:

(1) Basing the organization of roads by entire streets or by street segment. The choice should depend partly on the State Route linear referencing system option adopted for the longer term. Options 1 and 2 are conceptually more compatible with a county- or state-based measure system for State Routes. Options 3 and 4 are more compatible with a segment-based measure for State Routes.

(2) The choice of streets versus street segments may also have performance implications, depending on the GIS software platform adopted, because of the much larger number of route elements resulting under the street segment scenario.

(3) Usefulness of existing database in the setup of a linear referencing system. Its potential usefulness may be improved by linking it to a readily accessible road centerline file containing reasonably accurate street name data (e.g., U.S. Census TIGER files).

(4) Whether a County ID should be included to facilitate management use of the linear referencing system (as in Options 1 and 3) or not (Options 2 and 4).

5.4 Results of Evaluation

Based on the review of available alternative, Option 2 is the easier approach to implementation of a State Route linear referencing system in the short term. Option 4 is the most robust for implementation in the longer term.

For local roads, Option 1 is generally considered the most appropriate. Under this option, the route identification system is considerably simpler and results in a far smaller number of route units, especially in urban areas. The other options presented also offer reasonable alternatives, however.

The above evaluation demonstrates the complexities surrounding linear referencing systems. No one system is ideal and multiple systems may be appropriate depending on local conditions and investments already made.

6.

IMPLEMENTATION ISSUES

6.1 Initial Implementation

If the adopted linear referencing system and attribute data storage strategies for the GIS were to depart from the current segmentation system the definitions of the location units should still be preserved in some form. In the short term, this would allow new GIS users to view attribute data in a familiar format during the period of transition to a new linear referencing system. It may also be required to let GIS users continue to reference older data from existing systems in the longer term (for example, historical analysis of accident data).

6.2 Maintenance

The entities of the route-based system created during implementation of dynamic segmentation do not add new topological features to the network. Instead, the routes "drape" or overlay on top of the existing network topology. Nevertheless, the strong dependencies between a route system and its underlying spatial feature network require that updates in the latter be carried forth in the former by some means.

Route definitions and attribute data tables are generally impacted by changes to spatial elements in the network. In general, a highway section realignment incurs some change in the total highway length. For all routes which include this altered section, measures must be recalibrated to reflect this length difference for all points "downstream" from the realignment site. Also, the measures of affected records in all highway attribute, or event, tables covering these routes must be adjusted by the length differnece. At this time, the available dynamic segmentation technology is not very well developed to perform this recalibration in a user-friendly automatic fashion.

Under a dynamic segmentation scenario, unlike the current static segmentation implementation, changes in attribute data do not require updates in the spatial data. All changes are confined to those database tables that store the attribute data which is changed.

6.3 Exception Handling

The following are common types of exceptional features which also are encountered.

6.3.1 Divided Highways

Many highway segments, most notably Interstate highways, are typically encoded as separate, parallel links in the road centerline file. Current practice in many DOTs is to assign a different direction code for northbound and southbound lanes, for example. It is preferable, however, that to avoid ambiguity in highway referencing, a direction code continues to be applied as part of the route numbering convention.

6.3.2 Non-Contiguous Routes

At present, the robustness with which non-contiguous routes are handled differs between the vendors' dynamic segmentation products. Over the long term, this should cease to be an issue as these packages handle such routes more intelligently. Therefore, no special handling of non-contiguous routes is recommended with the long-term implementation options.

6.3.3 Highway Ramps

Highway ramps present a location reference problem because they represent a transition between two routes, and are not unambiguously a part of either of them.

As an alternative to the current reference system for interchanges, two possible implementation alternatives are:

(1) Set up a separate route system to cover highway ramps. Each interchange is assigned an ID which is a concatenation of the two major highways intersecting there. An additional sequence number may be required to handle multiple interchanges for the same pair of routes. Within an interchange, ramps may be assigned a Ramp ID or mileage may be measured from one ramp to the other within the interchange according to some ordering convention.

(2) Assign each ramp to the State Route from which traffic originates. The mileages of these ramps would be ordered by some convention and tacked onto the end of the mileage of the State Route proper.

6.4 GIS Technology

Not all GIS products handle the range of LRS methods described here. Some GIS packages favor base-offset methods while others prefer control point methods. The construction of "routes" also varies between vendor products. Thus, while most GIS allow the definition of LRS, there are some restrictions which the user will need to test prior to full implementation. It is not the aim of this review to evaluate different vendor capabilities (which are changing with each version) but to comment generically on defining LRS for use with GIS. As with any product the maxim *caveat emptor* applies.

6.5 Conclusions

Linear referencing systems were devised as a simple measurement system for highway authorities to keep track of highway facilities and associated data. Several different methods are in use. Until the emergence of GIS and other database integration systems, the issue of compatibility with other systems and configurability with a geographic map base rarely arose. So long as the facilities could be represented or associated to some degree this was regarded as acceptable.

The use of GIS highlights the deficiencies in this approach. GIS requires consistent mapping to the chosen scale of representation. This may be an arduous task in the short run but the long-term benefits usually make this very worthwhile. For instance, attribute data can be related to the maps *ad infinitum*, like an "electronic atlas," thus eliminating the need to manually redraw network data. Even where this can be plotted from a computer database, without GIS the format is limited to the database structure. With GIS, changes to maps can be made quickly and all the relationships are maintained.

GIS, in short, is intelligent mapping. LRS are important in defining the "intelligence" of the GIS network. A "smart" network utilizes a LRS method which is compatible with GIS topology and relational database management systems. Simple link-node route structures and arbitrary reference points rarely meet these criteria. In implementing LRS, highway authorities need to be aware of the capabilities of LRS for their chosen application and the compatibility with GIS. New techniques in GIS, such as dynamic segmentation, require the use of a LRS method. The exact method chosen will be affected by the preferred GIS product and vice versa.

Although LRS have been around for many years, the technology for locating facilities on the highway is not perfected. GIS provides a platform or data integrating environment to accomplish a better correspondence to real world conditions but much remains to be done. The use of GPS (Global Positioning by Satellite) and remote sensing data (satellite image and aerial photographs) is already having a significant impact. Image data can be collected quickly and software image processing techniques in association with GIS can rectify network files to improve positional accuracy, including allowance for elevation (x, y and z values). GPS surveys may succeed other LRS methods, especially those that rely upon local control points or reference points. As data collection becomes easier and more accurate, there is less need for complex route organization structures.

Appendix A

Description of the PennDOT Location Reference Scheme

Introduction

PennDOT's highway location reference scheme is based on a system of statically-defined segments. Initial segmenting of the PennDOT state highway system for the Roadway Management System (RMS) application was performed on the VAX mainframe in 1989.

According to PennDOT's *Location Referencing Field Guide*:

> "The Location Reference System (LRS) is designed to bring Pennsylvania's roadway designations into a verifiable, flexible, and constant engineering standard. It is the key to the collection, storage, and integration of roadway information within the department."[3]

As compared against the typology outlined at the beginning of this book, PennDOT uses a reference post method for location reference, supplemented by in-house printed and electronic documentation (including the straight line diagrams). The route organization scheme is a variation on a control section scheme, where attribute data is generally organized by fixed linear sections, and each section has a unique key value. In PennDOT's case, a concatenation of three keys is used (see Table A.1). Unlike control segments in many other states, however, individual PennDOT segments do not constitute in themselves topological links between intersections of state highways.

The data storage methods used in various databases borrow elements from the various methods discussed. For instance, the basic highway segments associated with RMS root records are static, but are not strictly of fixed length. At least one attribute record of every type is required for each such segment, resembling the static segmenting methods. Attribute data storage is implemented in a series of parallel tables, each of a particular theme (e.g., traffic count data) but containing multiple attribute columns which do not all necessarily hold over the same length.

Key elements and conventions of the general PennDOT location reference method are described in the sections below.

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3 PennDOT. *Location Reference System*, BART field guide. Harrisburg, PA: July 1991.

Table A.1 Location Reference Schemes Used in Selected PennDOT Databases

System Acronym	Full Name	Attrib. Feature Type	Location Referencing Scheme: Reference Key: CO	SR	SEG	Offset (ft): Begin	End	Other Key	Comments
ARS	Accident Records System	Point	√	√	√	√			CO/SR/SEG/OFFSET calculate manually using SLDs
BMS	Bridge Management System	Linear	√	√	√	√	√	BMS ID	Lat-long field exists, but not maintained
CMS2	Contracts Management System	Linear						Project ID	
MORIS	Maintenance Operations and Resource System	Linear						Project ID	May obtain CO/SR/SEG/OFFSET by cross-ref with straight line diagrams
PMS/PI	Project Management System/ Project Inventory	Linear						Project ID	CO/SR/SEG/OFFSET field exists, maintained annually
RMS	Roadway Management System								NO lat-long or state plane coordinates
	– A0 record (root)	Linear	√	√	√				
	– Bx records	Linear	(√)	(√)	(√)	√	√		
	– Cx records	Point	(√)	(√)	(√)	√			

A.1 County Identifiers

The county identifier (CO) is a two-digit number. This allows like-named segments on the same route in different counties to be uniquely identified. The 66 counties in Pennsylvania are numbered consecutively in alphabetical order. The County ID value of 67 refers to the City of Philadelphia.

A.2 State Routes

The State Route identifier (SR) is a four-digit number. Different value ranges are used for different highway types according to the following scheme:

- Interstate, US, and PA routes: SR numbers 0001 through 0999
- Quadrant routes: SR numbers 1000 through 4999
- Relocated traffic routes: SR numbers 6000 through 6999
- Interchanges: SR numbers 8000 through 8999
- Wyes, rest areas, escape ramps, etc.: SR numbers 9100 through 9499

Each length of roadway segment is assigned uniquely to one and only one State Route. Where two or more signposted routes coincide, the highway section is assigned to the route having higher priority (e.g., Interstate over US route, US route over PA route, and so on) or, if these routes have the same priority level, to the route having a lower number. This creates discontinuities in the lower-priority, or higher-number, route in such overlap situations.

An odd/even convention generally applies in the SR numbers, as follows:

- North/south routes: Odd-numbered SRs
- East/west routes: Even-numbered SRs

This convention does not always apply to US and PA routes.

A.3 Segments

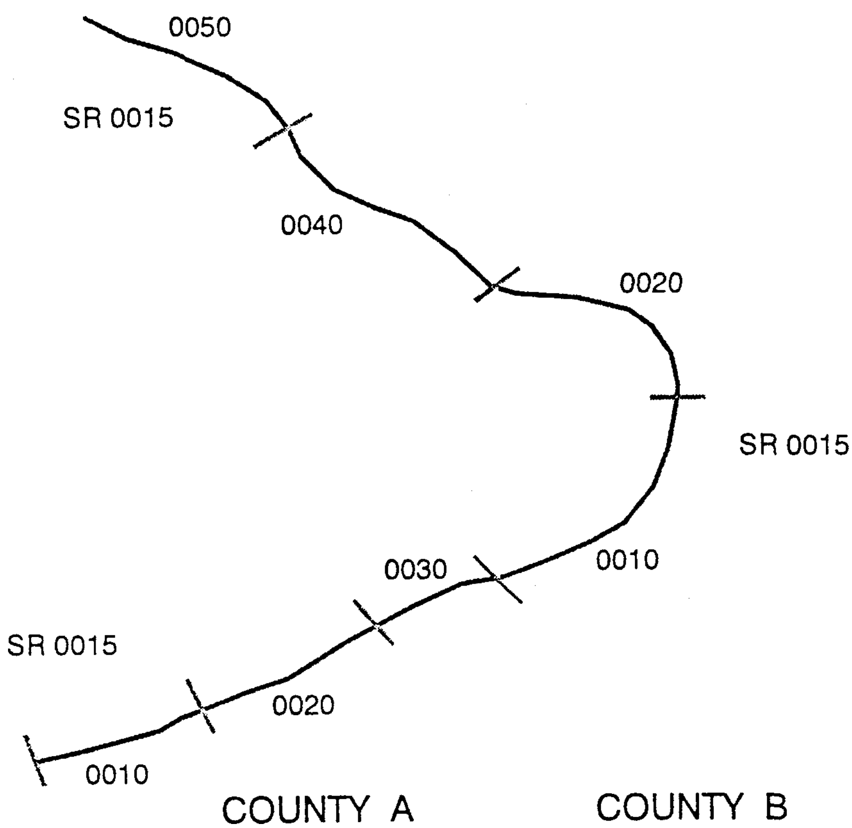
Each State Route is divided into a number of *segments* of approximately 1/2 mile long. Individual segments are assigned a four-digit number (SEG). Consecutive segments are numbered sequentially, incrementing by units of 10 generally in a northbound or eastbound direction.

For divided highway sections, odd-numbered segments (11,21,31, etc.) are used to reference the southbound or westbound lanes, paralleling the segments in the opposite direction, though this odd/even convention is not universal.

Numbering of route segments is restarted when the route crosses into another county. Should the route cross back into the former county, segment numbering picks up where it left off in the same county. (See Figure A.1.)

While state route intersections, bridges, local and township road intersections, and other features were often used originally to determine segment breaks, such breaks do not at present always occur precisely at one of these features. Several segments span intersections of state routes, for example.

Fig. A.1 Segment Numbering



Source: "Location Reference System", PennDOT BART field guide, July 1991

For divided highway sections, an odd/even convention applies to the SEG numbers as follows, though this convention is not universal (see also Figure 6.2):

- Southbound or westbound lanes: Odd-numbered SEGs
- Northbound or eastbound lanes: Even-numbered SEGs

For Interstate highways, sectioning is associated with mileposts (see Figure A.2).

A.4 Offset Measures

Milepoints, accumulated over segments in the highway attribute records, are also rezeroed when the route first crosses into a new county. Mile measures appear to be contiguous (i.e., have no gaps) even if the route is made up of several discontinuous pieces.

A.5 Field Signage

White wayside marker boards are placed in the field at segment break locations along state-maintained highways and at intersections of highways. These markers indicate SR and SEG numbers of the segment into which one would be traveling. At intersections, the markers indicate the segment to the left and the right (See Figure A.2).

A.6 LRS Problems

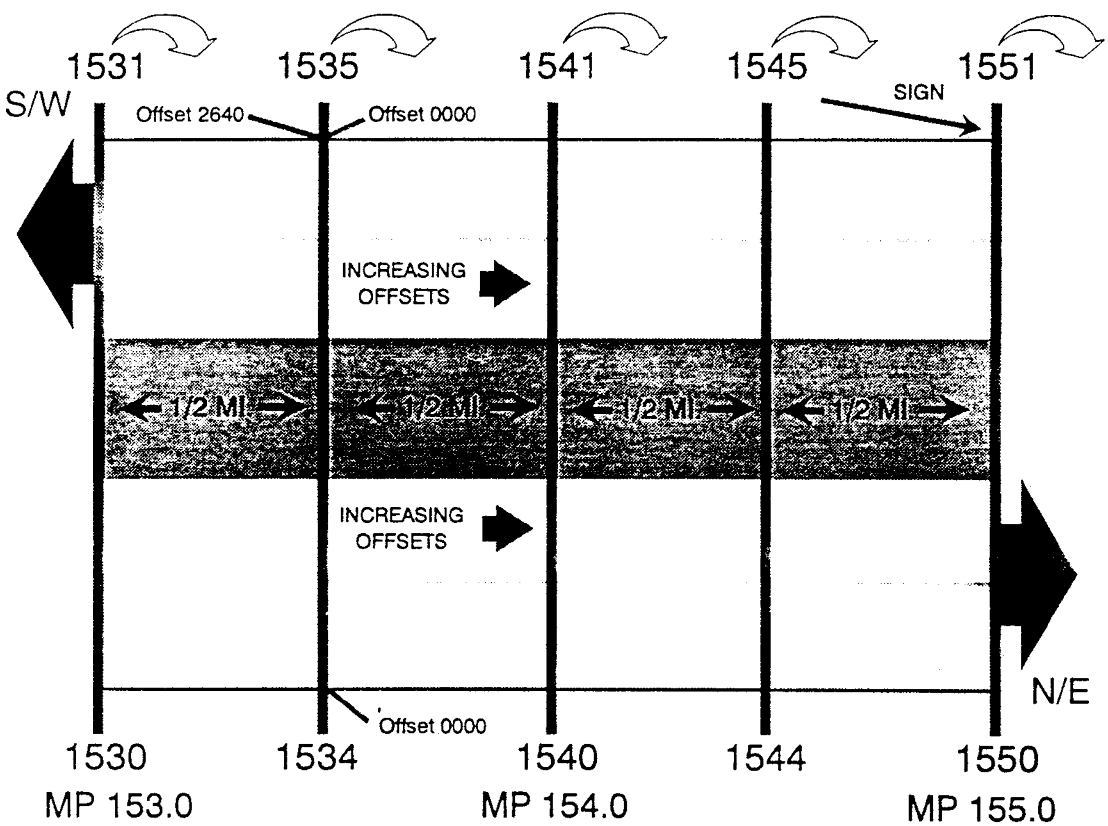
The following are major disadvantages of the current organization of PennDOT's "legacy" database systems, where many attributes are grouped into records describing statically-defined segments:

- Data redundancy results for those attributes that do not change in value between consecutive segments.
- Attributes may reflect only an average or approximation of conditions over the length of a segment.

Other problems of the current location reference scheme include the following:

- In contrast to the theory behind the current PennDOT location reference scheme, segments sometimes do not end at intersections.
- Due to construction or human error in the placement of segment markers, an average of 100 instances, maybe up to a maximum 200 to 300 instances, are updated daily in the RMS database. About 1% of all RMS segments might be changed annually.
- Many long-time field personnel do not like the current road referencing system in that they were used to the prior, simpler, Legislative Route system, in which individual road units could traverse entire counties.
- Lack of a County (CO) reference on the wayside marker boards may result in some ambiguity when collecting or locating data in the field.

Fig. A.2 Interstate Segmenting Convention



Source: "Location Reference System", PennDOT BART field guide, July 1991

Appendix B

Mapping the Nation's Highways in GIS by Converting State's Highway Performance Monitoring System Data into a National Highway Location Referencing System

Background and Overview

The Federal Highway Administration developed the National Highway Planning Network to enable the FHWA to map highway section data on a local, statewide and national basis. Most section information is provided by states in annual Highway Performance Monitoring Systems (HPMS) submissions to FHWA. Although HPMS carries some georeferencing information, the information is in most cases inadequate to locate road sections on a digital network. Moreover, the HPMS does not require provision of some data items that are critical to georeferencing.

GIS/Trans, working with Harvard Design and Mapping, examined the data sets and linear referencing methods in use in three states to consider how the FHWA could augment HPMS (or acquire additional data) to better support linear referencing, what data would be required and in what formats, how FHWA might assist states in compiling and providing standards for georeferencing data, and how data could be used to automate the creation of route systems.[4]

The states chosen as case studies were Pennsylvania, Colorado and Michigan. These states, selected after analysis of a questionnaire sent to all state DOTs, represented a range of approaches to linear referencing and were also able to provide digital data for their highway networks, segmentation and attributes.

Data provided on tape and diskette was imported directly or indirectly into ARC/INFO, which FHWA had chosen as the GIS for this project. Section attribute data was also supplied. Attributes were already pre-segmented for each state's own digital network, making the creation of initial coverages a relatively direct task. Finally, the NHPN for the test states were converted to ARC/INFO coverages. Techniques were developed to match DOT sections to the NHPN by associating sign route identifiers. This was successful for the most part (see Map B.1), in spite of differences in nomenclature and topology, and although no NHPN routes corresponded to certain state routes. Geometric transformations including

4 "Linking HPMS Data to Digital Highway Networks," FHWA Linear Referencing System PRoject, US DOT Contract DTFH61-92-Z-00046, Final Report, 1993 (Unpublished). Harvard Design and Mapping Co., Inc. and GIS/Trans, Ltd.

reprojection were required to visually compare the networks in order to construct linear measures for segmenting NHPN arcs.

Organization of HPMS

The spatial mapping of HPMS section data to NHPN was accomplished by adding additional fields to the HPMS geocoding record to correctly identify sign routes (see Table B.1). The DOT section data is not recorded in a standard format and Table B.1 illustrates the amount of leeway that DOTs have in completing the record.

Table B.1 Summary of Geocoding Features of HPMS Records

ITEM	START	WIDTH	NAME	CODING	COMMENTS
1	1	100	State Control	any	Opt'l lat-lon pairs
2	101	2	Year	NumNum	Decade & year
3	103	2	State	FIPS	Federal Numeric ID
4	105	3	County	FIPS	Federal Numeric ID
5	108	1	Rural/Urban	Num	1, 2 or 3
6	109	5	Urban Area	XXYYY	Sampling meth + ID
7	114	1	Type of Sect.	Num 1 2 3 4	LRS Coding Method: Route, Milepoint A-node, B-node, Sgmt Grouped Data (ID) Unique Number (ID)
8	115	12	Section ID Item 7 = 1 Item 7 = 2 Item 7 = 3 Item 7 = 4	varies	Depends on Item 7 XXXXXXYYY.YYY XXXXXYYYYZZ XXXXXXXXXXX XXXXXXXXXXX
13	132	1	Rte. Signing	Num 0 1 2 3 4 5 6 7	0-7; may be optional Not Reported Interstate (required) U.S. State County Township Municipal N.A. or not signed
14	133	5	Rte. Number	Num	Numeric w/ exceptions Non-Interstate optional
20	145	6	Sect. Length	Num	XXX.XXX in miles Section or Group

The HPMS was designed to cope with the variety of LRS in use but in doing so fails to provide any mechanism for cross-referencing or standardizing these for digital mapping. For example, PennDOT records segments by line or point features and there may be no correspondence between different databases. In general states adapt one system for HPMS recording purposes, in the three examples:

- Colorado — Fixed (1 mile) sections
- Pennsylvania — Semi-variable (<3900 feet) sections
- Michigan — Variable (1-25 mile) sections

Only in Michigan do sections generally correspond to highway features; these units are called Digital Control Sections and relate to maintenance activities. Colorado's roads are sectioned at milemarkers, and Pennsylvania segments roads such that no section exceeds 3,900 feet in length. The sections, which average a half mile in length, are defined by offsets from mileposts, and signs are posted at intersections and along roadways giving route and section identifiers. Only the interstates and the Turnpike are physically mileposted as described in Appendix A.

Putting HPMS on the Map

The HPMS records for geocoding graphic elements (routes; segments; network nodes; control points) can be improved by either amending the HPMS records or adding supplemental data files. Several methods are possible for accomplishing this:

1. Enhance HPMS geocoding by incorporating new data items

2. Request ancillary information from State Highway Authorities (SHAs) to support georeferencing

3. Provide SHAs with NHPN in digital and map form, with documentation

4. Obtain annotated maps from SHAs highlighting network characteristics

5. Augment the NHPN with state route inventory identifiers

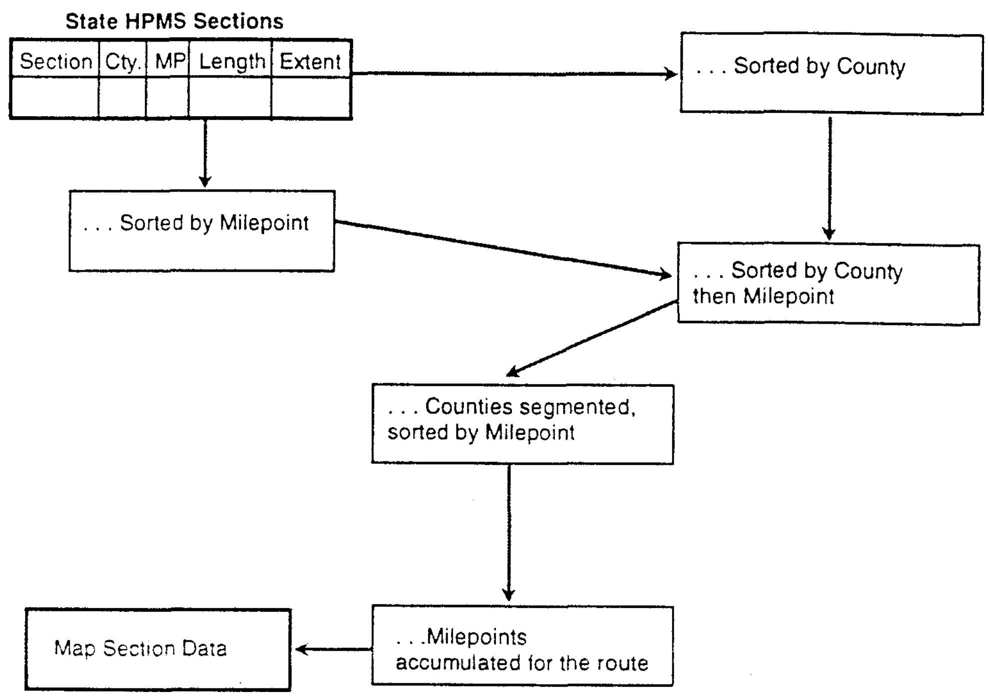
6. Develop standards for coding and exchanging highway network data

All of these methods can be used to enhance the HPMS. The FHWA LRS report recommended Option 1, modifying the structure of HPMS to incorporate a number of changes to enable correspondence between geocoding methods and LRS in use to be determined. This not only allows the data to be mapped more consistently and accurately, it also provides a mechanism for employing dynamic segmentation techniques, overcoming the restrictions inherent in segment delimitation. This provides more precise mapping of HPMS data.

The workflow for constructing routes from HPMS and mapping in NHPN is depicted in Figure B.1.

Figure B.1 Workflow Diagram

Converting State HPMS Data into a National Highway Location Referencing System



Conclusion

HPMS did not prove ideally suited to describe the metric and topological properties of highway systems. It is, however, capable of providing sufficient information to allow segments to be located on a digital network, linked into route systems and their attributes mapped into a GIS. Specific modifications to HPMS can alleviate some of these difficulties and provide more varied and detailed locational data.

The variety of linear referencing methods and conventions used by state highway agencies remain as challenges, however. DOTs organize data in different ways. Route identifiers and distance measures vary among the states' data files. The FHWA does not plan to mandate additional record-keeping or modifications to DOT operations. While FHWA could provide guidance, skeleton data files, annotated NHPN maps and even potentially data entry applications, these measures may be inadequate to encourage consistency among the states in their LRS data.