

Stakeholder's Workshop Information Report

Foreword—This SAE Information Report describes results of three workshops at which Public Sector participants discussed concepts and requirements for ITS Referencing Datums. The Intelligent Transportation Systems (ITS) Datum concept, developed by Oak Ridge National Laboratory (ORNL), has been advanced and promoted through technical R&D and through proof-of-concept testing. Through a series of public sector workshops, all levels of government were involved in setting requirements for ITS Datum standards and processes. Three workshops were held from December 1996 through June 1998. This information report documents the workshops; it is extracted from the ORNL document "Intelligent Transportation Systems Datum Public Sector Requirements Workshop Report, August 24, 1998, C. Goodwin, F. Latham, D. Siegel and S. Gordon," for a project sponsored by the U.S. Federal Highway Administration (FHWA). **DISCLAIMER:** Any opinions or recommendations contained in this report reflect the opinions of the authors and not necessarily those of the SAE Map Database Committee.

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1. Scope—This SAE Information Report describes requirements gathering workshops for Public Sector use of ITS Referencing Datums.

2. References

2.1 Applicable Publications—The following standards contain provisions which are referenced in this Information Report. At the time of publication, the editions indicated were valid.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1746—ISP-Vehicle Location Referencing Standard
SAE J2374—Location Referencing Message Specification

2.1.2 INTELLIGENT TRANSPORTATION SOCIETY (ITS) OF AMERICA DOCUMENTS—Available from ITS America, 400 Virginia Avenue, SW, Suite 800, Washington, DC 20024-2730, U.S. National Architecture Program documents on world-wide web, <http://www.itsa.org/archdocs/national.html>

Intelligent Transportation Systems Datam Public Sector Requirements Workshop Report, August 24, 1998, C. Goodwin, F. Latham, D. Siegel, and S. Gordon

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 FEDERAL HIGHWAY ADMINISTRATION DOCUMENTS—Available from U.S. DOT, FHWA, Office of Safety and Traffic Operations, ITS Research Division, HSR 10, 6300 Georgetown Pike, McLean, VA 22101.

Task B: Spatial Data Interoperability Protocol For ITS Project – Location Reference Message Protocol Preliminary Specification, February 29, 1996, Goodwin, C., Siegel, D. and Gordon, S.

Task B: Spatial Data Interoperability Protocol For ITS Project – Location Reference Message Specification: Final Design, June 28, 1996, Goodwin, C., Siegel, D. and Gordon, S.

Task B: Spatial Data Interoperability Protocol for ITS Project – Location Reference Message Specification: Revision A, September 18, 1996, Goodwin, C., Siegel, D. and Gordon, S.

Task B: Spatial Data Interoperability Protocol for ITS Project – Location Reference Message Specification: Revision B (MDI), May 22, 1997, Goodwin, C., Siegel, D. and Gordon, S.
Task C: Spatial Data Interoperability Protocol For ITS Project – The ITS Datum Preliminary Data Structure and Content, February 25, 1996, Goodwin, C., Siegel, D. and Gordon, S.
Task C: Spatial Data Interoperability Protocol For ITS Project – ITS Datum Final Design Report, June 28, 1996, Goodwin, C., Siegel, D. and Gordon, S.
Task A3: Nationwide Map Database and Location Referencing System Project – Functional Requirements for National Map Databases for ITS, December 31, 1994, Goodwin, C., Xiong, D. and Gordon, S.
Task B3: Nationwide Map Database and Location Referencing System Project – Technical Requirements for National Map Databases for ITS, July 31, 1995, Goodwin, C., Gordon, S.
Task F1: Nationwide Map Database and Location Referencing System Project – Recommendation for Location Referencing for ITS, December 31, 1994, Goodwin, C., Xiong, D. and Gordon, S.

- 2.2.2 NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY (NIST) DOCUMENT—Available from NIST, FIPS PUB 173, U.S. Government Printing Office, National Technical Information Service U.S. Department of Commerce, Springfield VA 22161

FIPS PUB 173 - Spatial Data Transfer Standard (SDTS), 1992

- 2.2.3 INTELLIGENT TRANSPORTATION SOCIETY (ITS) OF AMERICA DOCUMENTS—Available from ITS America, 400 Virginia Avenue, SW, Suite 800, Washington, DC 20024-2730

U.S. National Architecture Program documents on world-wide web -
<http://www.itsa.org/archdocs/national.html>

- 2.2.4 TRANSPORTATION RESEARCH BOARD PUBLICATION—Available from Transportation Research Board, 2101 Constitution Ave, NW, Washington, DC 20418

Transportation Research Circular 412 – Primer on Intelligent Vehicle Highway Systems, 1993.

- 2.2.5 OTHER PUBLICATIONS

Cherveny, Kevin, 1997, "Technical Response to *ITS Datum Prototype Final Design Report*," Memorandum dated April 1, 1997, 6pp

Fletcher, David, Espinoza, John, Mackoy, R.D., Gordon, Stephen, Spear, Bruce, and Vonderohe, Alan; "The Case for a Unified Linear Reference System; Proceedings. Enterprise Location Referencing Systems: Policies, Procedures and Standards for Implementation Workshop," Salt Lake City, Utah; July 1996

Goodwin, Cecil W. H., Dave Siegel, Stephen R. Gordon, and Demin Xiong; "Recommendation for Location Referencing for ITS Needs," Task F1: Nationwide Map Database and Location Referencing System Project, United States Department of Transportation, Federal Highway Administration Office of Safety and Traffic Operations, ITS Research Division, Contract DTFH61-91-Y-30066, Draft, June 30, 1995, 78 pp

Goodwin, Cecil W. H., David Siegel, and Stephen R. Gordon; "Location Reference Message Specification: Final Design," Task B: Spatial Data Interoperability Protocol For ITS Project, United States Department of Transportation, Federal Highway Administration Office of Safety and Traffic Operations, ITS Research Division, Contract 61-94-Y-00001, Draft, June 28, 1996, 40 pp

Gordon, Stephen R., Cecil W.H. Goodwin, and Demin Xiong, 1994; "Final Report on Status of Spatial/Map Databases," Report by Oak Ridge National Laboratory for U.S.DOT, FHWA, Office of Safety and Traffic Operations IVHS Research Division project 'Nationwide Map Database and Location Referencing System', June, 1994. 133 pp

Haas, R. P., J.W. Lau, C.W. Goodwin, S.R. Gordon; "Location Referencing Message Specification Test Report" Version 1.0, July 23, 1998

- Lerner-Lam, Eva, W. Todd Smith, Joseph R. Francica, and Ajay Rathi; "Digital Map and Spatial Database Requirements for ATMS," in "Surface Transportation: Mobility, Technology, and Society," Proceedings of the IVHS America 1993 Annual Meeting, Washington, D.C., April 14-17, 1993, pp. 560-568
- Siegel, David, Cecil W. H. Goodwin, and Stephen R. Gordon; "ITS Datum Final Design Report", Task C: Spatial Data Interoperability Protocol For ITS Project, United States Department of Transportation, Federal Highway Administration Office of Safety and Traffic Operations, ITS Research Division, Contract 61-94-Y-00001, Review Draft, June 28, 1996, 38 pp
- UTEERC (The University of Tennessee Energy, Environment, and Resources Center), ALK Associates Inc., Oak Ridge National Laboratory, and Viggen Corporation; "Meeting National ITS Spatial Data Needs", Task C2: Nationwide Map Database and Location Referencing System Project, United States Department of Transportation, Federal Highway Administration Office of Safety and Traffic Operations, ITS Research Division, Contract DTFH61-91-Y-30066, Review Draft Final Report, September 29, 1995, 119 pp
- VITAL (Vehicle Intelligence Testing & Analysis Laboratory, National Center for Geographic Information and Analysis, University of California, Santa Barbara), "The Cross Streets LRMS Profile-- Technical Evaluation", United States Department of Transportation, Federal Highway Administration Office of Safety and Traffic Operations, ITS Research Division, Contract DTFH61-91-Y-30066, Review Draft Final Report, December, 1997
- Vonderohe, Alan, et. al.; "Results of a Workshop on a Generic Data Model for Linear Referencing Systems;" National Cooperative Highway Research Program Project 20-27(2): Development of System and Application Architectures for Geographic Information Systems in Transportation, 1995
- Vonderohe, Alan and Hepworth, Todd; "A Methodology for Design of a Linear Referencing System for Surface Transportation;" Sandia National Laboratories Project AT-4567, December 1996

3. Definitions

- 3.1 Altitude**—Elevation above or below a reference datum, as defined in FIPSPUB 70-1(NIST, 1992); the z-value in a spatial address.
- 3.2 AVL**—Automatic Vehicle Location by use of technologies such as GPS.
- 3.3 Bandwidth**—The portion (frequency range) of the electromagnetic spectrum available to a communications channel.
- 3.4 Coordinates**—Pairs of numbers expressing horizontal distances along orthogonal axes; alternatively, triplets of numbers measuring horizontal and vertical distances.
- 3.5 Datum**—A set of parameters and control points used to accurately define the three-dimensional shape of the Earth (e.g., as an ellipsoid). The corresponding datum is the basis for a planar coordinate system.
- 3.6 DMI**—Distance Measuring Instrument. A device that measures as-driven distance along a roadway, performing the function of a precise vehicle odometer.
- 3.7 Geodetic Datum**—A mathematical model of the Earth's shape. A geometric set of five quantities which serves as a locational reference or base for other quantities. The five quantities are the latitude and longitude of an initial point, the azimuth of a line from this point and two constants necessary to define the terrestrial spheroid.
- 3.8 GIS**—Geographic Information System. A computer-based system for the storage, retrieval, display, and analysis of spatial data.
- 3.9 GIS-T**—Geographic Information Systems in Transportation

- 3.10 GPS**—Global Position System. A positioning system that relies on TDOA (time-distance of arrival) measurement of signals from GPS satellites to determine geographic location and other dynamic parameters for a receiver.
- 3.11 ILOC**—Intersection Location. A proposed European method of location referencing that specifies an intersection location based on geographic coordinates and ancillary roadway information.
- 3.12 Information Service Provider (ISP)**—In the context of the LRMS, a public or private entity which may be responsible for gathering, fusing, analyzing, and/or reporting transportation related information to users, including vehicles and non-mobile users.
- 3.13 Interpolation**—A mathematical or geometric method of determining the value of a variable between two points with known values.
- 3.14 Intersection**—In GDF, a complex feature, made up of a set of features such as 'Road Elements' and 'Junctions.' An intersection may be a simple junction of two roads, or may consist of more than two roads and entrance and exit ramps. Intersections may be planar (topologically connected in the same plane) or non-planar (not topologically connected), such as a flyover.
- 3.15 IOM**—Intersection Object Model. An ITS Datum term referring to a complex object model of an intersection, similar to a GDF complex intersection feature.
- 3.16 ISO**—International Standards Organization.
- 3.17 ISO API**—The ISO Application Programming Interface standard for data access to ITS databases.
- 3.18 ISO GDF**—The ISO Geographic Data File standard for exchange of ITS databases.
- 3.19 ISO PSF**—The ISO Physical Storage Format standard for storage of ITS databases on physical media.
- 3.20 ITS Datum**—A set of well-known and located ground control points on transportation networks.
- 3.21 ITS User Services**—The classification of ITS user applications into 31 categories, such as Incident Management (IM).
- 3.22 Junction**—In GDF, a feature that bounds road elements (or ferry connections). A road element is always bounded by exactly two junctions. A junction feature represents the physical connection between adjoining road elements.
- 3.23 Linear datum**—A set of well-known and located points used to register linear referencing networks to one another.
- 3.24 Link**—A topological connection between two nodes. A link may contain additional intermediate coordinates (shape points) to better represent the shape of curved features. A link may be directed by ordering its nodes.
- 3.25 Link Identifiers (or Link-ID)**—An identifier assigned to a link. Link-IDs may be arbitrary, or may be assigned by convention to assure that multiple occurrences of the same ID will not occur within one network or within the universe of similar networks or databases.
- 3.26 Location Referencing System**—System of determining the position of an entity relative to other entities or to some external frame of reference.
- 3.27 Measured Distance**—Cumulative distance measured along a road centerline from a reference node.

- 3.28 NAD (North American Datum)**—The official reference ellipsoid used for the primary geodetic network in North America.
- 3.29 NAD27 (North American Datum 1927)**—Geodetic datum defined by the geographic position of triangulation station Meades Ranch and the azimuth from that station to station Waldo on the Clarke spheroid of 1866.
- 3.30 NAD83 (North American Datum 1983)**—Geodetic datum defining an Earth-fitting ellipsoid and for relating existing coordinate systems to the Earth's center of mass. It is based on both satellite and terrestrial data used in developing the Geodetic Reference System of 1980 and later the World Geodetic System of 1984 (WGS-84). This improved Earth-centered model slightly changes the latitude and longitude of almost every point in North America with respect to the earlier NAD27 datum.
- 3.31 NHPN (National Highway Planning Network)**—A national road database including 225 308.16 km (140 000 miles) of roads of the National Highway System (NHS) plus other major arterials, totaling approximately 643 736.6 km (400 000 miles).
- 3.32 Node (0-cell)**—A topologically significant point, such as a simple intersection of roadways or other linear features, or an endpoint of such a feature.
- 3.33 Node Identifier (or Node-ID)**—An identifier assigned to a node. Node-IDs may be arbitrary, or may be assigned by convention to assure that multiple occurrences of the same ID will not occur within one network or within the universe of similar networks or databases.
- 3.34 Non-Planar Node**—A node that does not imply topological connection or navigability between roadways. An overpass can be represented in a database by a non-planar node.
- 3.35 NSDI**—National Spatial Data Infrastructure. A Federal, national-level collection of databases to be shared by multiple Federal agencies.
- 3.36 Planar Node**—A node that implies a topological connection between roadways, or that exists on the roadway planar network.
- 3.37 POI**—Points-of-interest. Points in a transportation network, such as transit stops, that are significant to transportation functions although they may not have topological significance in.
- 3.38 Pseudonodes**—Points in a spatial database without topological significance, such as points denoting political boundaries.
- 3.39 Rectification**—The mathematical process of translation, transformation, displacement, and scaling of a database to make possible registration to a coordinate system representing real-world spatial relationships, without distortions or other errors.
- 3.40 Reference Ellipsoid**—The mathematical model of the Earth used in geodetic computations.
- 3.41 Reference Node**—A node with respect to which distance measurements are made. In the ISP-Vehicle profile, Reference Nodes are simple intersection or endpoint nodes.
- 3.42 Spatial data**—Any data located in space by a location reference. For example, although temperature is a non-spatial measure in itself, the distribution of temperature over a country, conveyed by a map of isotherms, is spatial data.
- 3.43 TIGER**—Topologically Integrated Geographic Encoding and Reference Files - Digital map database files of the U.S. created for the Census Bureau for the 1990 census.

3.44 Topology—The logical relationships among map features in a digital base map. It can be used to characterize spatial relationships such as connectivity and adjacency.

3.45 World Geodetic System of 1984 (WGS-84)—An earth-centered global reference frame, including an earth model, based on satellite and terrestrial data. It contains primary parameters that define the shape, angular velocity, and the earth mass of an earth ellipsoid, and secondary parameters that define a gravity model of the earth. Primary parameters are used to derive latitude-longitude coordinates (horizontal datum). Secondary parameters are used for determining the orbits of GPS navigation satellites and define a coarse vertical datum; therefore WGS-84 is a complete geodetic system. EGM-96 is a refined model established in 1996.

4. Introduction—The Intelligent Transportation Systems (ITS) Datum concept was developed by Oak Ridge National Laboratory (ORNL) and its contractors as a possible way to satisfy requirements for public sector spatial data, to improve ITS data set interoperability, and to help integrate local GIS-T data sets. The concept has been advanced and promoted through technical R&D and through proof-of-concept testing. Through a series of public sector workshops, all levels of government have been involved in setting requirements for ITS Datum standards and processes for producing public sector databases.

Three workshops have been held since December 1996. The first workshop was held in Santa Barbara, California, to review existing plans and resolve issues related to both the Location Referencing Message Specification (LRMS) and ITS Datum work. This workshop resulted in significant input, including requirements, for the LRMS work from public sector and private sector participants. Following this workshop, the Location Referencing Task Force (LRTF) activity generated requirements for location referencing and ITS Datums in a series of meetings. Many requirements from the LRTF were incorporated into SAE J2374, Location Referencing Message Specification. Two workshops were then held to address public sector ITS Datum requirements specifically. The first workshop was held in Knoxville, Tennessee, in March of 1998. A second public sector requirements workshop was held at Santa Barbara, California, in June of 1998.

This document reports results of the workshops. It presents a snapshot of where we are with respect to ITS Datum requirements, standards, and practices. It is intended to clarify meanings and especially requirements and outstanding issues. In addition, the document offers conclusions related to ITS Datum requirements and uses, and how both LRMS and ITS Datum standards and practices can aid spatial data interoperability both regionally and nationally.

5. Problem Statement—Intelligent Transportation Systems (ITS) require that locations be registered to digital maps and transferred from one digital map to another. Locations of accidents, closed or slow sections of roads, or areas evacuated due to chemical spills or hurricanes must be defined, then transferred from one system component to another, for example from an Emergency Management Center to a responding vehicle. Sometimes these locations come from equipment like Global Positioning Systems (GPS); sometimes they are extracted from maps. In any case, locations need to be communicated accurately and without ambiguity between different digital map databases. This is the general **location referencing problem** for ITS.

Digital maps used across ITS (and transportation generally) vary in a number of important ways. Even for the same area, they come from diverse public and private sources, and so are different in how geographic reality is represented. For example, a Geographic Information System for Transportation (GIS-T) at a transportation center may need to integrate data for roads, transit systems, subways, buried electrical lines and pipes, etc., to perform operational tasks such as analysis and planning. Digital databases to be integrated for transportation may differ in level of spatial detail, in how accurate they represent geographic (locational) reality, and in how current (up-to-date) they are. Any one or all of these factors make it hard, in some cases impossible, for location references from a sending database to be understood properly by a receiving database, even for the same area.

The problem gets worse when Intelligent Transportation Systems are considered, since the nature of ITS, particularly public sector ITS, is to integrate applications across boundaries. As ITS systems become more complex and integrated technically and across existing legacy systems and geographic and political boundaries, the differences between maps make it difficult for applications using those maps to interoperate reliably and unambiguously.

Furthermore, because of the unique requirements of ITS User Services, it is inevitable that certain kinds of data that are important to ITS applications may not be derivable directly from any existing database. For example, accurate and up-to-date centerline data for the complete national road network is not available from existing data sources either singly or in aggregate. Each related database may provide part of the content, and for some areas, data from existing databases may be reasonably accurate, but no single source can provide all that is needed by every potential ITS user. It is almost certain that some data pertaining to transportation networks at a place will have to be collected from the field rather than derived from existing sources, particularly for public sector uses. Furthermore, for some ITS applications, modifications to the road network and temporary changes due to incidents will require a data infrastructure that will permit near real-time database alteration.

Thus, even with the best intentions and techniques for sharing, adequate databases simply do not exist to meet all known and foreseeable requirements for ITS. Quality data must be created, moved, and integrated within the context of more highly interactive distributed ITS systems, in near-real time.

6. *Project History*

"Where should we start? A conceptual model which may help to better define state, private and Federal roles, is a hub and spoke system analogous to that used by major airlines. Within this scheme, a national transportation map database network of local and private "spokes" are attached to state "hubs", possibly an enhanced version of the NHPN. In order for the states to serve as regional hubs, database content, location referencing, and exchange standards should be in place so that state DOTs [Departments of Transportation], MPOs [Metropolitan Planning Organizations], counties, municipalities, and private vendors can provide the local street data to hang on the hubs. Therefore, we recognize that states and localities are keys to the satisfaction of national-level goals for seamless ITS databases." (Gordon et al., 1994)

Location referencing and spatial data problems for ITS were recognized as important areas for research and government decision-making in the early '90s. A paper by Lerner-Lam, et al., (1993) reviewed the recognition of the problems at the time and addressed the relative roles of the public and private sector in solving them. In particular (and of particular relevance to much of the ITS datum discussion that follows), the paper expressed the need for a "network referencing system" that would use standard road link IDs to register together different digital map databases. The link IDs would be in the public domain, and it was thought at the time that private sector database vendors could and would provide "value-added" data to the public "base data" as a matter of course. (For the following discussion we will call this model of public-private roles the 'value-added' model.)

The paper also presented a new Federal initiative to "lay the foundation for efficient and effective digital mapping and spatial database management for IVHS" (op cit., p. 147). Oak Ridge National Laboratory (ORNL) was tasked by the Federal Highway Administration (FHWA) to review the requirements of ITS applications for spatial data and location referencing, and to determine whether any Federal action was necessary to ensure those needs are met, particularly for nationwide applications.

The 'Nationwide Map Database and Location Referencing System' project began in 1993. It attempted to address institutional, legal, and economic issues in addition to technology issues in order to assist public officials in the determination of appropriate public sector roles for ITS. As part of this project, public and private digital map data sources were inventoried, ITS functional and technical spatial data requirements were defined, and location-referencing methods were surveyed and evaluated with respect to their suitability for ITS applications.

The overall goal of the Nationwide Map Database and Location Referencing System Project was to define a national spatial data infrastructure for IVHS. This infrastructure was seen to include (from Gordon, et al., 1994):

- a. Standards for data sharing between organizations, both public and private, and between components of operational systems;
- b. Standard methods of referencing geographic locations;
- c. Standard architectures for spatial databases;
- d. A high quality national database "hub" to which local data from both public and private sources could be attached by way of the data sharing standards.

In addition, the project took on the tasks of attempting to develop consensus positions on spatial database issues, to increase commonality of language and hence understanding within the ITS community (and user sub-communities) regarding those issues, and to define and present a national point of view. Part of this rather ambitious consensus building was an explicit attempt to bridge the gap between the IVHS and GIS-T communities and explore ways in which they might work together for mutual benefit.

7. Interoperability Proposals

- 7.1 A Common Database**—It became apparent early in the project that the location referencing problem and the ITS digital map database problem were tightly inter-related. In fact, there would be no location referencing problem if everyone in a place, be it a city, a region, or the country as a whole, used the same database. If this were done, IDs of network nodes and links could be used for spatial references without ambiguity. (This does not mean that the database would be good enough to support ITS applications, just that interoperability between applications would be easier.) This could be achieved by either adopting one existing database, be it public or private in origin, by making a new one, or by a combination of both within a region. For example, if a national ITS database of all roads were constructed, or if one private sector map database were used, interoperability between applications would be facilitated.

This approach was seen to have serious problems, not the least of which is cost. We estimated that making a detailed and accurate public sector map database of all the country's roads would cost over \$500 million. Comparably sized map databases developed by the federal government have cost as much, and have taken a decade to complete.

We also estimated that it would cost another \$100-200 million a year to support the organization necessary to keep it updated. The ITS map database requirement for up-to-date data means that updates must be continually fed from the local level, which may be an impossible requirement for a centralized federal agency to do in a timely manner. This problem is particularly acute for transportation networks, which may change ten percent per year in some areas. The inevitable result is a patchwork of sections of data with varying currency.

Another disadvantage has to do with non-technical issues. For a large spatial and functional domain such as that envisioned for ITS in the US, the construction of a national ITS database would require a policy debate with regard to private and public sector roles. All of these difficulties argue for the creation of a spatial data infrastructure with the standards, networks, links, and institutional framework in place to permit local update of national databases.

- 7.2 Interoperability Standards**—Because of these problems, the ORNL work over the last few years has stressed interoperability between databases of different kinds and qualities by the development of standards. Two standards were proposed: the Location Referencing Message Specification (LRMS) and the ITS Datum.

- 7.2.1 THE LRMS—Proposed location referencing methodologies have dealt with the problem of communicating locations between databases in practical and standard ways. Much research and testing has resulted in the definition of the Location Referencing Message Specification (LRMS), which specifies standard location reference messages for ITS (Goodwin et al., 1995, 1996). The LRMS is presently in ballot by the Society of Automotive Engineers (SAE) as an official SAE J2374. One of the profiles (Cross-streets) within the LRMS has been put forward as a national standard location referencing method for Information Service Provider (ISP)-vehicle references and is being standardized as SAE J1746.
- 7.2.2 ITS DATUM—The second interoperability proposal coming out of the ORNL project was the ITS Datum. A datum generally is a framework for referencing, that is, it specifies things with respect to which references are made. Many kinds of datums are of interest to ITS; two were proposed initially for an ITS Datum:
- A **geodetic datum** specifies a horizontal (latitude and longitude) and vertical (altitude) reference framework for the earth. It defines a model of the earth, against which measurements of latitude, longitude, and altitude can be made. In other words, it is a framework for 3-D referencing wrapped around the Earth that allows the location of any point to be described.
 - A **linear datum** specifies reference points along linear features such as roads and railroads. This is a case of fewer dimensions, since referencing is restricted to the linear feature with respect to a certain point such as a milepost, a known landmark, or an intersection with another road.

The ORNL project proposed a geodetic datum standard and a linear datum standard for ITS applications, collectively termed the **ITS Datum**. Previous documents described the ITS Datum as a network of reference control points that could be used to support location referencing between databases of different kinds (Siegel et al., 1996). The control points, corresponding to major road intersections and termed the ITS Datum Node Set, could be used as local origins for local coordinate offset referencing, as ground control points that map database vendors could use to register and “rubber sheet” their digital maps, thereby bringing different maps more into alignment with one another, or as national standard nodes with known node IDs for node and link referencing.

The ITS Datum was also proposed as a national skeleton network (map database) to which local, more detailed road network representations could be attached, in a “mosaic” of Federal, State, and local responsibility. A prototype ITS Datum was generated from the National Highway Planning Network (NHPN), including roads of the National Highway System (NHS) plus other major arterials. The 643 736.6 km (140 000 miles) of NHS roads alone represent 70% of commercial road miles and 80% of tourist miles, and therefore would support many national-level interoperability requirements for ITS.

- 7.3 **Spatial Data Interoperability Testbed**—A component of the ORNL spatial data work strongly related to the ITS Datum is the Spatial Data Interoperability Testbed project. The primary purpose of this project has been to test spatial data interoperability standards, particularly the Location Referencing Message Specification (LRMS) and the ITS Datum concept for public sector spatial databases. Testing is being performed at Knoxville, Tennessee through a subcontract to Viggen Corporation, and at the Vehicle Intelligence Testing and Analysis Laboratory (VITAL) at the University of California, Santa Barbara through the California Department of Transportation's (Caltrans) Testbed Center for Interoperability (TCFI).

The Spatial Data Interoperability Testbed effort has had significant impact on location referencing standards. The Information Service Provider (ISP)-Vehicle profile (Cross-streets) in particular has received extensive testing (VITAL, 1997, Haas et. al., 1998), which has resulted in significant changes to the Information Service Provider (ISP)-Vehicle standard (SAE J1746). Other LRMS profiles are being tested, both alone and in the context of standard message sets and communications devices. The Testbed is also being used for proof-of-concept testing of the ITS Datum in preparation for deployment nationally and to satisfy local public sector data requirements. Under development are rules and standards for point selection and placement to best serve ITS applications, data models that deal practically with the complexities of intersections, and practical and cost-efficient operational methods for database construction and maintenance.

8. Related Activities—Several related activities are underway in transportation. This section briefly describes some of the more important ones; at least of which the authors are aware.

8.1 NCHRP Linear Referencing Programs—The National Cooperative Highway Research Program (NCHRP), sponsored by the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA), has sponsored research into Geographic Information Systems applications to transportation problems (known as GIS-T). Much of this work has focused on development of linear referencing technologies, since linear referencing is commonly used by state DOTs. At a workshop held in Milwaukee in 1994 (Vonderohe, et. al., 1995), much progress was made in developing a standard linear data model to support GIS-T and the terminology to support the data model. In particular, the concept of 'anchor points' and 'anchor sections' were defined. Following the workshop, the standard linear data model progressed in the project NCHRP 20-27(2), "A Generic Model for Linear Referencing Systems," and ITS Datum points were proposed by the ORNL project as an anchor point set for the NCHRP activity.

The ORNL project is working closely with NCHRP personnel in developing datum concepts and technical designs to support GIS-T linear referencing. A new NCHRP project, 20-47, "Quality and Accuracy of Positional Data in Transportation," is also of relevance to ITS Datum work.

8.2 NSDI Framework Transportation Identification Standard—The National Spatial Data Infrastructure (NSDI) "framework" activity through the Federal Geographic Data Committee (FGDC) Ground Transportation Subcommittee (cf. Dr. Bruce Spear of the Bureau of Transportation Statistics) is concerned with developing a transportation data component. The transportation Framework element aims to develop and maintain transportation data from public and private sources. BTS has proposed developing an NSDI Framework Transportation Identification Standard that would facilitate data sharing between public sector databases. This standard can be viewed at the website, http://www.bts.gov/gis/fgdc/web_intr.html. Quoting from the proposed standard, "The objective of this content standard is to specify methods for identifying linear geo-spatial features that can be implemented within existing data structures without some of the topological problems cited above. Furthermore, the proposed standard should allow users to create customized topological networks from the reference segments without modifying the properties of the reference segments themselves. Successful achievement of this objective will facilitate transactional updates to framework transportation databases by allowing new transportation features to be added without changing existing transportation segments. The standard should define a transportation segment in such a way that it is independent of cartographic scale, cartographic representation – irrespective of scale, attributes which can change over time, and network topology. Each defined transportation segment can then be assigned a unique identifier that does not need to be modified for different applications or for additions of new transportation features."

A preliminary workshop was held at Wrightsville Beach, NC, in December 1997. The preliminary data modeling work is intended to be compatible with the generic linear data model developed under the National Cooperative Highway Research Program (NCHRP) Project 20-27, and uses the terminology of anchor points and anchor sections from those activities. Framework personnel and ITS Datum project personnel are coordinating efforts at the ITS Datum workshops and other liaison activities.

8.3 USGS—The U. S. Geological Survey (USGS) is developing framework transportation pilot projects and partnerships with several states (e.g., Georgia, Michigan, West Virginia, Vermont, Kentucky, New Mexico, Texas) (Charley Hickman, personal communication). ITS and national linear datum work may relate to those projects in the future. Of particular relevance to ITS Datum design, a presentation at the Wrightsville Beach workshop by Steven Guptill described Network Datum Point (NDP) and Network Datum Section (NDS) concepts that are very similar to ITS Datum nodes and logical links. The presentation also dealt with datum maintenance by a hierarchy of authorities and techniques for registration. This discussion can be found in Section III, pages 4-7 of the Wrightsville Beach report.

8.4 International Standardization Activities—Project personnel are actively involved in international standardization activities related to location referencing and spatial data issues. Specifically, the International Organization for Standardization (ISO) Technical Committee (TC) 204, Working Group 3, TICS Databases, has the following Work Items in process:

- a. The Geographic Data File (GDF) standard for TICS database exchange;
- b. The Physical Storage Format (PSF) standard for databases on media;
- c. An international Location Referencing standard;
- d. An Update Publishing standard; and
- e. An Application Programming Interface (API) for access to TICS databases.

As part of the Location Referencing activities, project personnel are sharing testing information with the European EVIDENCE project, which aims to test the European ILOC (Intersection Location) methodology for location referencing. This information sharing may grow to encompass new European attempts to improve public sector data sharing capability through incorporation of linear referencing requirements into the GDF standard. Of particular interest to the US ITS Datum activity is the use of Reference Point sets to support linear referencing.

In addition, ISO TC211 conducts activities on location referencing (chiefly coordinate-based) and data exchange standards for geographic information. Project personnel maintain liaison with these activities.

8.5 Public and Private Roles in ITS Datum Creation and Use—One issue discussed at length at both Public Sector ITS Datum Requirements workshops is the distinction between ITS Datum, NSDI Framework, and GIS-T Linear Referencing data models. To a large extent, the discussion has been driven by the different roles of linear datums. As Hickman put it in his Knoxville workshop report: "For ITS, the main roles of the linear datum are to support database interoperability and real-time location message exchange. For GIS-T, the roles may be to support accurate dynamic application of road inventory attributes and linear event management. For NSDI transportation framework, a linear datum may support data improvements through conflation and transactions, and the representation of transportation features at multiple levels of detail."

The *NSDI Framework Transportation Identification Standard* project proposes the assigning and reporting of identifiers for Framework Transportation Segments (FTSeg), and voluntary process guidelines for data collection, and is therefore similar in scope to the proposed ITS Datum work. In both these activities, coordinate information is included, although node placement and accuracies required by applications are different.

The role of coordinates is particularly important to ITS applications. Without coordinates, private vendors of data and/or private companies which make software to handle the data, must agree to 'understand' public links, whether FTSegs or ITS Datum links. That is, they must agree to take those link identifiers and translate them into their own internal identifiers. This approach was rejected by Navigation Technologies (Navtech), the major national supplier of accurate ITS datasets, in 1997, on grounds of cost and uncertainty regarding compliance and how it could be achieved technically. As was pointed out by Navtech (Cherveny, 1997), useful local level datums would be very expensive for the private sector to accommodate if it implied costly modifications to their databases.

What vendors of private detailed street databases agreed to, however, was the use of coordinates and street name information for conveying locations of intersections and links into vehicles. This concept is expressed in the ISP-Vehicle (Cross-Streets) profile within the LRMS. This least common denominator approach is universally applicable, but, as extensive testing by this project has shown, it is not universally successful, due to differences in the underlying datasets themselves in terms of network coverage, detail, currency, and accuracy of data elements and geographic coordinates.

Obviously, in order to use the ISP-Vehicle standard to facilitate the “value added” model for private sector roles, the public sector base maps must have coordinates available for the transfer. Lacking them, there is no longer a viable methodology for adding value from proprietary datasets to public base maps and we are left with, again, the private ITS data world and the public GIS-T data world.

Another 'bottom-line' conclusion we have reached from testing is that location referencing between two different datasets is only as good as the datasets themselves. Public datasets will interoperate better if they conform to consistency and quality standards when they are produced. Similarly, data sharing in integrated GIS-T implementations will be facilitated by having public sector datasets that are consistent and open. GIS-T network inconsistencies are real and common, at all data levels, which makes the conflation (registration) problem non-trivial when performed in GIS-T environments, and possibly ruinous for real-time ITS applications. ITS Datums, combined with software based on their use, offer the possibility of near real-time conflation and data sharing to the public sector.

One final point: although the GIS-T requirement for data fusion carries over to ITS applications (indeed, it is a primary function and difficulty for ISPs), there remains a separation between GIS-T and ITS operations within an integrated ITS architecture. GIS-T functions demand GIS base maps against which various resources and activities related to an integrated multi-agency environment can be conflated or cross-registered by GIS tools. In some cities, existing base maps are superior in accuracy and quality **as framework base maps** to those available for ITS-specific applications, and can easily and cheaply be converted to ITS Datum standard formats. In other places, such high quality maps do not exist and private sector maps may become candidates for ITS Datums, if mechanisms and agreements can be put in place to protect proprietary value. In any case, private sector detailed navigation maps, as an example, would probably be first choices for inclusion in GISs as navigation layers.

9. **Current Project Goal**—It is our view that database quality and availability remain important issues and represent potential stumbling blocks for ITS deployment. Therefore, we view the goal of this work to be **the definition of a practical methodology for construction of public domain ITS databases to support the integration of ITS systems, to facilitate spatial data interoperability, and to meet both private and public sector ITS requirements at all levels.** This view focuses on the development of data models that deal practically with the complexities of intersections, and on practical and cost-efficient operational methods for ITS Datum framework database construction and maintenance.

These datums are “base data” in the “value added” model. They can be used to register other public sector databases, or private sector databases if IDs can be made public or through the more advisable method of the ISP-Vehicle location referencing standard. They will fill in the holes where the private sector does not provide adequate coverage or quality for public or private sector users.

Public domain ITS databases can occur at multiple levels. We support a national-level, coarse ITS Datum for major highways, railroads, and intermodal transfer points to serve as a framework for both public and private database integration, including linear referencing databases common in transportation. Also, production of densified ITS Datums in cities and regions can support integration of ITS systems. We expect that all levels of government will be involved in setting requirements for these databases, and that some level of cooperation between the private and public sectors is possible through a clear establishment of the “value added” model between the public and private sectors.

Furthermore, we consider that ITS Datum standards and processes, well tested and proven operationally, are essential **foundation standards** for ITS. As Figure 1 illustrates, the important transportation information present in ITS Datum standards and processes supports the NSDI Framework activity, the NCHRP linear referencing activity, ITS standards generally, especially the new ITS planning User Service, and the development of a new NHPN network and many other public sector databases.

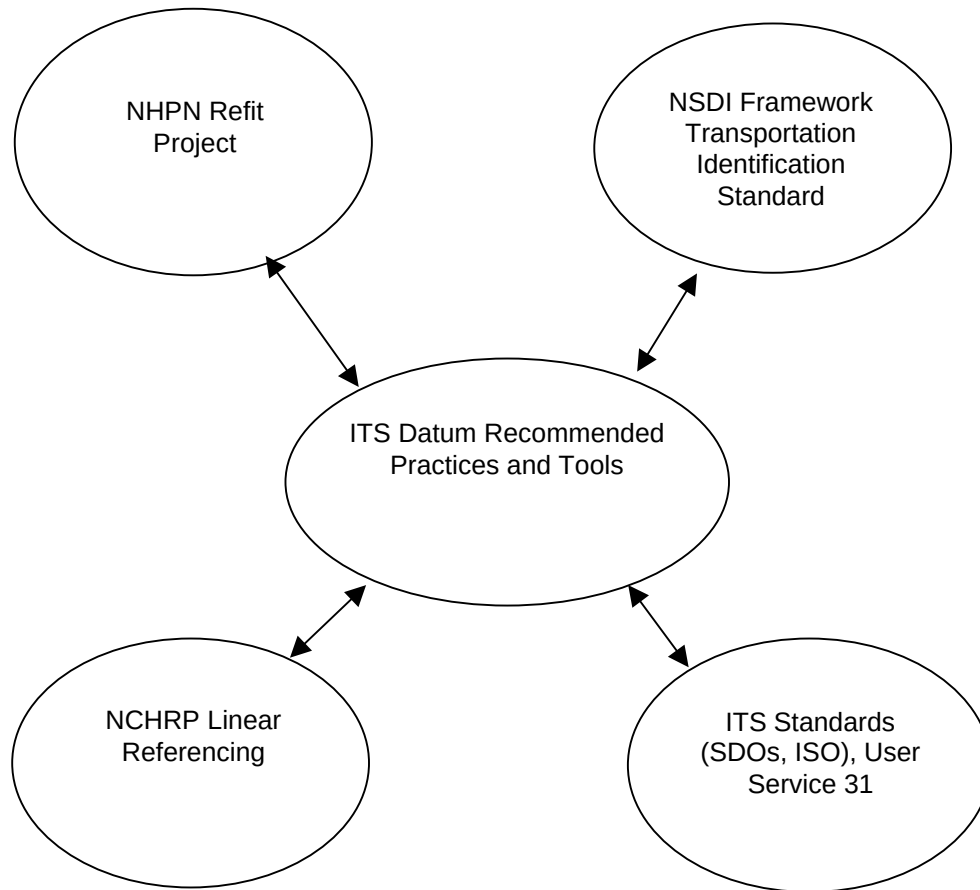


FIGURE 1—ITS DATUM RECOMMENDED PRACTICES AND TOOLS AS A FOUNDATION SPECIFICATION FOR FEDERAL ACTIVITIES

10. Next Steps—We believe sufficient input from public sector communities has been provided to proceed with the next steps in ITS Datum development and deployment. Specifically, the following steps need to be taken:

1. The ITS Datum data architecture must be modified to support the diversity of potential users, including both public and private sector users, at national, statewide and local levels, for all surface transportation modes;
2. Field methods that establish and adjust ITS Datum reference objects must be defined;
3. Proof-of-concept testing will be essential to both 1 and 2 and should be initiated;
4. Operational experience with ITS Datum construction and use should be gained through local deployments.

Item 4 bears a closer look. As Alan Vonderohe has pointed out in a critique of earlier datum work, “a major reason behind the difficulty with the standardizing the ITS Datum concept is the lack of operational experience. Although other countries (notably Japan) have created national transportation datums, there is a substantial lack of “hands-on” experience in the U.S.” He then went on to recommend a small scale pilot project to validate ITS Datum concepts and develop and test new ones (Vonderohe, 1996). We believe this step is essential and should even be expanded to the point of building operational deployments over the next two years at two or more ITS deployment sites, perhaps in conjunction with a new round of Model Deployment sites.

Both state and local databases at adequate levels of data accuracy, quality, and detail are in many cases only in initial stages of development. Financial means vary enormously, and sometimes institutional barriers to both new technologies and new attitudes must be overcome. Fitting data from state and local sources into a national data infrastructure will require timely specification of nationally valid standards for data exchange, database content, and quality. With timely specification of these standards, national goals may be attained at little additional cost to the states and localities.

The key to making such databases possible is partitioning of the job and sharing costs between the public and private sectors. Proper partitioning of the job means defining real and significant requirements. Clearly, the private sector map database vendors understand the requirements of their customers, and invest heavily to satisfy them. If the public sector has significant requirements for national-level or regional and local ITS map databases, then it is reasonable to expect public funding from the appropriate level of government. Issues of contracts to private parties for database construction, and public agency roles, would be dealt with in this process. Determining requirements, benefits, costs, responsibilities, and exploring funding mechanisms, institutional issues, and ways to make it all happen is our task for the non-technical side of the ongoing ITS Datum work.

11. Strawman ITS Datum Design Decisions—Following the Santa Barbara requirements workshop, project staff made 'strawman' design decisions based on all workshops and technical analyses to-date. This section lists the design decisions for consideration by the spatial data community and other parties interested in ITS Datum technical issues. They will be used both as starting points for ITS Datum test deployments and for future ITS Datum workshops.

11.1 ITS Datum Issue - Topological enforcement—The ITS Datum provides, among other things, a positional reference for ITS applications. The problem of positional disagreement of coordinate placement between a reference and target database is the driving factor behind researching practical location referencing solutions. Until planimetrics are routinely captured at extremely high accuracy and until maps with lesser accuracy are positionally corrected, such solutions are needed for interoperability between map databases from disparate public and private sources.

Users of dissimilar spatial data may employ the high accuracy control points of an ITS Datum to either rubber-sheet spatial data or to generate hybrid referencing schemes that register high accuracy datum points to base map planimetrics in a semi-real time, automated fashion. Such methods may utilize an ITS Datum as a set of reference nodes and links relative to which locations may be expressed as offsets, determined by measured distance. In this usage model, an ITS Datum will function as a series of accurately surveyed points.

The Strawman ITS Datum format identifies connectivity of points where movement is permissible. However, that does not mean that an ITS Datum is a topologically correct base map itself. Accurate datum locations are matched to existing target map data and used to correct positions of real world features that maps represent as spatial objects. Maps managed in various coordinate systems or projections may use standard transformation procedures to match the datum to their existing map data.

Topology refers to connectivity and adjacency. Node topology is explicitly coded in the Strawman ITS Datum ASCII flat-file. Every node entry in the file accurately describes a real world location in terms of coordinates and points to connecting nodes. Unconnected points are permitted; such points may be classified as points-of-interest along the network, or off the network. They may be non-planar as well, for example a point representing the location on an overpass. Links contained in the flat-file are expressed as an ordered from-node and to-node structure, which reflects the direction that is allowed for flow through the network.

Connectivity between nodes varies; one node may have no connecting nodes while another could have five. However, no matter how many connected nodes exist, the ITS Datum maintains one row per connection (or stand alone node). Each ITS Datum point is a one-node tie-point to an intersection, with each A→B ITS Datum record (link) duplicated by a B→A ITS Datum record (link) if the roadway is bi-directional.

Providing extended turntables in an ITS Datum is not necessary because the structure incorporates laws of allowable travel through the network. Turntables, which are used by many GIS-T and ITS applications such as vehicle navigation, will be available through value added organizations, not from an ITS Datum itself. Thus, an ITS Datum remains generally applicable and universally accessible. Basic logical link information is implicit in the ITS Datum via connected node lists, and higher order chain structures or routes can be assembled from such links by applications.

Note that an ITS Datum is not a topological base map. The lack of topology allows additions of new datum points that intersect existing 'pathways' between datum points, thus becoming new rows, or records, in ITS Datum files, which are identified by level and governing organization. ITS Datums only supply logical links (without shape points) between datum nodes. It is the user's discretion as to how the new data may be associated to a map that will be managed in a true topological structure.

ITS Datum nodes are depicted in Figure 2. In this scenario the nodes in yellow connected by a yellow line have been introduced to an earlier version of the ITS Datum, perhaps as a result of densification. It is not necessary to re-evaluate or analyze the original node structure. High-accuracy ITS Datum control points are introduced into map data and applications that use them. The decision will then be made by the local application whether or not strict topology is to be maintained. If so, new breaks in connectivity are introduced with new linear interpolations assigned to the broken links. The application-driven software decides if A-D becomes a new topologic link.

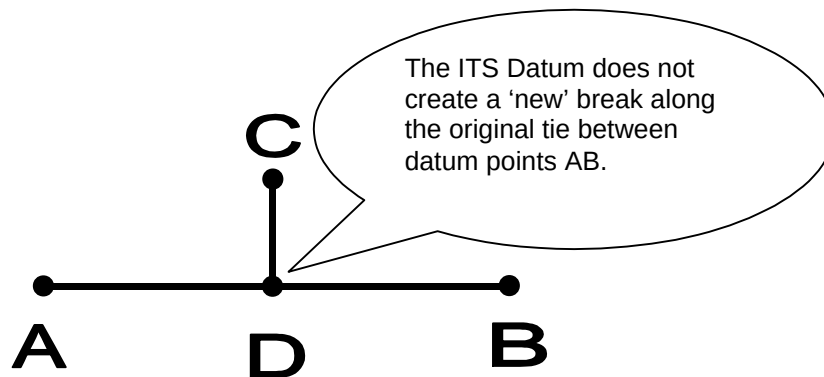


Figure 2—Inserting new nodes

Specific to GIS-T, GIS software provides the capability of multiple level representation and correction of feature locations. Such abstractions of features can occur at a point, line or even polygon level via complex feature representation. In part, this design rule was established because custodianship and maintenance of an ITS Datum are hierarchically decentralized. Densification or insertions will come from organizations that do not control the entire ITS Datum. Thus, it does not become the responsibility of the agency that makes the insertion to create a new ITS Datum record for D-A and A-D.

11.2 ITS Datum Issue - Node Density—The density of an ITS Datum node network is determined by national requirements for interoperability. While an ITS Datum node may eventually be located at every intersection, interoperability at the national level does not require that level of detail. The ITS Datum *prototype* consisted of approximately 50 000 points, created from each roadway intersection from the National Highway Planning Network. The Strawman ITS Datum architecture consists of at least two levels: a national framework level, with a density similar to that of the prototype, and a regionally densified level. (The possibility exists for intermediate levels, e.g., state, as well. Ongoing USGS work, as described in Section III pages 4-7 of the Wrightsville Beach report may offer additional insight into tying levels together.)

The Level-1 Strawman ITS Datum concept supplies the initial framework for location referencing and parallels the collection points as seen in the prototype datum. The Level-2 datum is a denser network representation where localized intersections are appended to the national framework. In a level-2 datum representation, even more datum points may be collected and measured relative to one surveyed point (centimeter range) or via wide area DGPS. In this case the intersection object model (IOM) principals of interchange representation may become another method for employing ITS Datums with existing base map data, or even creating new maps (See ITS Datum Prototype Specification, 1996). The data model used will be similar if not identical to that of ISO GDF.

Because node density is a factor of the density of roads and streets in an area, the spatial density of the ITS Datum node network will not be uniform across the country. However, node density is a factor in location referencing accuracy and may also be a factor in the success of the LRMS for some ITS applications.

For example, for an application using link referencing based on ITS Datum links, high node density is preferable. However, a product primarily using geographic referencing may not be greatly affected by ITS Datum node density unless interchanges cover large geographic areas. Different ITS applications will therefore have different node density requirements to support for particular location referencing implementations. In addition, the LRMS profiles impose node density requirements due to restrictions on data sizes (number of bits allowed) for geographic offsets, and the accumulation of positional error for linear referencing on long links.

11.3 ITS Datum Issue: Node Placement Rules—For the 1996 prototype, ITS Datum reference nodes were placed relative to the subset of gore points at an intersection where turning options are present. As a vehicle travels into an intersection there will come a point (or distance) along the lane where the vehicle's path will diverge, based on the turning decision. This point, which can be defined by a turn from either the right-hand or left-hand lane, will be called the turning option mark, and is a decision point where a turning option is present.

An ITS Datum point is collected where roadway centerlines depict decision points on a network. Gore points represent obvious decision points along a roadway but are not suitable for positioning datum points because of their instability and because of the lack of any consistent mechanism to place their location in the field. In the case where centerlines do not necessarily represent what appear to be natural decision points, such as at T-shaped intersections, the datum point is collected at the intersection of the centerlines (cf. Figure 3.)

Desired accuracy for a Level-1 ITS Datum is 2 to 5 meters; this accuracy range is broadly affordable and will satisfy the majority of ITS application data accuracy requirements defined to-date. Quality improvement is of course possible beyond that. The methodology for datum collection has not yet been proven in the field. The problem in fixing a centerline or decision point location in the field is compounded by the method of collection, including a number of human factors. For example, data capture from a moving vehicle is subject to human reflex error and variance and individual interpretation of environments. While this is the preferred collection method in terms of cost, it is clearly not as accurate as standard surveying practices. However, there are methods to correct the ellipsoidal error associated with point capture from a moving vehicle. Additionally, these points can be 'pasted' into a standard base map during collection.

The prototype ITS Datum was not envisioned as a series of control monuments but rather as intersections of major roadways across the country. The Strawman ITS Datum is also not a series of brass field monuments, although nothing prohibits physical markers or benchmarks from being placed in a specific area if they are required by an application. Node placement rules for the Strawman ITS Datum are not complete. However, they will be made from the viewpoint of the driver of a vehicle navigating with the aid of information referenced to an ITS Datum.

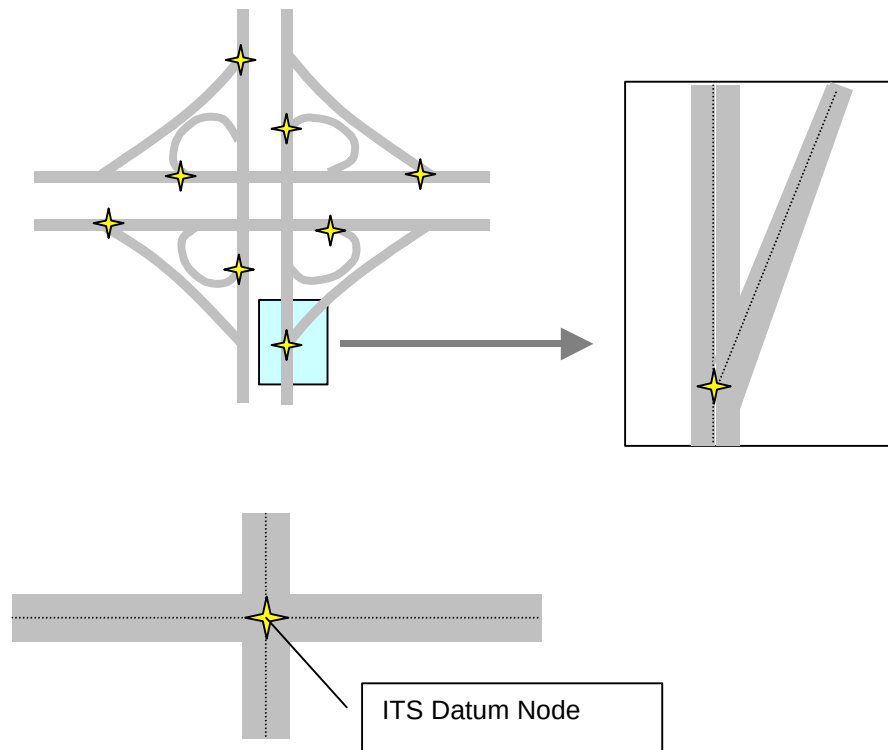


FIGURE 3—ITS DATUM NODES AT ROAD CENTERLINE INTERSECTIONS

11.4 ITS Datum Issue: Node and Link IDs—A unique, permanent, node identifier is assigned to each ITS Datum node. The identifier, determined by a hierarchical ordering schema, could be uniquely tagged using a concatenation of coordinates. However, the ITS Datum workshops have demonstrated a need for more field analysis. The Strawman ITS Datum node ID's are structured using administrative boundaries, as follows:

State FIPS | County FIPS | Unique ID (within a state).

Development of ITS Datums will most likely occur with the participation of federal, state, local and even private organizations. The numbering scheme reflects an orderly methodology that is both extensible and flexible.

There are two preferred methods for encoding ITS Datum fields. One would be to provide fixed field widths for each node entry. The other, resulting from ITS Datum and NSDI Framework workshops, uses a dot to separate each component of the numbering scheme. The dot rule makes Node ID's appear similar to Internet node numbering schemes, e.g., 'State FIPS.County FIPS.Unique ID.'

Two link identifiers are provided for each Strawman ITS Datum link: the from-node/to-node ID pair, and an explicit NSDI Framework-formatted link-ID. Additional link information (length between nodes and names) is included in order to support linear referencing systems.