

The Case for a Unified Linear Reference System

David Fletcher, John Espinoza, R. D. Mackoy, Stephen Gordon, Bruce Spear and Alan Vonderohe

***Abstract:** Three distinct transportation interest groups—transportation facility managers, civilian transport users, and military transport users—currently collect and maintain separate, often redundant or inconsistent, information. Some progress has been made toward integrating these data within each domain. However, the flow of information between them has received less attention.*

Working groups from each domain met to explore a single location-control framework that would encompass all the domains. They concluded that a single unified system could meet the needs of all transportation users. This paper discusses preliminary user and technical specifications for a unified approach, several factors impeding the strategy, and a research agenda for moving forward.

The transportation industry demarcates its activities and data into three functionally and institutionally separate domains. Transportation infrastructure management activities (e.g., planning, design, construction and maintenance) produce the transport links (e.g., roads, rail lines, transit routes) used for travel. In contrast, civilian and military transport operations focus on finding and using the best transport links. Each of these three transportation interest groups—transportation facility managers and civilian and military transport users—currently collects and maintains separate, often redundant or inconsistent in-

formation. This information involves the status of passengers, freight, material and vehicles plus state information about the transportation system itself.

Although there has been some progress made in integrating these data within each domain, identifying and improving the flow of information between them has received less attention. Since activities initiated in one domain affect conditions in the others, defining these flows is crucial to the next generation of planners, traffic managers and transportation service users. For example, construction and maintenance activities influence civilian and military route choices and travel times. Conversely, large-scale military movements disrupt civilian travel and have potentially major effects on the infrastructure. This intertwined interest in the transportation system identifies the need for data integration not only within each sphere of interest but among the spheres as well. Although recent policy statements by the U.S. Departments of Transportation and Defense indicate a desire to share information, significant technical and institutional barriers exist.

Over the past decade, information analysts in all three domains have independently concluded that site and event locations are primary information needs and that location attributes are primary keys in developing information integration strategies. Knowing where components and events are relative to one another is essential for planning and operational decision-making. Additionally, these locations serve as a significant integrating mechanism when used as the basis for the organizing information and designing geographic information systems for transportation (GIS-T). Consequently, while there has been considerable work done in each domain to define location reference methods and standards, no one has attempted to define a unified approach applicable across all three domains.

Recognizing the fair degree of overlap among these independent efforts and the opportunity to establish a

David Fletcher is an associate director of the ATR Institute at the University of New Mexico. His research interests encompass the breadth of topics constituting transportation informatics, including GIS-T and location referencing.

Juan Espinoza Jr. is a senior member of technical staff at Sandia National Laboratories in Albuquerque, NM. He has been involved for 17 years in many national security related fields such as facility safeguards and security, treaty verification, information system surety, and advanced transportation.

R.D. Mackoy is a senior member of technical staff at Sandia National Laboratories and has been there for 11 years. His specialty is in interfaces to computers, both carbon-based firmware and hardware.

Stephen Gordon is the manager of the ITS Research Group in the Center for Transportation Analysis, ORNL.

Bruce Spear is director of the Office of Geographic Information Services at the U.S. Department of Transportation, Bureau of Transportation Statistics, in Washington, DC. Prior to this, he was the GIS program manager at the Volpe National Transportation System Center in Cambridge, MA.

Alan Vonderohe is professor of civil and environmental engineering at the University of Wisconsin-Madison. His current research focuses on location referencing and data modeling for GIS-T.

single location-control framework encompassing all three domains, representatives from each domain met to explore such an option¹. Those representatives, along with several invited location experts, conducted a day and a half of technical discussions. The group concluded that a single, comprehensive approach to location control could meet the needs of public sector, civilian and military transportation users. The group also determined that this approach should be led by the federal government and supplemented by state and local transportation efforts.

The attendees also identified several factors impeding the adoption of a single, location-control strategy. They developed preliminary sets of user and technical specifications for a unified approach. They identified a research agenda addressing certain technical implications of the specifications and generated institutional recommendations for moving forward. This paper is a report of those findings.

What is a Unified Linear Datum?

The National Cooperative Highway Research Program (NCHRP) Project 20-27(2) generic data model for linear referencing systems defines a linear datum as:

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

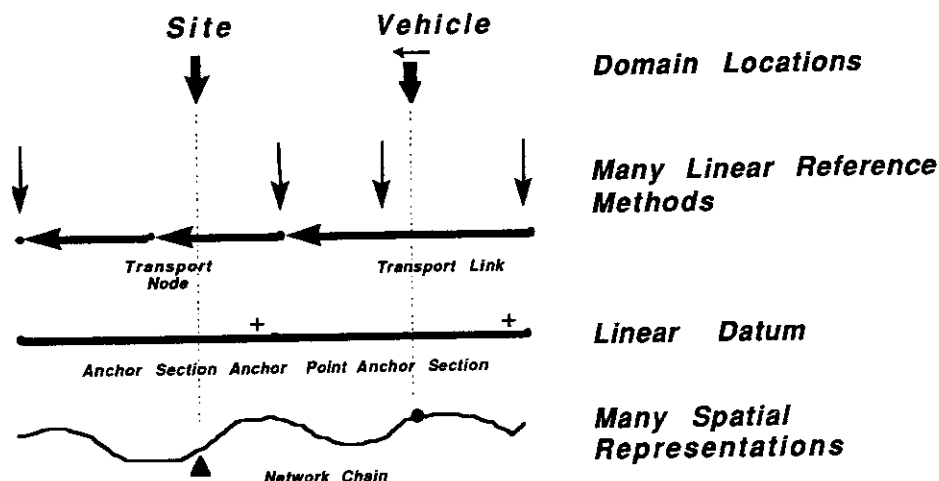
(Vonderohe *et al.* 1995)

Figure 1 illustrates the relationships among the various objects comprising a linear reference system. Domain-specific applications determine actual transportation objects and events labeled as domain locations. Each site or vehicle can be located by various linear reference methods using combinations of field and office procedures, unique to that domain or application. Multiple application dependent topologies (i.e., transport links and nodes) can be defined and referenced to the datum as well. The key innovation offered by the universal datum is that all of the application specific objects are referenced to a single datum. This datum can also be attached to multiple cartographic representations for display purposes.

A unified linear datum encompasses national, statewide and local transportation facilities and controls infrastructure, vehicle and container locations. The significant point is that public sector transportation managers, the ITS community and the military all use the *same* underlying datum. This common structure will provide for the unambiguous transfer of location-based data both within and among these groups. Of course, not all applications will require every component contained in the datum. The unified approach requires only that there be exactly one anchor section controlling a specific fragment of the transportation system. This section controls all location methods that fall within its linear extent.

The control framework is *not* a transport systems application network. That is, the datum does *not* include any transport systems flow topology or application data (e.g., capacity, demand or impedance characteristics). Routes, junctions, intersections, terminals, travel links and other domain-specific objects *relate* to the datum; they are not parts of it. Control surveying principles, not

FIGURE 1. Schematic view of the Linear Reference System



on-transport logic, guide the procedures for determining the locations and extents of the datum components (Vonderohe and Hepworth 1998).

The control framework is also *not* a unified linear reference method. That is, each domain will still continue to develop and use independent reference methods. In turn, these methods will themselves be incorporated into distinct reference systems. The control framework is used to register these multiple methods and systems in order to transform locations collected in one method into locations referenced by another method. These transformations rely on the ability to relate all locations to the datum.

Issues Impeding Linear Datum Unification

Several issues impede the progress toward a unified, surface transportation-location strategy. These are a combination of conceptual, semantic, technical and operational factors. True unification will depend on overcoming each of these.

1. There is considerable confusion over the distinctions between field, map and database "location" concepts. Field data collectors generally view locations as measurements referenced to an arbitrary number of known reference objects. Mapmakers view locations as Cartesian coordinates referenced to some planar origin. Database designers view locations as data-indexing mechanisms. Each camp uses a variety of measurement and coordinate systems. Because of the contextual differences among field, map and data base views, each requires separate objects, and business rules. Field positions, map locations and database addresses are *not* the same attributes and will not generally have the same coordinate values.² Many transportation agencies attempted to use field locations or map positions as database keys. This strategy was difficult to maintain

over time because of the dynamic nature of the field locations (e.g., changes in route designations and changes in mile point values resulting from realignments). A smaller number of agencies were equally unsuccessful in their attempts to use data base keys as field locations.

2. Over the past few years there have been several national efforts aimed at producing a standard non-proprietary model specification for linear reference (Seigal *et al.* 1996; Vonderohe *et al.* 1995; Fletcher *et al.* 1995). However, at this time there is still a lack of "universal" consensus about these specifications. Indeed, most people in this field still do not understand the concept of an application independent linear datum used only to control the relative locations of linear objects and events.
3. Although the first linear reference software appeared more than 20 years ago, there is still a lack of technical support (i.e., products and services) of linearly referenced location data. Most software is still *ad hoc* and idiosyncratic. Most of these proprietary approaches have sacrificed conceptual rigor for application specific performance enhancement. To the best of the authors' knowledge, only a few commercially available software systems can support the requirements laid out in the cited references.
4. Given the lack of a standard specification and the consequential lack of supporting technology, the final impedance to a unified approach is the lack of operational experience with developing and managing large control frameworks. There is not enough "real-world" experience to convince any but the most risk tolerant to abandon their current efforts and adopt a new strategy.

Propositions Concerning the Unified Linear Datum

The case for a unified linear datum starts with the following propositions. These propositions outline the basic technical and institutional architecture for the datum. Table 1 illustrates various control datums used in the

TABLE 1. Comparison of Datum Characteristics³

Dimension	Datum Name	Datum Object	Reference Object	Location Specification	Custodian
3-D	WGS84	3D Cartesian axes, origin at earth's center of mass	Satellite constellation	X, Y, Z	DOD
2-D (Horizontal)	NAD83	Ellipsoid	Horizontal control station	f, l	NGS/States
2-D (non-mathematical)	PLSS	Section Corner	Monument	Town, Range, Section, part	BLM/ Counties
1-D (Vertical)	NAVD88	Geoid	Benchmark	elevation	NGS/States
1-D (Linear) proposed	linear reference datum	Anchor section, Anchor point	Traversal reference point (TRP)	TRP + offset	DOT/States

³ This Table was adopted from Vonderohe [4].

United States and serves as the basis for the following propositions:

1. The need for national (or international) surface transportation-location control is very similar to the need for geographic horizontal and vertical control. Historically, the need for navigation charts created horizontal and vertical control systems. Intermodal surface transportation navigation needs of the future justify the proposed linear datum (Seigal *et al.* 1996). Additionally, as Table 1 illustrates, the proposed structure of the linear datum is analogous to other established datums.
2. Federal custodianship of national datum objects used for navigational purposes has precedence as shown in Table 1. Such custodianship leads to the establishment of a national datum, plus policies and recommended procedures for expanding the datum for local purposes. In addition, public laws created each of the existing national datums. No such legal mandate for a surface transportation datum currently exists.
3. Surface transportation location control is multi-modal and multi-jurisdictional and controls regions of varying extents (e.g., international, national, corridor, statewide, regional, municipal). State and local jurisdictions will add linear datum objects to the national framework (i.e., densify the network). This proposition is consistent with the way in which control points are managed in the horizontal and vertical datums.
4. Linear datum objects can and should be tied to at least the WGS84 3D datum. Tying the linear datum to a mathematical datum provides the same benefits as tying the Public Land Survey System to a mathematical datum (e.g., reference object recovery, mapping, data fusion).

Universal Datum Specifications

The following specifications are an incomplete set of requirements for the unified linear datum. These specifications represent the datum users' expectations.

1. The purpose of the datum is to transform locations between the real-world space and data-world space(s) and to project positions between data spaces.
2. The datum needs to be a consistent, nationwide framework accessible to public and private customers.
3. Multiple public domain and proprietary databases will use the datum.
4. Although the datum itself must be in the public domain, many applications using this framework will be proprietary.
5. The datum needs to be able to control location at multiple levels of resolution (e.g., highway location, roadway location, lane location).
6. The datum needs to be able to control locations determined by many different methods (e.g., route and mile point, route and reference point, control section and offset).
7. Each functional domain has distinctly different accuracy specifications. This is a function of either the smallest objects (i.e., the highest resolution) in the domain(s), the

need to discriminate the relative distance between two objects or the precision of the location measurement devices.

8. Navigation and traveler information functions need 3- to 5-meter positional accuracy. The need to discriminate between or resolve the location of individual vehicles determines this requirement.
9. Datum and reference objects need to be identified easily in the field. These objects also need to be fixed, stable and recoverable over long periods of time (decades, if not longer).
10. The unified datum should be domain-content (i.e., application) neutral.

Design Specifications

The workshop participants developed a preliminary set of design specifications for the datum guided by the following design principles. A more detailed set of specifications may be obtained from the primary author.

- Field location reference objects need not be the same as datum objects. The same real world feature (e.g., an at-grade intersection) may have a number of roles and be represented in the database by multiple objects (e.g., a node, an anchor point, a traversal reference point).
- The linear datum can be expanded over time to accommodate new surface transportation facilities. The datum can also be expanded to control facilities not originally included.
- Existing and proposed applications will create additional design requirements. The initial datum design must be flexible enough to accommodate as yet unidentified applications. At the same time the design should not introduce any application biases (e.g., cost, performance).

Research Questions

Before the unified datum can become a reality, many operational questions remain. The workshop participants identified a number of issues as essential. Most of these dealt with the selection and measurement criteria for the datum components—anchor points and anchor sections. In other words, what is the required accuracy, precision and resolution of the components? Many of the questions are addressed by Vonderohe and Hepworth (1998).

Recommendations

In order for the unified linear datum to exist, it needs an institutional context. The participants agreed that the overwhelming use of the unified approach will be for ITS applications. As a result, it makes sense that the datum be established and supported by this initiative. The following recommendations are based on that assumption.

1. Synthesize a single domain model for surface transportation-location reference incorporating multiple location-

- reference methods from the three existing separate domain models. This synthesis is more likely to involve adopting a consistent set of terms and definitions to describe identical concepts as opposed to having to reconcile divergent ideas.
2. Incorporate this specification into the ITS Linear Reference Standard.
 3. Extend the FGDC Geospatial Positioning Accuracy Standards to include linearly referenced points.
 4. Develop joint policies and procedural standards for establishing national, statewide and local datums.

Conclusion

The nation's transportation community is at a crossroads concerning its approach to providing useful location information to its customers. We can continue acting separately and according to provincial interests. Or we can combine efforts and act in the nation's interest. Establishing a single unified linear reference system would be a major step to making the transportation information system as seamless as the transportation system itself.

Notes

1. The workshop was held in Madison, Wisconsin on May 10–11, 1996.
2. The differences are related to the precision, accuracy and resolution of the data.

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