Problems of Cartographic Design in Geographic Information Systems for Transportation

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Geographic information systems for transportation (GIS-T) seek to integrate the geospatial approach of GIS and the tabular approach of conventional transportation analysis. GIS-T deals with such topics as network analysis, linear reference systems, travel demand modeling, and intelligent transportation systems. Conventional cartographic treatment of route features is reviewed in the context of the mapping challenges introduced by GIS-T. Problems in the visualization of complex linear data are identified and examined as cartographic design issues. Cartographic requirements are specified for mapping route-based data and basic design issues are identified. The representation of complex route-based data layers is posed as an undeveloped specialty of cartographic design. Some of the issues involved in developing such fundamental principles are summarized and potential avenues of research are suggested.

INTRODUCTION

Transportation has been a subject of maps for centuries. One can hardly think of a more basic kind of map than a drawing of route directions, whether sketched in the sand with a stick or on a notepad with a pencil. "The ancestry of the road map can be traced to the earliest cartographic efforts..." according to Thrower (1996, 204). Geographic information systems (GIS) are the latest technology to be employed in the service of mapping transportation systems. Recent developments have led to the integration of GIS with the tabular information systems that have long served transportation management and analysis. This hybrid of technologies is sometimes called *GIS for Transportation*, or *GIS-T*. GIS-T was conceptualized and defined by Dueker and Vrana (1992), Vonderohe (1991, 1993) and others both in academia and in professional practice. A defining characteristic of GIS-T is its capacity to perform both transportation and geographic analyses on a common system of networks and routes. Some transportation applications of network analysis are: 1) to understand the behavior of a network (calculate the shortest path from point A to point B); 2) to determine efficient traverses of a network (find the shortest path to visit a selection of places); and 3) and to allocate resources (determine the capacity required of a bus route).

Network analysis is supported by a formal topological structure of links connected at nodes. Modeling transportation systems this way is a useful application of graph theory (Bunge 1966). By reducing the system to a graph, network analysis becomes a purely topological matter with no need for geographic context. GIS-T introduces a geographical representation of the network that locates the transportation system in real space, allowing analysis of the system's geographic as well as its topological characteristics.

Positioning data along the routes within a network is another important function of GIS-T. Transportation organizations need information about features and events that occur on the routes comprising the network, such as the locations of accidents on highways. Positioning features on the links of a network is accomplished by reference to linear distance measures like highway mileposts, rather than by geographic coordinates. In this paper the term *route-based mapping* will be used to identify this function of GIS-T. Route-based mapping is supported by *linear reference systems* that assign to each network link a unique route identity with beginning and ending distance measures. This data model enables GIS-T software to plot tabular data according to its linear reference system location-highway number and milepost, for example. As with network analysis, this function need not occur in geographic space, but can be done on a straight-line diagram of the route. Incorporating the linear reference system data model into GIS-T, however, enables route-based data to be analyzed geographically and presented cartographically.

The purpose of this paper is to examine the cartographic implications of data based on linear reference systems, and to suggest avenues of investigation leading to a better understanding of route-based mapping. GIS-T technology is used by national, regional and local transportation agencies for the management and operation of highway, railroad and transit systems. State departments of transportation, for example, generally use mileage measures to determine positions of features on highways. Each highway route is assigned a unique identifier, and formal starting and ending points. Measuring from the route's starting point, cumulative mileage is used as a linear locator along that route. "Route 66 at milepost 100.5," for example, identifies a unique location: a specific distance down a specific highway (FGDC 1994). Just as a geographic reference system enables location by latitude and longitude, so does a linear reference system (LRS) enable location by route and milepost.

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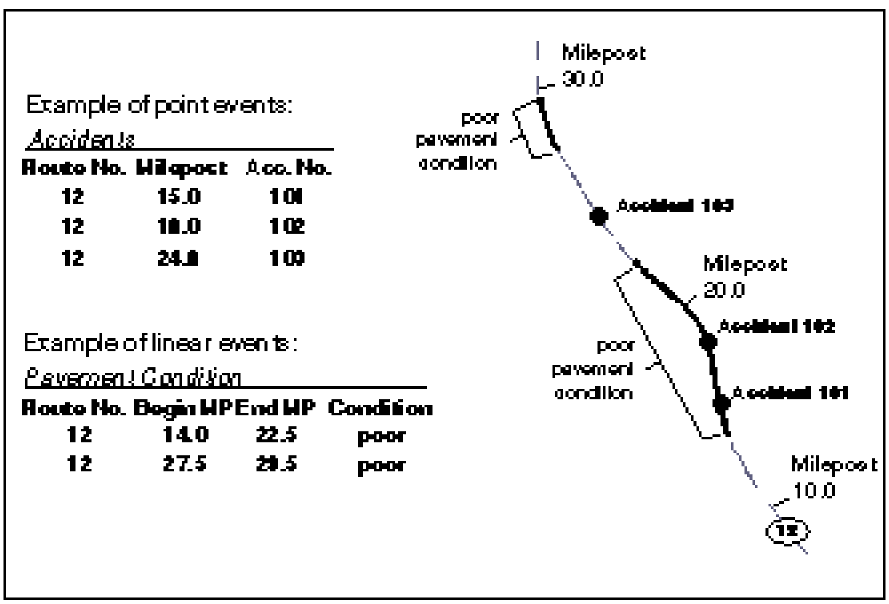

Figure 1. Tables of data indexed to a linear reference system by State Route and Milepost *are plotted by the GIS-T process called* dynamic segmentation.

The process of interpolating positions in a linear reference system is called *dynamic segmentation* in the GIS-T literature. Figure 1 shows an example of how route data are plotted on maps through dynamic segmentation. Data representing features and activities that occur on routes are often referred to as *event* data in the GIS-T literature (Dueker and Vrana 1992). This term expresses the concept that objects positioned along routes may be ephemeral or persistent, physical or intangible. Both a culvert and a collision are logically equivalent as *events* on a route. Consider a hy-

This paper presents some of the cartographic problems with mapping route data, suggests map design tactics and identifies issues needing research. The cartographic challenges of linear thematic mapping are not entirely new, but the volume of such activity is expanding rapidly, placing new demands on cartographers. In Muehrcke's (1973, 61) words, "Surges in cartographic activity have followed inventions which allowed cartographers to transcend previously insurmountable obstacles." The characteristics of linear reference systems, and the data based on them, are described here along with the conventional cartographic approaches to representation of linear attributes. The cartographic literature offers little guidance to the map designer seeking tactics or practical ideas for representing elaborate route-based features. Ruggles and Armstrong (1997, 39) tender a theoretical framework incorporating GIS networks into the cartographic paradigm, but theirs is a conceptual overview of the general network mapping problem, touching only briefly on the cartographic behavior of linear reference systems. The "special difficulties" of dynamic segmentation that Ruggles and Armstrong recognize are described here and organized as cases of data representation. The types of route data that need to be represented and the anticipated forms of cartographic expression are used to indicate the kinds of map symbology that must be rendered successfully. Those characteristics of maps that are likely to represent route data successfully are proposed as cartographic design requirements for route-based mapping. Finally, issues of route-based mapping needing cartographic research are identified.

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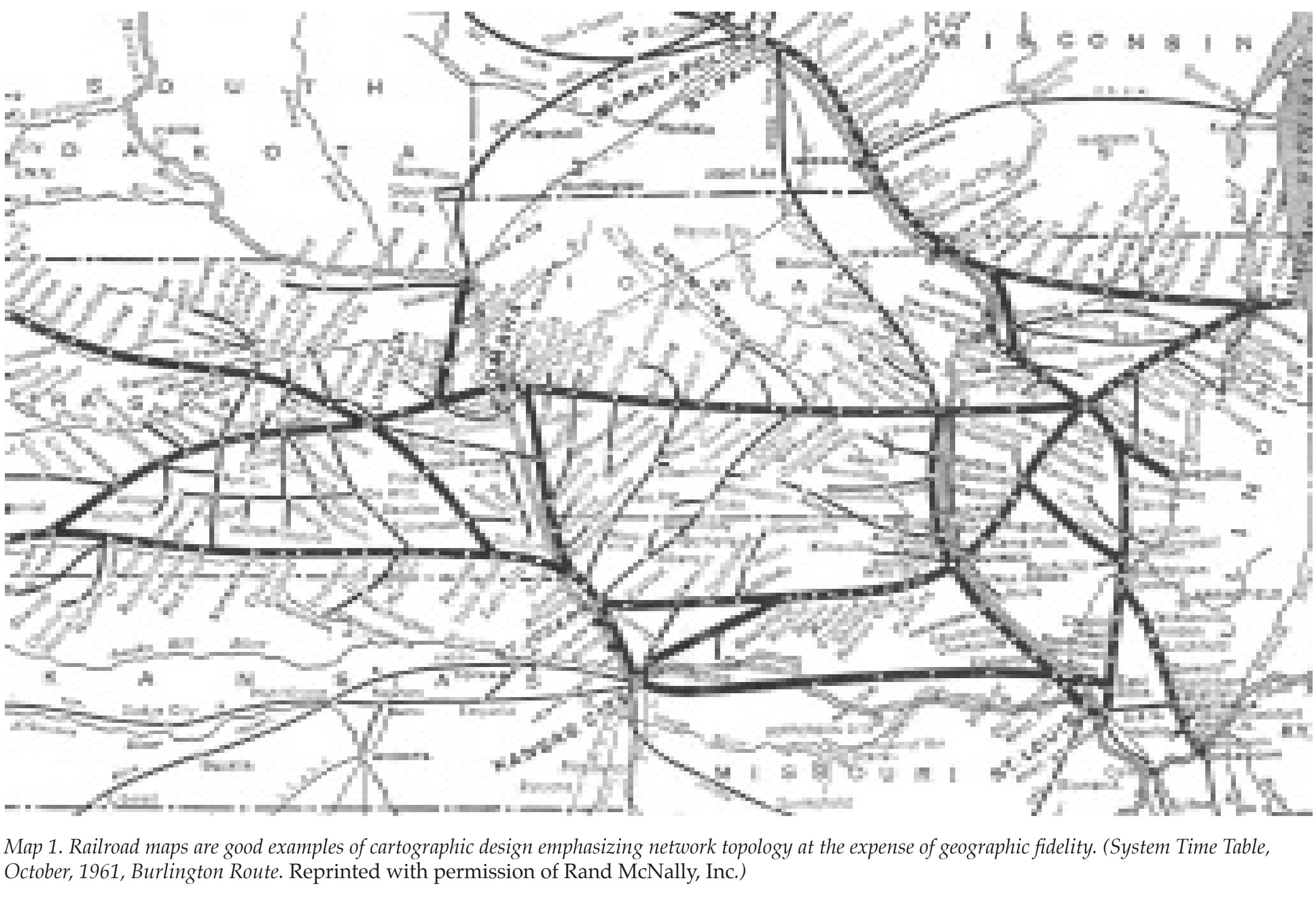
REVIEW OF THE CARTOGRAPHIC LINE

The cartographic line is used to mimic features of elongated form like rivers and roads, to delimit measurement classifications like contours, to bound areas such as political units, and for artistic effects as in the use of hachures and waves. Of particular interest here is the cartographic line's role in representing transportation networks such as roads and railways. The concept of the cartographic line as a *route* is very old. The Peutinger Table is an oft-cited example of a route map perhaps as old as the 1st century (Goss 1993). Medieval guide maps symbolized routes as a series of events and landmarks astride a corridor (Brown 1950). The transformation of a geographic route into a linear corridor with features along side is obviously not new. Strip-format maps have a long cartographic history as route-following guides (MacEachren 1986).

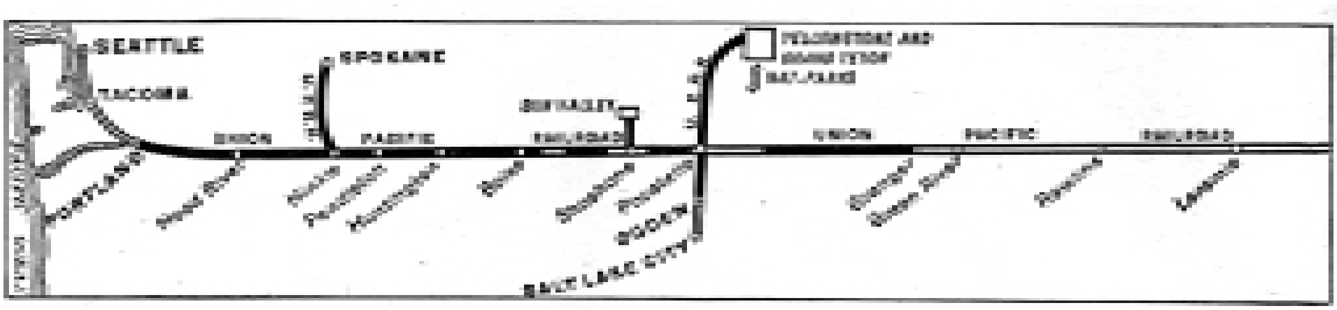
A *route* is a path on which awareness of cardinal, three-dimensional space is unnecessary for successful navigation so long as one follows the correct route in the correct direction. Bunge (1966, 51) conceived of routes as "connections between places" and noted that "Early motorists directed themselves with the aid of descriptive logs or itineraries which told them to proceed so many miles in such a direction from one prominent feature to another." Changes in trajectory are of merely local interest if one's task is to follow the path by landmarks and signs, or in more formal terms, to traverse route segments from one reference point to another. Route logic is that of following directions rather than that of navigating geographically.

The technological developments of the industrial revolution, in particular the railway, advanced the refinement of the route as a geospatial object. In railway system maps, the route is depicted as a compromised spatial and logical transformation. Railroad systems were often mapped with little more than the largest water bodies and political divisions for base map reference (Map 1). Station names and route connections had precedence over geographic space or natural features. These maps approached the schematic character of topological diagrams with their smoothed and straightened lines and cartoon geography. Besides simplifying the syspothetical accident database that stores route number and milepost (the LRS position) for each accident. Because an accident occurs at one and only one route and milepost, accidents are point data—each accident is a discrete event located by route identifier and milepost. The route identifier picks out the specific route in question from all others in the network, and the milepost value indicates distance along that route from its starting point. Dynamic segmentation software interpolates a position for that milepost based on the length of the line representing the route. Milepost 15.0, for example, is plotted halfway along the line between mileposts 10.0 and 20.0. Other kinds of route features are linearly continuous, spanning multiple mileposts. For these features, as with pavement conditions in Fig. 1, two mileposts delimit the range of each event to be mapped. Dynamic segmentation interpolates the positions of these beginning and ending mileposts and creates a segment along the route between them.

Route-based mapping is a rapidly growing form of cartography for transportation organizations. A state transportation department is likely to have thousands of highway features indexed by route and milepost. Some of these are physical infrastructure features like highway ramps, signs, signals, bridges, pavement materials, lane widths, railway crossings and tunnels. Others are ephemera such as traffic volumes, accidents, animal kills, construction zones, and management areas. Dynamic segmentation allows the mapping of these diverse, complex data sets that heretofore have been impractical to plot manually. These vast stores of transportation network features are becoming available for cartographic representation through dynamic segmentation.



Map 1. Railroad maps are good examples of cartographic design emphasizing network topology at the expense of geographic fidelity. (System Time Table, October, 1961, Burlington Route. Reprinted with permission of Rand McNally, Inc.*)*



Map 2. The strip map is a kind of cartogram that represents a route in its elementary conceptual form. (Time Tables, January 11, 1959. Reprinted with permission of Union Pacific Railroad*).*

tem's complexity for presentation, a promotional purpose of these designs may have been to make the routes appear efficient and direct. Further abstraction made timetable cartograms as much graphic representations of the railroad's schedule as they were transformations of geographic space. The strip map, reduced to a pure route by the removal of geographic constraints, logically complemented the time table's sequence of station names stacked neatly in a column (Map 2).

Early highway maps, unlike those for railroads, included much geographic reference detail like hydrography, physiography and political boundaries. Automobile travel often required a more holistic set of navigational skills than travel by rail, air, or vessel. Because the automobile was operated by an individual rather than by specially trained crews, motorists needed tools to do their own way-finding in geographic space. With the ascendance of automotive travel, map publishers took the opportunity to serve a growing map market. In the United States, federal highway funding began in 1916, and national highway numbering in 1926. By the end of the 1920's the road map was a distinct cartographic genre, and publishers had begun elaborating roadway symbols with attributes like surface type, use, highway name, and jurisdiction (Map 3). From that time to the present highway symbolization has been a specific cartographic design problem.

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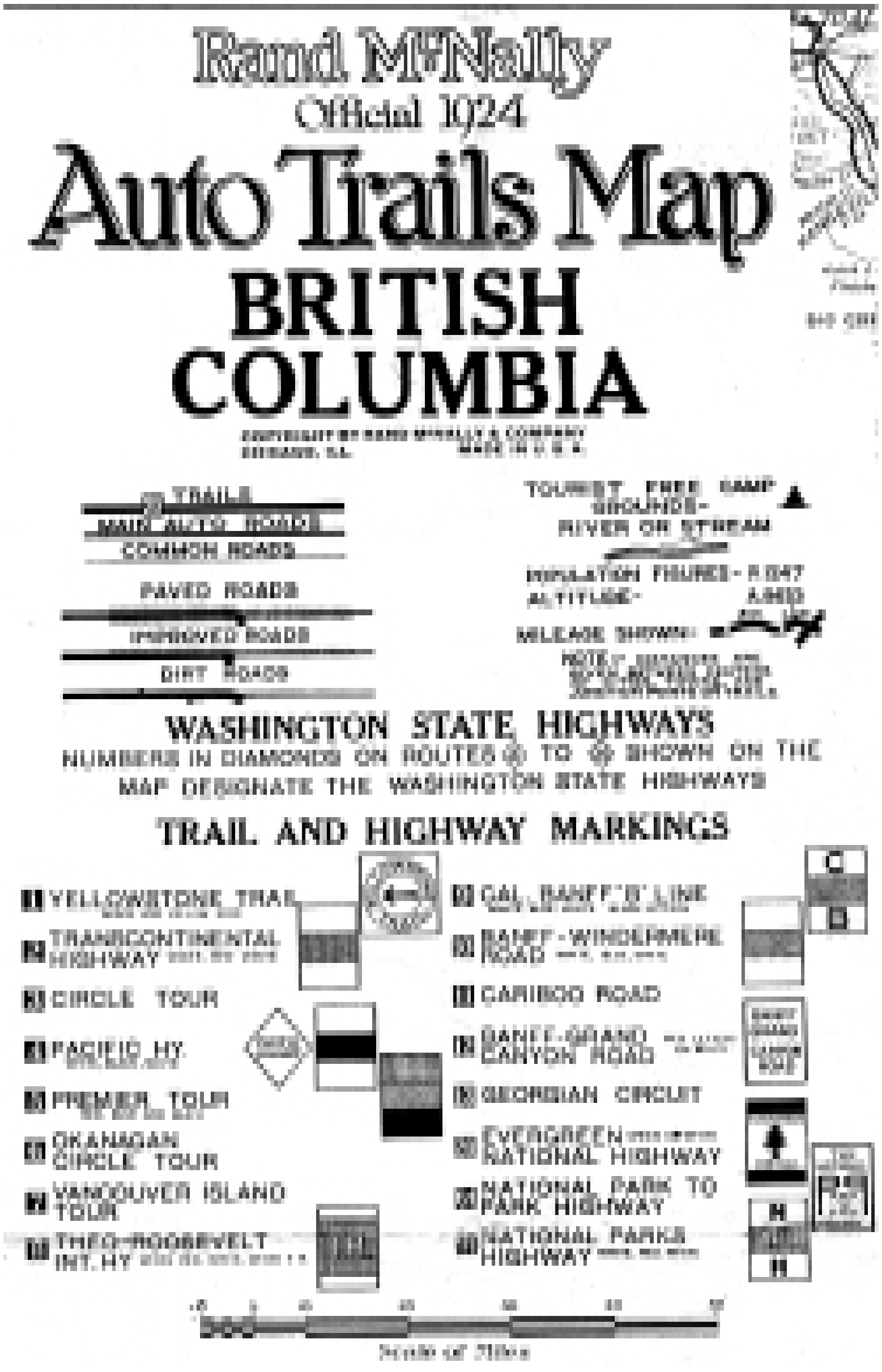
As state highway departments became institutions for funding, building, and maintaining public roads, they adopted systematic operations and management methods, in particular the concept of highways as fixed paths with formally established mileposts. By the 1970's most transportation agencies had the well-developed milepost (or kilometer-post) measuring systems that are now called linear reference systems. Mileposts became the index for locating myriad highway attributes and events: construction projects, surface types, functional classification, signals, signs, bridges, roadside maintenance, and accident sites. A planner or engineer could create a project location map by interpolating the project's beginning and ending mileposts from reference mileposts shown on a base map. In Map 4 we see a construction project location mapped by reference to "stationing," an engineering convention of linear measures in hundreds of feet. This was, in effect, dynamic segmentation performed manually. The stage was set for the integration of tabular and geospatial databases through the transformation of data between linear and geographic reference systems.

Cartographic Design for Linear Reference Systems

Linear reference systems are the contemporary manifestation of the age-old route concept. Routes are defined administratively as logically related



Map 3. Early in the development of road maps, publishers began distinguishing defined routes—named "auto trails," in this case—and symbolizing their characteristics. (Auto Trails of British Columbia, 1924. Reprinted with permission of Rand McNally, Inc.*)*

subsets of a transportation network. Ownership (state, county, city, or private), level of service (arterial, collector, or local access) and operating practices (bus routes) are examples of factors often considered in devising a route identification system. Measurements for each route in a linear reference system are based on the idea of using an odometer to establish standard distances to reference points along a route's extent. This is in fact how routes are calibrated for linear reference systems. The linear measures start at an officially designated initial point and continue along the encompass all classes of measurement-nominal, ordinal, interval and ratio. For example, accidents may possess attributes about injury classification, number of vehicles involved, time of day, or estimated speed. Any of these might be of interest as a basis for classifying symbology. Continuous events like pavement condition can have equal complexity of attributes: age, type of material, thickness, depth of rutting, or number of lanes, any of which could be classified to represent the pattern of values. Thematic maps for transportation will often need to depict the simultaneous interaction of multiple variables of multiple types of events.

Reviewing the cartographic literature for guidance with these problems reveals a conspicuous void. Most treatments of the cartographic line revolve around linear symbols for entire, discrete lines standing alone, rather than points or segments that are derivative features of lines. Wright (1944) noted the potential of "variable line symbols" but could not recall such use in practice. Ullman's (1957) commodity flow work contained some elegantly effective flow maps, and Monkhouse and Wilkinson (1966) showed an intriguing multivariate flow map of bus frequency by system owner. One theoretical discussion pointed out that variations in thickness, pattern and color could be used to indicate thematic data on lines (Hazlewood 1970). The typical contemporary discussion of linear symbology culminates with flow maps that show ratio data by proportional line thickness (Robinson, *et al* 1995; Dent 1993). Some effective flow map techniques can be unearthed among the older sources (Campbell 1984). Cuff (1982) demonstrated the superimposition of an abstract flow volume arrow over

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Map 4. Open-cased road maps provided the base for manually interpolating the location of information by route and milepost. Here, a construction project is plotted and labeled with "stationing," a kind of linear reference system used by highway engineers. (ca. 1970. Courtesy of Washington State Department of Transportation*)*

route to the designated end point. The *route log* produced by this process contains linear measures for standard reference points along the route. Junctions, bridges, tunnels and so forth are each assigned their own milepost value. By using these reference points as well as physically posted milepost signs, any feature of interest can be assigned an interpolated or estimated milepost value. Highway departments and railroads have databases full of features indexed this way. Because LRS measures are interval data there can be theoretically an infinite number of discrete points or unique segments along a route.

Most highway departments in the United States employ an LRS to locate features and activities on their highway systems, and much of this information is stored in relational database systems. Some of these data, like accident records or traffic counts, for example, have a high frequency of change. Mapping them by manual interpolation of location, as in Map 4, would be a futile exercise with costs far outweighing benefits. GIS-T, however, offers a technology that automates this process to make the vast stores of route-based data available for cartographic representation. In map production, plotting the data is the easy part. While completing the final design, mapmakers trying to produce a presentable map are likely to find themselves struggling to move and resize symbols and text that were originally expected to be an automatically plotted data layer. As more route-based data become available to GIS, clients will escalate their requests for innovative and analytically complex representations. The cartographer working with dynamic segmentation in the GIS-T environment faces the quandary of having a tremendously powerful new data compilation tool generating graphic design challenges for which there is essentially no body of experience, tradition, or customary reference to consult for insight.

One way to organize this problem is to identify the distinctive elements of route-based mapping that are independent of theme, locale, and the technicalities of LRS implementations. Three characteristics of the route-based mapping problem emerge as central elements influencing cartographic representation: the spatial constraints of lines, the properties of events, and the properties of thematic data in general.

Spatial constraints of lines—The most basic cartographic problem of route-based data involves simple spatial conflict of map symbols. Events should be constrained tightly to the narrow corridor on which they occur in order to preserve geographic accuracy and to maintain good graphic association for the map reader. Point events may coincide exactly, or occur closely enough that their symbols overlap. Linear events may coincide exactly, partially or at an intersection. With small data sets or simple network systems these problems are simply part of the traditional map design task. When hundreds or thousands of such cases occur, or when the map is a continuously revised screen display, the problem becomes a crucial design issue.

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Properties of events—Event data have particular characteristics inherited from the route data model:

- *linear orientation*— Events may exhibit directionality (forward v. backward) and sidedness (left v. right).
- *velocity*— Events that flow exhibit both direction and speed.
- *length*— Events may be modeled as either points or lines, depending upon the resolution of the data and scale of representation.
- *chronology*— Events may have various durations, sequences and frequencies of occurrence.

Properties of thematic data—As thematic data, the attributes of events the geographical rendition of its true route. Fisher (1982) presented four different approaches to flow volumes on a network. The only reference to route-based data may be Keates' (1989) description of the difficulty of maintaining point feature data for road maps. The literature offers some general guidance for linear data, but is apparently barren of any guiding cartographic principles for the depiction of point data on routes. For their part, developers of the GIS-T concept have focused on functional and business requirements (Vonderohe, *et al* 1993; FGDC 1994; Dueker and Butler 1996), and on data structures (Dueker and Vrana 1992; Vonderohe 1995) rather than on cartographic representation.

An effective device for examining the relationship between elements of symbology and classes of data measurement has been to depict examples for each case in a table (Robinson *et al* 1995, Muehrcke 1992). A logical extension of this approach demonstrates some of the issues of route-based mapping. Figure 2 shows how point symbols can vary by size, pattern and color to represent most types of data. Interval and ratio data present some special difficulties, however. It is difficult to envision how a point symbol's pattern might change on a continuous scale to represent interval or ratio data values. Color could be varied in hue or value on a continuous scale but the effectiveness of such point symbols is questionable.

Linear data (Figure 3) present a similar case. Line color and pattern are widely understood as graphic variables for showing nominal and ordinal data, like road classification and surface quality. Line color and pattern are not, however, traditionally considered suitable for interval and ratio data, where line thickness has been the convention.

Figure 4 depicts examples of how coincident and overlapping event data sets might be displayed. Displacement, the setting off of additional symbols parallel to the route, can effectively show the clustering of coincident events when the number of cases is few. This tactic would probably work poorly with more than a few cases. Rather than displace symbols to the side, one could simply let them superimpose where they coincide. Carefully planned symbology might allow readers to recognize the component elements, but again, the question is how far this can be taken. A third approach to coincident events might be to use a symbology

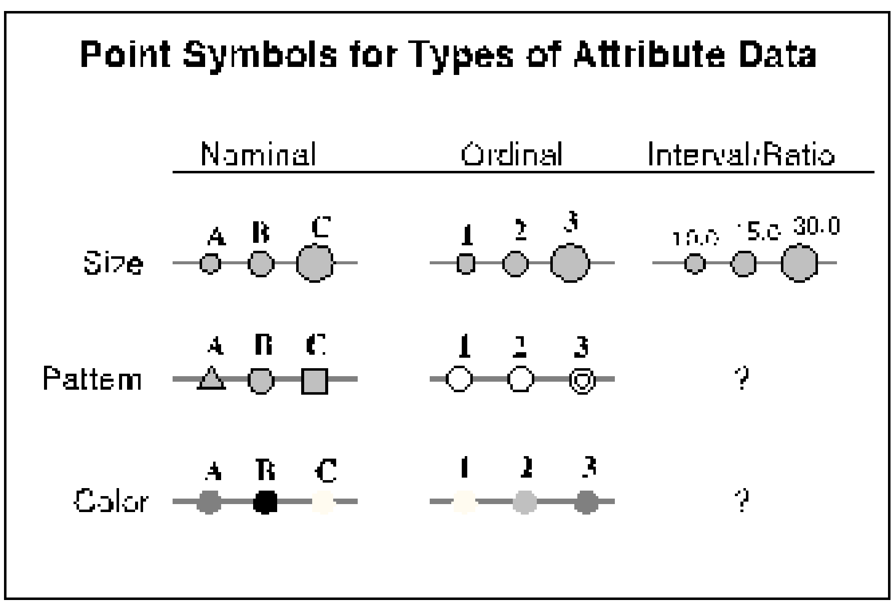

Figure 2. Point symbols for mapping route-based data.

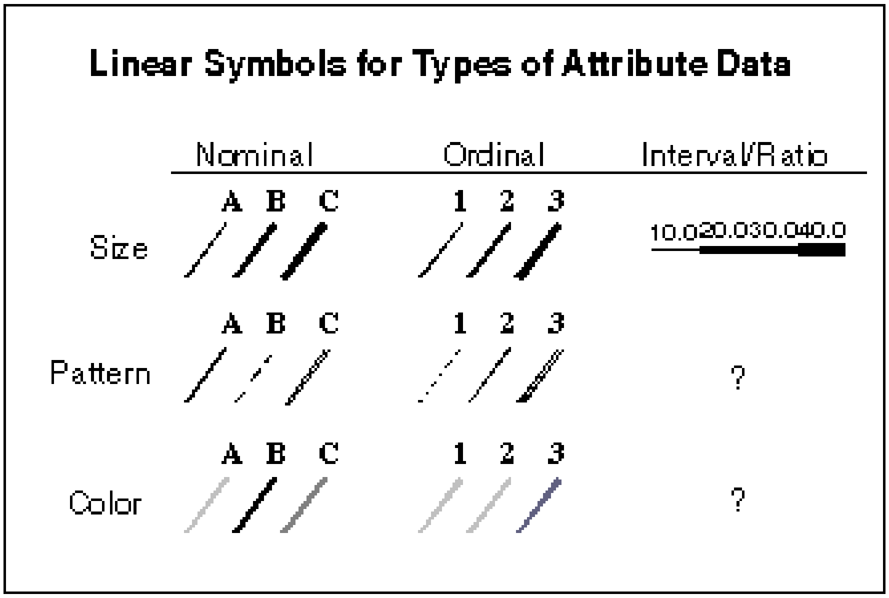

Figure 3. Linear symbols for mapping route-based data.

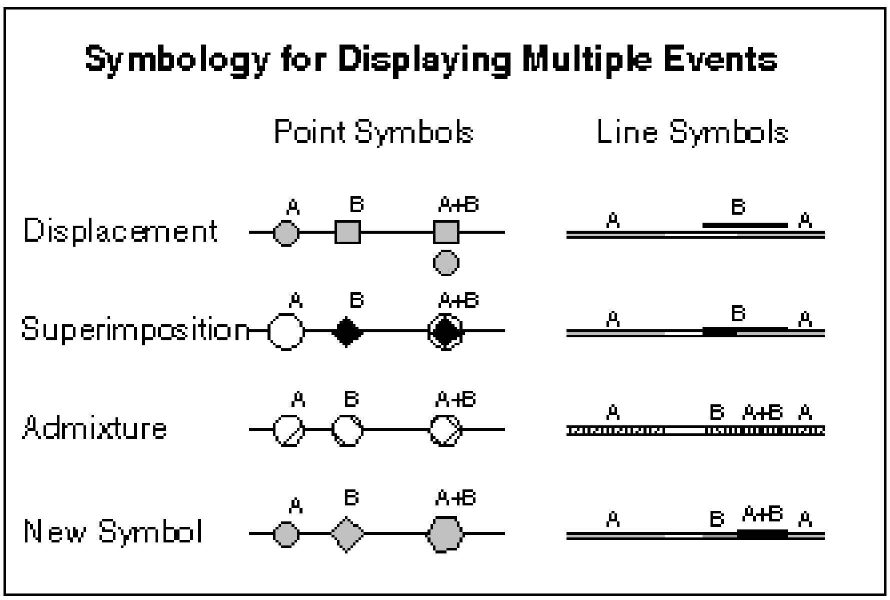

Figure 4. Some of the symbology options for representing coincident and overlapping instances of route-based data.

that works in admixture: symbols that when superimposed create a new symbol that the reader can de-compose. This might serve well for cleverly designed patterns, but color is another matter. Can we presume map users would read a purple symbol as the coincidence of blue and red symbols? And how would this supposedly intuitive logic of subtractive colors work on a computer display? A fourth option is to use a distinct new symbol for instances of coincidence and overlap, a solution of limited usefulness. Each case in Figures 2, 3, and 4 could be the starting point for lengthy examination of the many techniques available for cartographic representation.

CARTOGRAPHIC REQUIREMENTS FOR ROUTE-BASED MAPPING

A specification for route-based mapping begins to emerge when one considers the three characteristics of route-based mapping—spatial conof texture on gray scales (Smith 1987). Bivariate color scales were investigated by Olson (1981) and the interactions of colors on maps have been studied by Brewer (1997).

Another major topic of research has been the choropleth map. Representative examples of work in this area include studies on the selection of class intervals (Olson 1972); the accuracy of choropleth data representations (MacEachren 1985); the ability of map readers to creatively use maps (Carstensen 1986); the performance of computer display maps (Gilmartin and Shelton 1989); and the effectiveness of sequenced displays (Slocum *et al* 1990).

Little of this research applies directly to the design challenges of route-based mapping and such help as it offers comes from inference rather than prescription. This is not to deny that research in psychology and cartography has contributed to our understanding of the capabilities and limitations of map symbols, and there may be experimental work worth revisiting. New perception and cognition studies that build on the foundation of work such as that noted above could contribute much to new knowledge about the visual perception of points and lines that are superimposed on, or offset from, a reference network.

The cartographic requirements of route-based mapping outlined above are general. For each mapping problem there will be a unique combination of elements at work. In particular, there are major differences in the use of, and thus the design of, maps for print versus those for computer display. Given the cartographic requirements identified, the relevant research available to date, and the expected direction of technology, the following five general arenas of research are called for.

First, there are the problems of basic symbol interpretation, such as the estimation of the length of lines. If proportional point symbols are used with the expectation that some map readers will attempt to estimate the value represented by a specific symbol, is it not plausible to expect readers of route-based maps to visually estimate the lengths of segments? How accurately do map readers estimate line length in various cartographic settings? Will a bright yellow line be judged as accurately as a black one, and what is the effect of line thickness? The kind of research sought here is exemplified by that of Gill (1988, 1993) who conducted experiments regarding map readers' responses to route symbology. His work offers practical suggestions as well as insight into how route maps are used. Route-based mapping may require a re-examination of symbol perception research. For example, will the findings of past research on symbol size estimation apply when point symbols are superimposed on lines? How well do point symbols superimposed on lines perform under various combinations of hues and values for background, line, and point symbol?

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Another area of interest is the set of graphic tools available as desktop publishing software solidifies its presence in mapmaking. Many of these tools should be useful to route-based mapping. Vignettes or halo effects around symbols might be used systematically to portray attributes or characteristics of linear data. Line patterns might be varied in proportion to a data attribute, but is such a symbol effective? Could continuously varying hue be used to represent interval or ratio data on a line? With the ability to manipulate text as a graphic object, could it be cartographically effective to incorporate labeling directly into symbols? Experimenting with ways to vary symbols unconventionally in proportion to attribute values could expand the set of tools available for route-based mapping. The cartogram could also be revisited in the context of route-based data, with the conventional strip map used as a starting point. For certain purposes, a relaxation of geographic space could yield maps showing their straints, event properties, and attribute properties—in light of the kinds of map design problems beginning to be experienced at state transportation departments. Maps of route data are used for: 1) analysis to compare events over time, show different kinds of events together and to visualize the nature of a problem; 2) presentations to boards, commissions, the public; and 3) displays of the operational status of transportation networks. In this environment, maps are published most often as short-run, short-lived plotter output and computer screen displays. Lithography plays a minor role. Both precise data representation and visual clarity are top priorities. Cartographers handling route-based data will face some or all of the following requirements.

"New perception and cognition studies . . . could contribute much to new knowledge about the visual perception of points and lines that are superimposed on, or offset from, a reference network."

Display coincident point and line events—Cartographers need to display enlightening combinations of data for maps to achieve their potential as tools of revelation. Methods are needed to successfully represent numerous layers of event data. The problems of event coincidence and overlap can involve not only a single set of data, but diverse data sets that need to be shown together.

Display multiple event attributes—The complexity of transportation data will frequently require multivariate symbols. Collisions, for example, may have attributes of speed, type of vehicle, and temperature.

Time—Much of the data associated with routes is most valuable when analyzed temporally. Transportation networks are dynamic: both physical and operational conditions continually change. Meaningful analysis often depends on the representation of change over time.

Generalization—The fluidity of scale available in GIS software will require transformations between event types. A single event might be shown as either a point or a line, depending on data quality, map scale and audience.

Labeling—Effective quantitative and technical maps often require thorough labeling of relevant features. Methods are needed for doing this across all scales of display and with all types of media.

Live maps—Automated displays of real-time data, such as continually monitored traffic volumes and roadway conditions, require map symbology that will work successfully with little human intervention.

Topics for research in cartographic design

In its current stage of development, route-based mapping presents more cartographic questions than solutions. Fundamental questions to ask are: What are the goals of route-based mapping? Do these maps work? What does the profession of cartography contribute to this particular kind of data representation?

Psychophysical and cognitive studies have been a central theme of contemporary academic cartography, but surprisingly little research can be found on linear symbology. Perceptual and cognitive research studies of cartography have addressed some of the basic graphic elements used in thematic maps. There has been considerable work done on point and area symbols, and on various characteristics of choropleth maps. Point symbols (the circle, especially) enjoy a forty-year legacy as the subject of research covering such topics as the perception of apparent value (Flannery 1956), the effectiveness of different kinds of point symbols (Flannery 1971, Cox 1976, Heino 1995), and the importance of visual contrast (Griffin 1990).

Color and area patterns have also been prominent subjects of research on the human factors of map reading. Studies have been done on the perception of gray-scale intervals (Williams 1958), shading patterns (Jenks and Knos 1961), un-classed cross-hatching (Peterson 1979), and the effect occur. Such data may be discrete or continuous, permanent or ephemeral, stationary or moving. The mapping of data based on a linear frame of reference poses particular cartographic difficulties that have not been developed thoroughly in the mainstream cartographic literature.

The need for design strategies based on sound principles grows as GIS practitioners embrace the measured route as a base on which features can be mapped. A table of graphic techniques by data type was used as an initial framework for classifying the application of linear graphic variables to route data. This indicated the need for principles of design that address the unique cartographic constraints of route-based symbology such as the effective treatment of symbol conflict, coincidence, interval and ratio data types, and multivariate symbols.

Perceptual and cognitive research is called for to improve our understanding of how well various symbologies work for route data, and how well route-based maps convey knowledge to map readers. These will need to be addressed for both the print and computer screen environments. The depiction of time is of particular concern in the transportation arena, where much of the data represent dynamic phenomena. Cartographic animation and interaction are another arena in which route-based mapping should present unique challenges and possibilities.

". . . interaction with live maps promises to alter some of our basic approaches to cartographic presentation."

The problems of route-based mapping outlined in this paper indicate that maps will be increasingly made from *data*, rather than from other maps. Geographic data models are evolving away from their cartographic roots. Most GIS data sets today originated cartographically and analyses based on them are influenced by cartographic idiosyncrasies. This will change, however, as global positioning system (GPS) data and digital ortho-imagery gain use as GIS data sources. Route logs calibrated by GPS data will eventually replace digitized map lines as the "datum" on which linear reference systems are represented. Geospatial data will become scale-independent. Cartographers need to be better equipped than ever to understand, and explain, the cartographic purposes served by the transformations they apply in presenting data on maps. In an era of increasingly complex analytical expectations, using ever more precise and accurate data, cartographers may well be asked to describe explicitly—perhaps quantitatively—the generalizations (introduced errors) applied to the map representations.

An assumption underlying this discussion is the proposition that route-based mapping is to be done, but the availability of a new tool does not necessitate its use. As mapping for linear reference systems develops, cartographers have an opportunity to consider whether it is to be the techniques, or the cartographers, that will be making maps. Cartography involves the transformation of data into representational visual models that communicate, enlighten, persuade and provoke. The knowledge to be gained from route-based mapping depends in part on the ability of cartographers to define the relationship between data models and visual representations of data. If cartography is a transformation process that would inform GIS output with knowledge, then the analysis and explanation of that transformation in the clearest terms possible is an endeavor that cartographers can scarcely fail to pursue.

SUMMARY AND CONCLUSIONS

Brewer, Cynthia (1997). "Evaluation of a Model for Predicting Simultaneous Contrast on Color Maps" *The Professional Geographer*, 49(3):280-294.

Brown, Lloyd (1950). *The Story of Maps*. Boston: Little, Brown & Co.

Bunge, William (1966). *Lund Studies in Geography, General and Mathematical*

thematic features more clearly or pointedly, like the railroad system maps discussed earlier.

Third, many of these publishing software tools can be applied in electronic media as well. Research is needed to indicate how well they serve the needs of route-based mapping for computer displays. The cartographic design problems of screen displays are beginning to receive some attention. Maps in this medium have the dimension of time as a graphic variable that cartographers have begun to explore (Peterson 1997; Karl 1992). Animated maps could help with the effective presentation of complex combinations of linear events by leading the map reader through the data sequentially (Slocum, *et al* 1990). This could be especially effective for the dynamic nature of a great deal of transportation data, for example, the diurnal cycle of traffic volumes and flow directions. Coincident features might blink. Blinking or shimmering point symbols could express one variable, color another, and shape a third. The blink microscope effect might be employed to reveal temporal differences in large, complicated data sets. Dots could run along lines to depict flow direction and speed. Shimmering waves could flow within lines to indicate direction and intensity of a flow. A methodical examination of time as a graphic variable would augment knowledge about symbol cognition to produce guidelines for mapping route-based data. Such studies could add particularly to the effectiveness of live maps of transportation system conditions. Another question for contemporary map design research is the determination of design methods for maps that are to be recognized as the same document in both print and computer display. Such visual equivalency could be important to organizations trying to disseminate authentic information.

"The problems of route-based mapping outlined in this paper indicate that maps will be increasingly made from data, *rather than from other maps."*

Fourth, interaction with live maps promises to alter some of our basic approaches to cartographic presentation. Interaction enables the map reader to affect the nature of the display at will. Pop-up annotation is beginning to appear in computer map applications (click on or pause the mouse over a state and its name appears). For mapping route data interactive features could be designed to respond to display scale and to help clarify problems of event coincidence. Lines could collapse into points, and points resolve into lines, at appropriate display scales that the user selects. It should be possible to generalize numerous occurrences into fewer representative events, and to transform a threshold density of points into a linear event. Short network segments and the events occurring on them could receive special treatment at small display scales.

Finally, there is the problem common to both print and computer display of how effective route-based maps can be in communicating quantitative information. How is the character of linear data grasped when a continuous phenomenon is sampled at discrete locations? What does the map reader understand as the difference between point and line symbols along routes? Cartographers have few qualms about generating continuous statistical surfaces from sample points. How should this be done linearly? The concept of linear clusters, aggregations of either discrete points or short segments, may need development. Highway planners use a formula to determine when a cluster of High Accident Locations becomes a High Accident Corridor. Shall cartographers adopt this algorithm *prima facie* or develop their own?

REFERENCES

Recent developments in geographic information systems technology enable the mapping of large volumes of transportation data heretofore considered impractical to represent cartographically. These developments use formally defined and measured routes as the basis for positioning thematic data by reference to the route numbers and mileposts at which they

Gill, Graham (1993). “Road Map Design and Route Selection.” *The Cartographic Journal*, 30(2):163-166.

Gilmartin, Patricia, and Shelton, Elisabeth (1989). “Choropleth Maps on High Resolution CRTs/ The Effects of Number of Classes and Hue on Communication.” *Cartographica*, 26(2): 40-52.

Griffin, T.L.C. (1990). “The Importance of Visual Contrast for Graduated Circles.” Cartography, 19(1): 21-30.

Goss, John (1993). The Mapmaker’s Art. Hong Kong: Rand McNally.

Hazlewood, L.K. (1970). “Semantic Capabilities of Thematic Maps.” Cartography, 7(2): 69-75.

Heino, Aarre (1995). “The Presentation of Data with Graduated Symbols.” Cartographica, 32(1):43-50.

Jenks, George F. and Caspall, Fred C. (1971). “Error on Choropleth Maps: Definition, Measurement, Reduction.” Annals of the Association of American Geographers, 61(2): 217-244.

Jenks, George F. and Knos, Duane S. (1961). “The Use of Shading Patterns in Graded Series.” Annals of the Association of American Geographers, 51(3): 316-334.

Karl, Doris (1992). “Cartographic animation: potential and research issues.” Cartographic Perspectives 13: 3-9.

Keates, J. S. (1989). Cartographic Design and Production. London: Longman House.

MacEachren, Alan (1985). “Accuracy of Thematic Maps/ Implications of Choropleth Symbolization.” Cartographica, 22(1): 38-58.

MacEachren, Alan (1986). “A Linear View of the World: Strip Maps as a Unique form of Cartographic Representation.” The American Cartographer, 13(1):7-25.

Muehrcke, Phillip C. (1992). Map Use. Madison, Wisconsin: J P Publications.

Muehrcke, Phillip C. (1973). “Trends in Cartography.” Cartography, 8(2): 61-77.

Monkhouse, F.S. and Wilkinson, H.R. (1966). Maps and Diagrams. London: Methuen.

Olson, Judy M. (1972). “Spectrally Encoded Two-Variable Maps.” Annals of the Association of American Geographers, 71(2): 259-276.

Peterson, Michael P. (1979). “An Evaluation of Unclassed Cross-Line Choropleth Mapping.” The American Cartographer, 6(1): 21-37.

Peterson, Michael P. (1997). “Cartography and the Internet: Introduction

Geography, Series C, 2nd edition. Lund: CWK Gleerup.

Campbell, John (1984). *Introductory Cartography*. Englewood Cliffs, New Jersey: Prentice-Hall.

Carstensen, Laurence W. (1986). "Hypothesis Testing Using Univariate and Bivariate Choropleth Maps." *The American Cartographer*, 13(3):231-251.

Chrisman, Nicholas (1997). *Exploring Geographic Information Systems*. New York: John Wiley & Sons.

Cover, Robert K., Fletcher, David R., and Henderson, Thomas E. (1993). *Transportation and Geographic Computing Concept*. Albuquerque: Alliance for Transportation Research.

Cox, Carleton W. (1976). "Anchor Effects and the Estimation of Graduated Circles and Squares." *The American Cartographer*, 3(1): 65-74.

Cuff, David J. and Mattson, Mark. T. (1982). *Thematic Maps, Their Design and Production*. New York: Methuen.

DeMers, Michael N. (1997). *Fundamentals of Geographic Information Systems*. New York: John Wiley & Sons.

Dent, Borden (1993). *Cartography, Thematic Map Design*, 3rd ed. Dubuque, Iowa: Wm. C. Brown Publishers.

Dent, Borden (1972). "Visual Organization and Thematic Map Communication." *Annals of the Association of American Geographers*, 62(1): 79-93.

Dueker, Kenneth J. and Butler , J. Allison. (1997). *GIS-T Enterprise Data Model with Suggested Implementation Choices*. Research Project Report 101. Portland: Center for Urban Studies, School of Urban and Public Affairs, Portland State University.

Dueker, Kenneth and Vrana, Ric (1992). "Dynamic Segmentation Revisited: A Milepoint Linear Data Model." *Journal of the Urban and Regional Information Systems Association*, 4(2): 94-105.

Federal Geographic Data Committee Ground Transportation Subcommittee (1994). "Linear Referencing Systems." http://www.bts.gov/gis/fgdc/pubs/lrs.html

Fisher, Howard T. (1982). *Mapping Information*. Cambridge, Mass.: Abt Associates.

Flannery, J.J. (1956). "The Graduated Circle: A Description, Analysis and Evaluation of a Quantitative Map Symbol." Unpublished doctoral dissertation, University of Wisconsin.

Flannery, J.J. (1971). "The Relative Effectiveness of some Common Graduated Point Symbols in the Presentation of Quantitative Data." *The Canadian Cartographer*, 8(2): 96-109.

Gill, Graham (1988). "Experiments in the Ordered Perception of Coloured Cartographic Line Symbols." *Cartographica*, 25(4): 36-49.

and Research Agenda." Cartographic Perspectives, 26: 3-12.

Robinson, Arthur H., Morrison, J.L., Muehrcke, P.C., Kimmerling, A.S., Guptill, S.C. (1995). Elements of Cartography, 6th ed. New York: John Wiley & Sons.

Ruggles, Amy J. and Marc P. Armstrong (1997). "Toward a Conceptual Framework for the Cartographic Visualization of Network Information." *Cartographica*, 34(1): 33-48.

Slocum, Terry, Robeson, Susan H., and Egbert, Stephen L. (1990). "Traditional versus Sequenced Choropleth Maps in Experimental Investigation." *Cartographica*, 27(1): 67-88.

Smith, Richard M. (1987). "Influence of Texture on Perception of Gray Tone Map Symbols." *The American Cartographer*, 14(1):43-47.

Thrower, N.J.W. (1996). *Maps and Civilization*. Chicago: University of Chicago Press.

Ullman, Edward L. (1957). *America Commodity Flow*. Washington, DC: University of Washington Press.

Vonderohe, Alan (1994). "Draft Report on the Results of a Workshop on a Generic Data Model for Linear Referencing Systems." Milwaukee, Wisconsin.

Vonderohe, Alan P., Travis, L., Smith, R., and Tsai, V. (1993). *Adaptation of Geographic Information Systems for Transportation Report 359*. Washington, DC: Transportation Research Board, National Academy Press.

Williams, Robert Lee (1958). "Map Symbols: Equal-Appearing Intervals for Printed Screens." *Annals of the Association of American Geographers*, 48(2): 132-139.

Wood, M. (1968). "Visual Perception and Map Design." *The Cartographic*