operational, initiates an "idea": a new application. If this new application is extensive, then another analysis phase is conducted to determine the feasibility and cost-benefits of the new application. If these analyses determine that the new application should be implemented, the application undergoes design and implementation stages and finally becomes operational, completing a new cycle. This is the evolutionary nature of information systems: the life cycle of systems.

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See also Needs Analysis; Specifications; System Implementation

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LINEAR REFERENCING

Linear referencing is the process of associating events to a network. The network may represent roads, rivers, pipelines, or any connected set of linear features. The events associated with the network may be pavement conditions, road sign locations, or any objects that are best located by their positions along the network. Linear referencing is a georeferencing process in which the underlying datum is a network rather than a coordinate system. In this entry, the elements of linear referencing are defined, the benefits of employing linear referencing are summarized, and a seven-step process for performing linear referencing is outlined.

Linear Referencing Defined

A *linear referencing system* (LRS) is a support system for the storage and maintenance of information on events that occur along a network. A LRS consists of an underlying network that supplies the backbone for location, a set of objects with well-defined geographic locations, one or more linear referencing methods (LRM), and a set of events located on the network. A *linear referencing method* is defined as a mechanism for finding and stating the location of a point along a network by referencing it to a known location. A LRM determines an unknown location on the basis of a defined path along the underlying transportation network, a distance along that path location, and—optionally—an offset from the path.

The Benefits of Linear Referencing

The primary benefit of using linear referencing is that it allows locations to be readily recovered in the field, since these locations are generally more intuitive than locations specified with traditional coordinates. Second, linear referencing removes the requirement of a highly segmented linear network, based on differences in attribute values. More specifically, there are many network attributes that do not begin, end, or change values at the same points where the network is segmented. The implementation of linear referencing permits many different attribute events to be associated with a small set of network features. Moreover, linear referencing allows attribute data from multiple sources to be associated with the network, promotes a reduction in redundancy and error within the database, facilitates multiple cartographic representations of attribute data, and encourages interoperability among network applications.

Linear Referencing as a Process

To implement linear referencing, several procedures must be completed. These procedures are presented as an iterative seven-step linear referencing process.

Determine Application, Representation, and Topology

There are fundamental differences in the structure of networks for different applications. Road and river networks, for example, do not have similar topological structures. The attributes and the analytical methods associated with different network types require different network representations. Therefore, the first step in a linear referencing process is to define which network data sets and spatial representations are to be employed for the application at hand.

Determining Route Structure

The next step is to determine the route structure. The term *route* in this context is the largest individual feature that can be uniquely identified and to which events can be linearly referenced. Any linear feature can become the underlying element defining routes, but, generally speaking, a route should be longer than the events to be referenced so that event segmentation is minimized. For example, if streets are the target network for linear referencing, one may want to define the routes as single entities that represent the entire northbound and southbound directions of travel along the street, even though there are many underlying features (different blocks of the street between intersections) in the network data set. Routes may be further divided if the street name or prefix changes somewhere along the length of the route. Figure 1 shows the definition of four routes along an arterial road, based on direction of travel, street name, and street prefix.

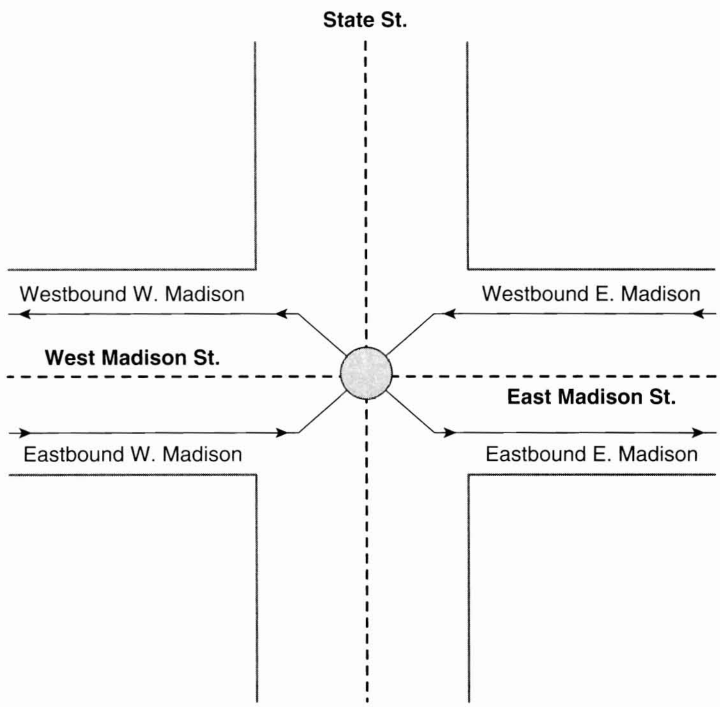

Figure 1 Defining Routes

Determining Measures

The third step is to determine measures along the routes. There are three considerations in doing so: the most appropriate unit of measure, the source for the measure values, and the direction of increasing measures. The most appropriate unit for measures along routes is a function of the application and the audience. The source of measure data has historically been of subject of intense debate. In some cases, data collected in the field and stored in databases external to the GIS are of higher quality. Increasingly, the capture of GIS data using remote-sensing technologies has raised the accuracy of spatial databases and encouraged their use for measurements along networks. The direction of increase of measure values should be consistent with the needs of the application and should be logically consistent with the topological structure. For example, if linear referencing is to be used in the context of emergency response, the measures would best be designed to increase such that they are consistent with increasing address ranges along the streets.

Create Events

Given a set of routes and measure information associated with those routes, the next step is the collection of event data. Event data are occurrences along the network. Events can be point or linear in character. Point events represent objects located at specific measures along a route. Linear events have a consistent attribute along the network. There are an infinite number of possible events to locate along a network. Typical point events may be the locations of street signs or bridges along a road network, switches along a rail network, or monitoring stations along a river. Linear events could represent varying pavement conditions along the road, speed limits on a rail network, or depths associated with a river. Events can be digitized from maps, collected in the field, or automatically generated by remote sensing technology.

Display Event Data, Cartographic Output

Linear referencing provides new information regarding network processes, but this can lead to poor cartography due to graphical clutter and information overload. Therefore, the next step is to carefully choose the parameters for display of the events. The display of linearly referenced events is referred to as *dynamic segmentation.* The decisions regarding display of event data are dependent on several factors, including the media on which the data will be displayed and the scale of the representations. One visual benefit of dynamically displaying event data is the ability to display multiple linear events along the same feature, accomplished through offsetting the events so that all events are visible in relation to the route itself and in relation to other events. A common example of this is seen on subway route maps. Figure 2 shows three types of events offset from the underlying road network in order to display them all simultaneously.

Analysis With Linear Referencing

With routes and event data in hand, analysis can be performed through techniques such as overlays, intersections, and other spatial analysis techniques incorporated in GIS. In some cases, linear referencing allows new database queries to be made that differ from those based on the underlying network. However, while significant analytic capability is added with linear referencing, other traditional GIS analytic capabilities are lost. Most important, events do not contain topological information that is mandatory for most network analysis. For this reason, both traditional network and event representations must be maintained coincidently.

Data Maintenance

To keep this newly created linear referencing system functional, it is important that the route and event data be maintained properly. Geometric changes during editing, changes in measure values with the movement of real-world features, and the addition of more precise measurements all demand an ongoing process of data maintenance.

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See also Data Modeling; Network Analysis; Representation

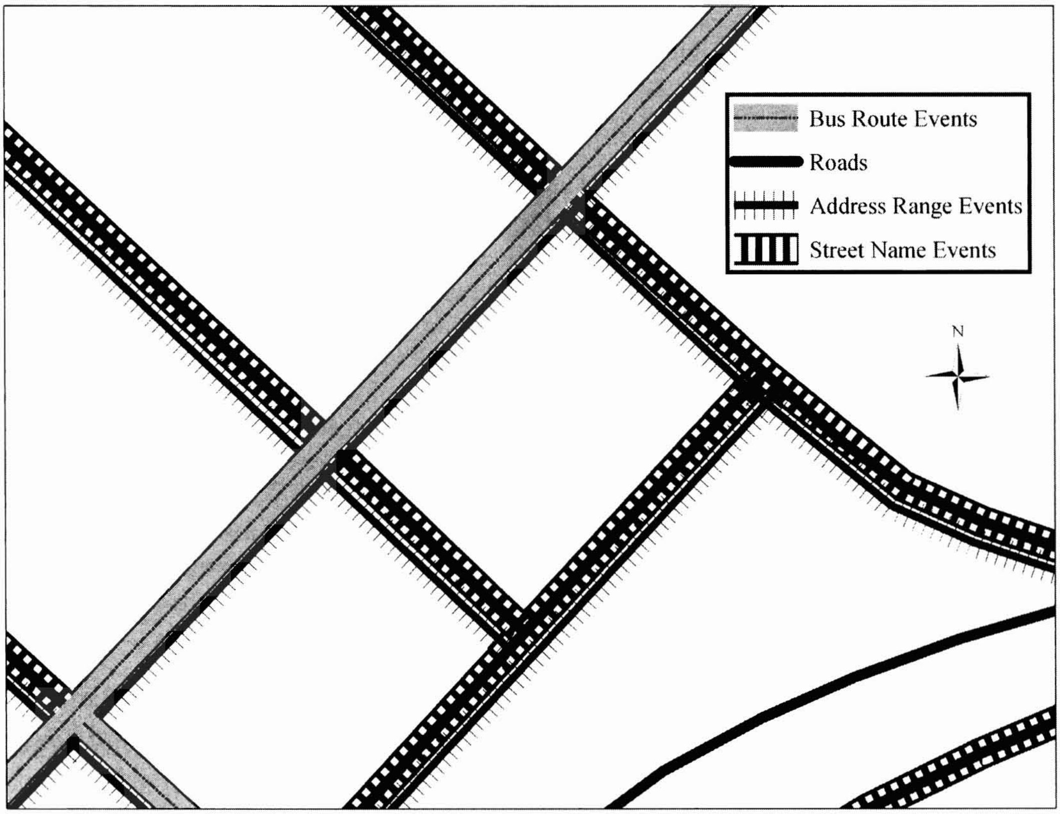

Figure 2 Dynamic Segmentation to Display Multiple Events

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Location-Allocation Modeling

Some time ago, a real estate professional stated that there were three important issues in selecting a site for a business: location, location, and location. Although there are other important issues in business site selection, location is definitely one of the most important. *Location modeling* involves the development of a formal model and solution approach to identify the best place for an activity or a set of places for a set of related activities. *Allocation* is the related task of allocating services or activities provided by the facilities in order to meet geographically distributed demand. *Location-allocation models* optimize both location and allocation simultaneously.

There are many fundamental areas in which geographic information science (GISci) has advanced the field of location modeling and site selection. To discuss the role of GISci in location-allocation modeling, it is important to first define the difference between problems of location and problems of location-allocation. Then, we present a broad class of location-allocation modeling constructs that represent many different application areas. Finally, we describe how geographic information systems (GIS) are becoming an integral component in location modeling and how GISci is now joining operations research to provide some underlying scientific elements to the modeling process.

Example of Location Modeling

We may wish to locate positions across a city from which to dispatch ambulances in order to minimize the average time it takes to respond to an emergency call for service. To calculate the level of service provided by an ambulance location plan, it is necessary to depict how demand for emergency medical services (EMS) varies across a city as well as how long it might take an EMS vehicle to travel from any one point in the city to some other point. Using such data, it is possible to build a location model, comprising mathematical equations and location decision variables, which can identify optimal or near-optimal patterns for deploying a given number of ambulances.

To depict this problem within a geographical construct, one needs to define the form of representation (or abstraction) for demand locations, potential dispatch sites, and modeling response time. For example, demand can be represented by points, polygons, or on a raster, while response time can be modeled by calculating distances or travel times along a route.

Types of Location Problems

There are two principal types of location problems: (1) location and (2) location-allocation. To describe the differences between these two types of problems, consider the problem of locating several dry-cleaning shops, Shop A and Shop B, in an urban area. Assume for the moment that these two shops will be owned by the same firm. Thus, it would be important to locate Shop A and B in such a manner that the market area of Shop A does not overlap much with the market area of Shop B; for, if they overlapped much, then the two stores A and B would compete for the same customers and the potential total revenues for the two stores would be less than what might be possible by locating the two stores farther apart.

We also know that the market area that can be drawn around a dry-cleaning business is constrained by the fact that a store is unlikely to be used much unless it is convenient to the customer, either close to home or close to a route that is frequented by the potential customer (e.g., on the journey from home to work). The process of assigning potential customers to a store location or dividing customers between two stores is called *allocation,* a component that is a key feature in location-allocation modeling. Pure location problems do not have an allocation component.

Model Classes

Location-allocation models have been developed for a variety of different needs, from locating ambulances to locating manufacturing facilities. Table 1 classifies location-allocation models according to general themes. The basic metrics listed are the variable or variables that are to be optimized in the solution.