# CHAPTER TWO

# GEOGRAPHIC INFORMATION SYSTEM (GIS)

# &

# LINEAR REFERENCING

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# GEOGRAPHIC INFORMATION SYSTEM (GIS)

# &

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## 2.1 Introducing GIS

A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. The acronym GIS is sometimes used for geographical information science or geospatial information studies to refer to the academic discipline or career of working with geographic information systems and is a large domain within the broader academic discipline of Geoinformatics.

A GIS can be thought of as a system that provides spatial data entry, management, and retrieval, analysis, and visualization functions. Generally, a GIS implementation may be custom-designed for an organization. Hence, a GIS deployment developed for an application, enterprise, or purpose may not be necessarily interoperable or compatible with a GIS that has been developed for some other application, enterprise, or purpose. What goes beyond a GIS is a spatial data infrastructure, a concept that has no such restrictive boundaries.

In a general sense, the term describes any information system that integrates stores, edits, analyzes, shares, and displays geographic information for informing decision making. GIS applications are tools that allow users to create interactive queries (user-created searches), analyze spatial information, edit data in maps, and present the results of all these operations. Geographic information science is the science underlying geographic concepts, applications, and systems.

The first known use of the term "Geographic Information System" was by Roger Tomlinson in the year 1968 in his paper "A Geographic Information System for Regional Planning". Tomlinson is also acknowledged as the "father of GIS".

## 2.2 GIS Definition:

Geographic Information System (GIS) is a computer system build to capture, store, manipulate, analyze, manage and display all kinds of spatial or geographical data. GIS applications are tools that allow end users to perform spatial query, analysis, edit spatial data and create hard copy maps. In simple way GIS can be define as an image that is referenced to the earth or has x and y coordinate and it's attribute values are stored in the table. These x and y coordinates are based on different projection system and there are various types of projection system. Most of the time GIS is used to create maps and to print. To perform the basic task in GIS, layers are combined, edited and designed.

GIS can be used to solve the location based question such as "What is located here" or Where to find particular features? GIS User can retrieve the value from the map, such as how much is the forest area on the land use map. This is done using the query builder tool. Next important features of the GIS is the capability to combine different layers to show new information. For example, you can combine elevation data, river data, land use data and many more to show information about the landscape of the area. From map you can tell where is high lands or where is the best place to build house, which has the river view. GIS helps to find new information, figure (2.1).

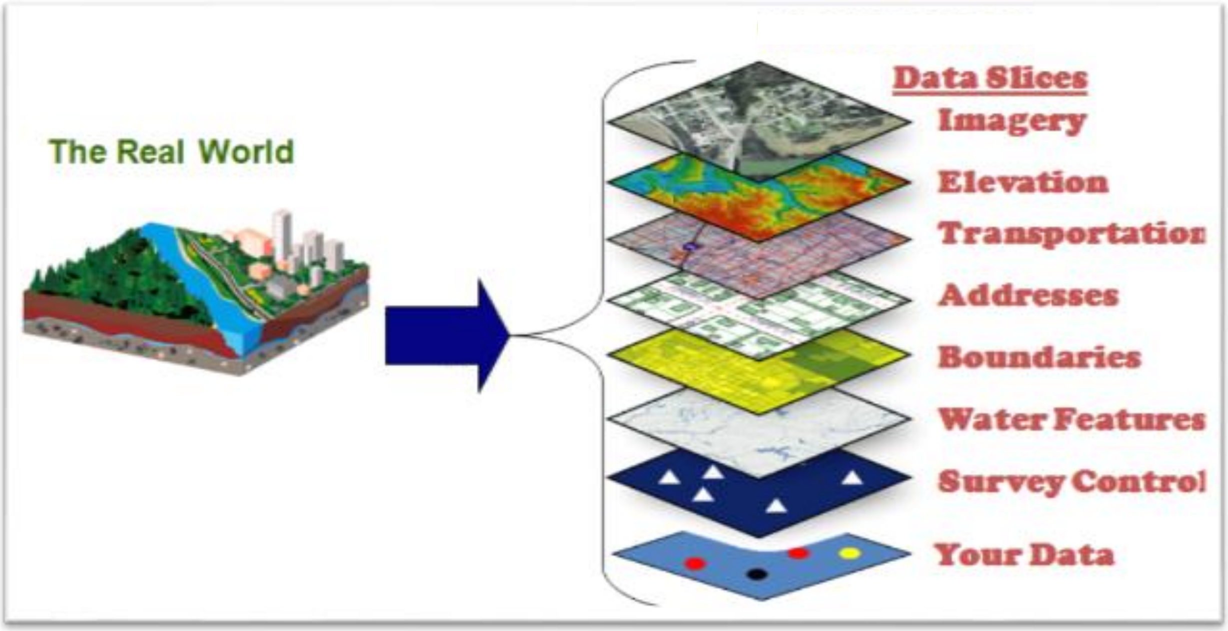


Figure (2.1): Real World Representation in GIS Model

### 2.2.1 How GIS Works:

- Visualizing Data: The geographic data that is stored in the databases are displayed in the GIS software.
- Combining Data: Layers are combined to form a map of desire.
- The Query: To search the value in the layer or making a geographic query.

### 2.2.2 Advantage of GIS:

- Better decision made by government people.
- Improve decision making with the help of layered information.
- Citizen engagement due to better system.
- Help to identify communities that are under risk or lacking infrastructure.
- Helps in identifying criminology matters.
- Better management of natural resources.

- Better communication during emergency situation.
- Cost savings due to better decision.
- Finding different kinds of trends within the community.
- Planning the demographic changes.

### 2.2.3 Types of GIS Data:

**Raster Data:** Raster data store information of features in cell based manner, figure (2.2). Satellite images, photogrammetry and scanned maps are all raster based data. Raster model are used to store data which varies continuously as in aerial photography, a satellite image or elevation values (DEM- Digital Elevation Model).

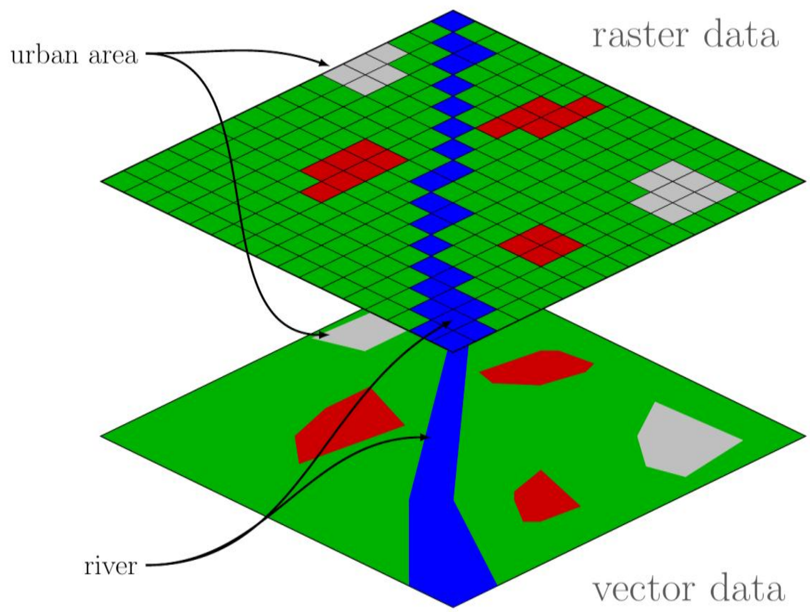


Figure (2.2): GIS Raster Data

**Vector Data:** There are three types of vector data, points, lines and polygons. These data are created by digitizing the base data. They store information in x, y coordinates.

Vectors models are used to store data which have discrete boundaries like country borders, land parcels and roads, figure (2.3).

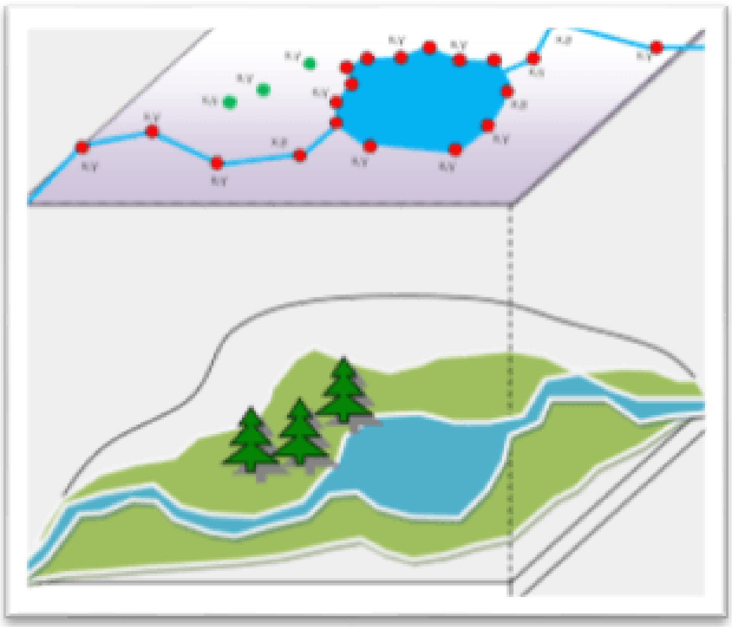

Figure (2.3): GIS Vector Data

## 2.3 GIS Application

### 2.3.1 Disaster Management

Hurricane Katrina is seen by many as the first time that GIS was used a disaster management tool. Thanks to newly available technology, the first responders on the ground shared a great deal of data about street plans - particularly which streets were and were not accessible and the extent of the flooding. Despite that FEMA and the government came in for criticism, many agree that the efforts of data transmission both prior to and during initial relief efforts were vital to relief efforts.

### 2.3.2 Crime Statistics

GIS is now vital to law enforcement and planning in terms of crime statistics. Though most police forces in the USA have used them for a long time, automated and digital mapping of reported crime has made the process much easier, especially when looking at different types of crime from different departments in larger cities. The ability to share maps and look for correlations between different types of crime can give police a much better idea of an overall picture of a wider region . The study cited here also permitted community leaders and the police to get a better understanding of each other, facilitating two-way dialogue.

### 2.3.3 Archaeology

GIS is now critical to many elements of archaeology as it takes on more elements and characteristics of an environmental science. There are many applications in the field of historical research but none has been more beneficial than the prediction of historic site location. Several US universities recently plotted an area to the south of the Caucasus to identify prehistoric sites and areas that may have potential for future on-the-ground research, most notably of the migration route out of Africa in antiquity. The project successfully identified a number of potential new sites for future investigation.

### 2.3.4 Civic Planning

GIS has been a superb tool for rural and urban planning for the last few decades, working out local tax rates, planning desirability and mapping social deprivation, where new roads could go or which should be prioritized for repair. It is now a vital part of our green future too. As with regular and previous methods of planning utilities, using the landscape is far more critical to planning. Cascade in Montana is a prime site for wind farms and there is a website that uses GIS data to plot wind speeds over the course of a year in order to best site the wind farms.

## 2.4 linear referencing definition

A linear referencing system consists of a set of line features, on which events, elements, and characteristics can be located based on a reference to the line itself rather than through absolute x,y coordinates. Events are things that happen on or to the line feature, such as crash locations and highway projects. Elements are objects that exist on or near the line feature, such as signs or guardrails. Characteristics describe the line features, like speed limits or number of lanes. In ArcGIS, the term event is used to represent events, elements, and characteristics when they are stored in tables that use a relative distance from the starting point of a line, called a route, to describe a location.

In figure (2.4), the aerial photograph is displayed with a line feature class, with streets and events rendered on it. The signs are represented as points, and pavement conditions are represented as lines. Construction projects are also rendered as a brown line along routes and overlap the pavement condition events. The locations of the construction projects could be related to the condition of the pavement to ensure projects are in place where the road conditions are poor rather than good.

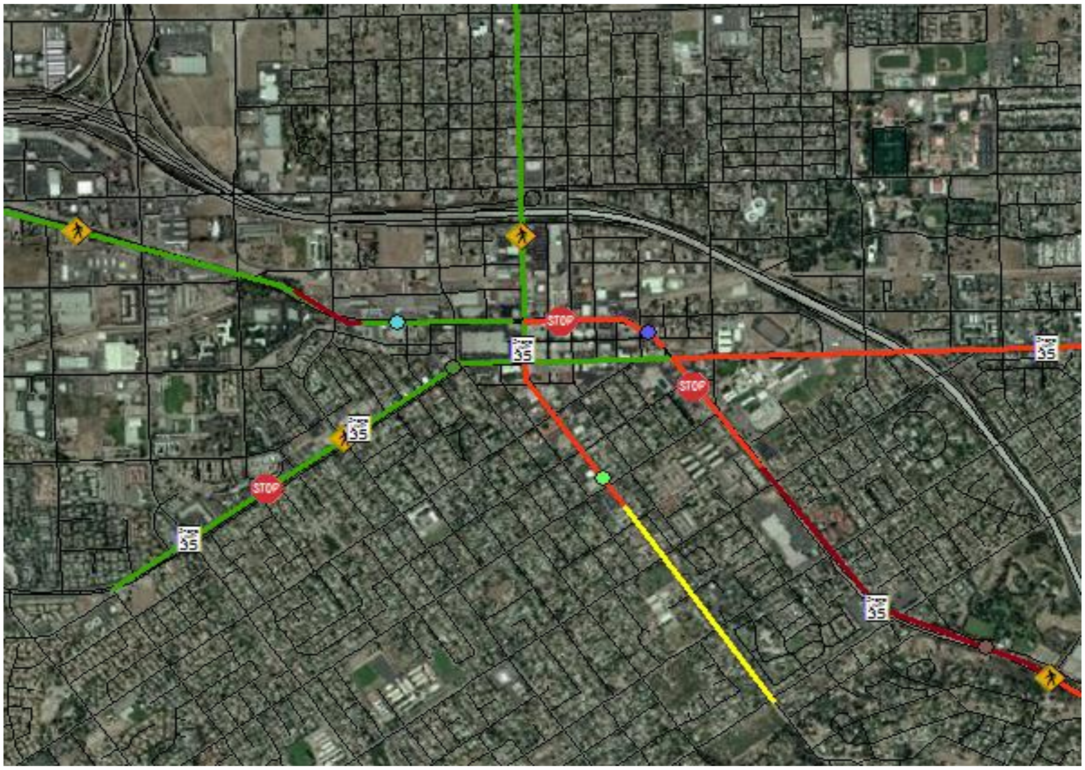


Figure (2.4): Line Feature Class

The linear referencing system tools in Production Mapping allow you to work with linearly referenced events on routes. This includes the ability to create, move, modify, and split events as appropriate for your data.

Both point and line events can be created using the event layers that are currently loaded in your map. After they are created, you can move point events along corresponding route features; line events can be extended or trimmed as needed, split at a specified location; shared line events can be adjusted based on the to- or from-point; and both types of events can be deleted.

The tools allow you to work with events visually instead of modifying table records. That is, instead of updating a value in a measure field, you can drag a point in the map to move it.

## 2.5 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.

## 2.6 Linear referencing applications

### 2.6.1 Highways and streets

Agencies that manage highways and streets use linear referencing in a variety of ways in their day-to-day operations. For example, linear referencing is useful for the following:

- Assessing pavement conditions
- Maintaining, managing, and valuing assets for example, traffic signs and signals, guard rails, toll booths, and loop detectors
- Organizing bridge management information
- Reviewing and coordinating construction projects

Linear referencing also facilitates the creation of a common database that traffic planners, traffic engineers, and public works analysts can use for cross-disciplinary decision support.

Figure (2.5) is an example displaying pavement conditions.

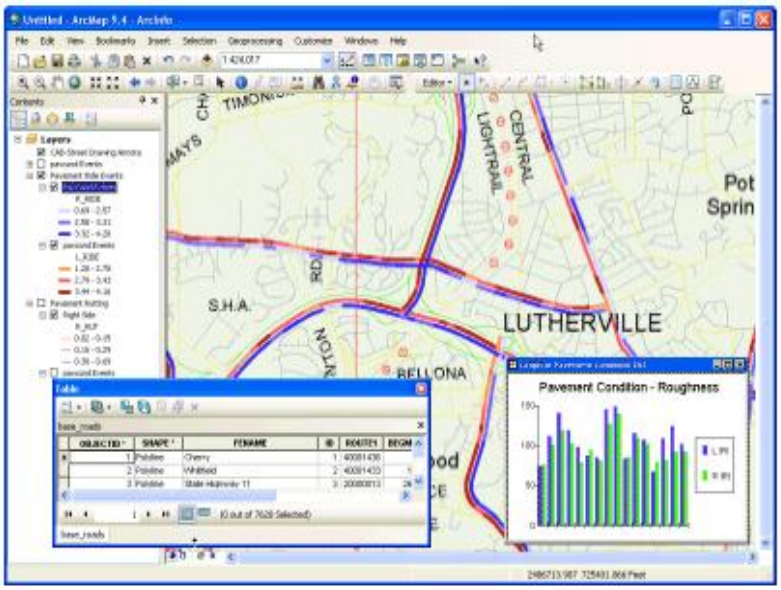


Figure (2.5): Pavement Conditions

## 2.6.2 Transit

Linear referencing is a key component in transit applications, and it facilitates such activities as these:

- Route planning and analysis
- Automatic vehicle location and tracking
- Bus stop and facility inventory
- Rail system facility management
- Track, power, communications, and signal maintenance

- Accident reporting and analysis
- Demographic analysis and route restructuring
- Ridership analysis and reporting
- Transportation planning and modeling

Figure (2.6) shows the results of a corridor study, displaying the number of traffic accidents along a stretch of highway.

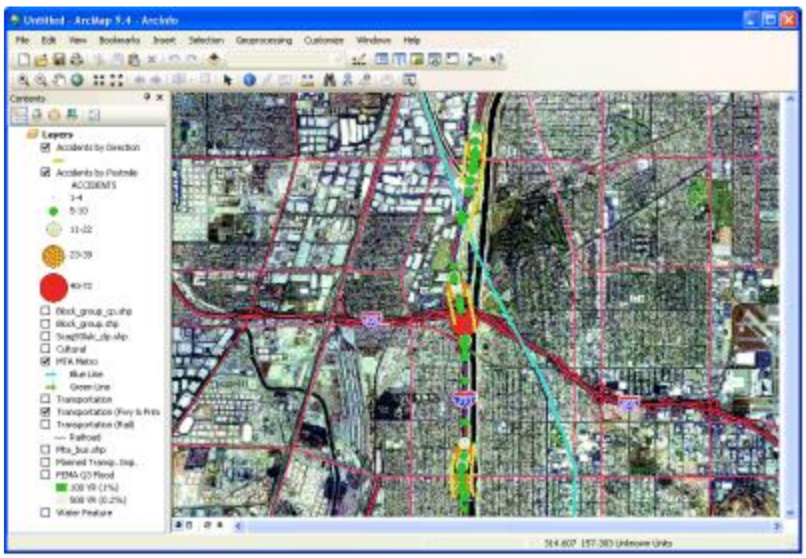

Figure (2.6): Traffic Accidents in a Corridor Study

### 2.6.3 Railways

Railways use linear referencing to manage key information for rail operations, maintenance, asset management, and decision support systems. Linear referencing makes it possible, for example, to select a line and track and identify milepost locations for bridges and other obstructions that would prevent various types of freight movement along the route. Furthermore, linear referencing can be used to display track characteristics or view digital images of bridges and obstructions.

Figure (2.7) is an example of analyzing rail clearances along a rail line.

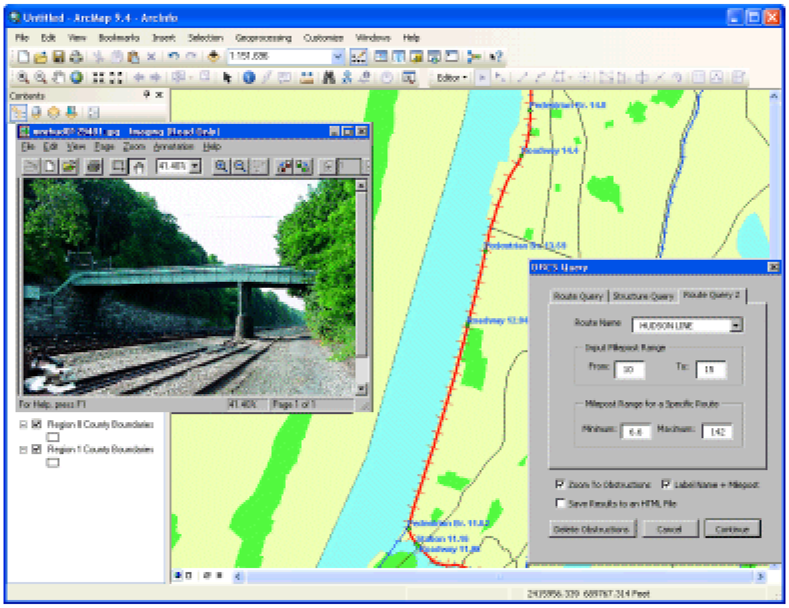


Figure (2.7): Analyzing Rail Line Clearance

### 2.6.4 <u>Oil and gas exploration</u>

The petroleum industry manages tremendous volumes of data used in geophysical exploration. Seismic surveys, or shotpoint data, are used to help understand the underlying geology in an area. The nature of seismic data is that it must be represented as both a linear object—the seismic line—and a collection of point objects (the shotpoints). Both the seismic line and the individual shotpoints have attributes, must be maintained at the same time, and are used in modeling applications. Linear referencing helps solve this problem.

Figure (2.8) shows an example of posting and labeling seismic lines and shotpoints in the Gulf of Mexico.

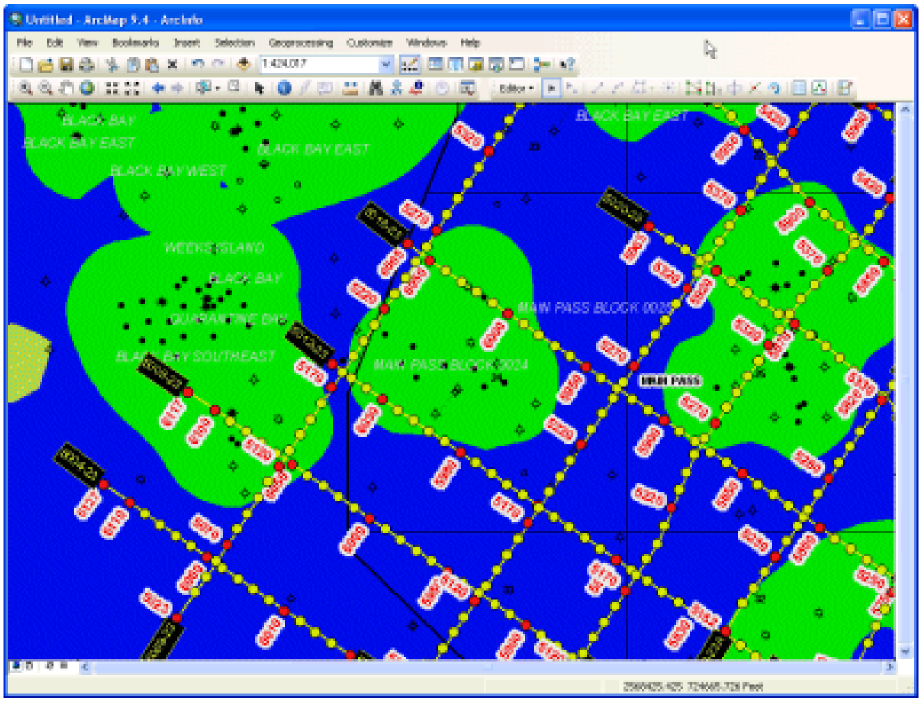

Figure (2.8): Posting and Labeling Seismic Lines and Shot points

### 2.6.5 Pipelines

In the pipeline industry, linear referencing is often referred to as stationing. Stationing allows any point along a pipeline to be uniquely identified. As such, stationing is useful in these applications:

- Collecting and storing information regarding pipeline facilities
- Inline and physical inspection histories
- Regulatory compliance information
- Risk assessment studies
- Work history events
- Geographic information, such as environmentally sensitive areas, political boundaries (for example, state and county), right-of-way boundaries, and various types of crossings

In figure (2.9), pipeline coating material types are being examined.

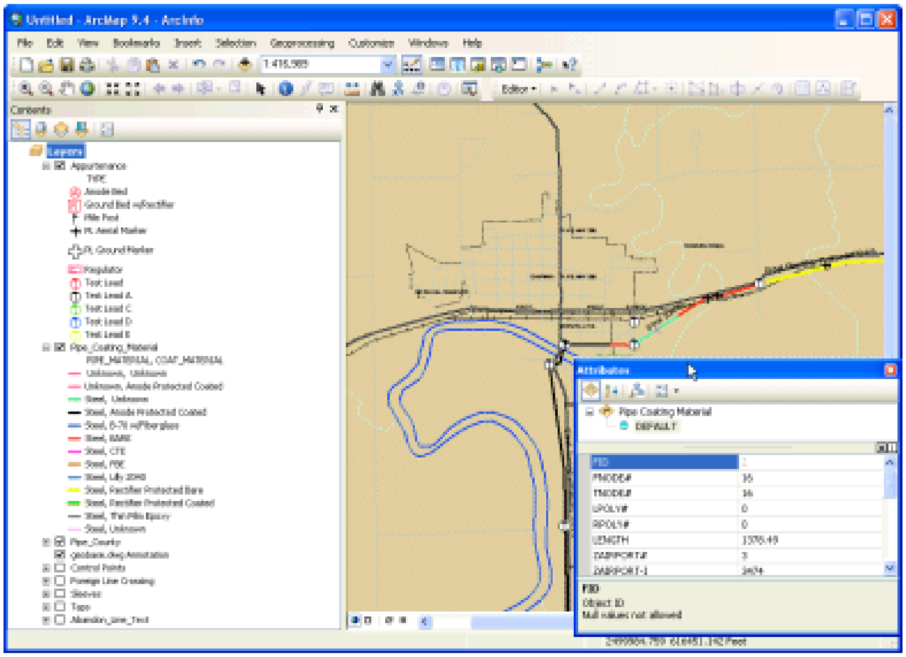

Figure (2.9): Pipeline Coating Material Types are Being Examined

### 2.6.6 Water resources

In hydrology applications, linear referencing is often called river addressing. River addressing allows objects such as field monitoring stations—which collect information about water quality analysis, toxic release inventories, drinking water supplies, flow, and so on—to be located along a river or stream system. Furthermore, the measurement scheme used in river addressing allows the measurement of flow distance between any two points on a flow path.

In figure (2.10) shows a monitoring stations along a hydrology network are identified.

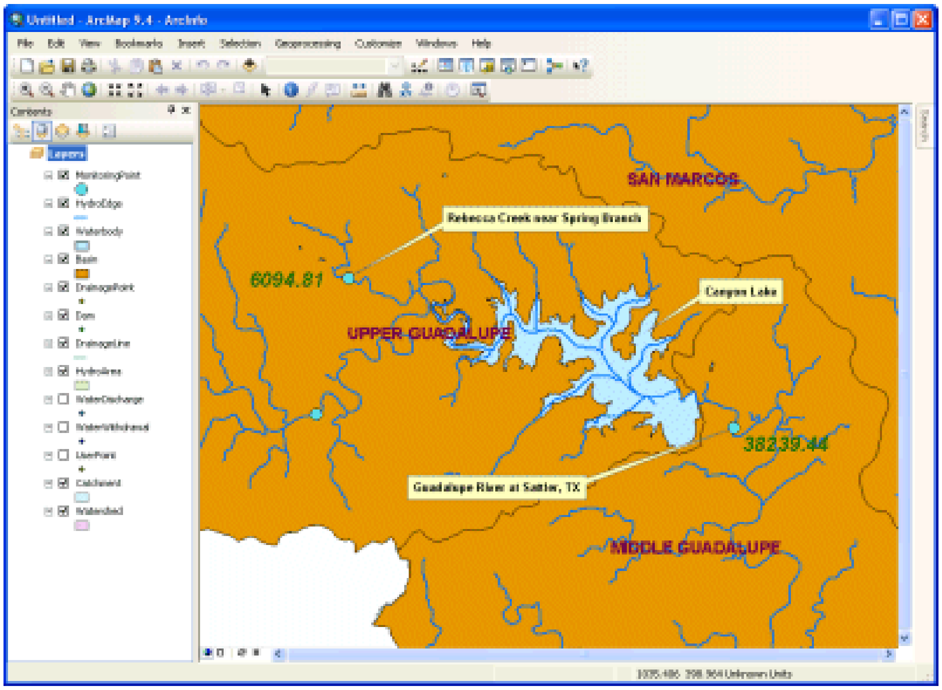


Figure (2.10): Identifying Monitoring Stations along a Hydrology Network

## 2.7 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.

### 2.7.1 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.

### 2.7.2 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 (2.11) shows the definition of four routes along an arterial road, based on direction of travel, street name, and street prefix.

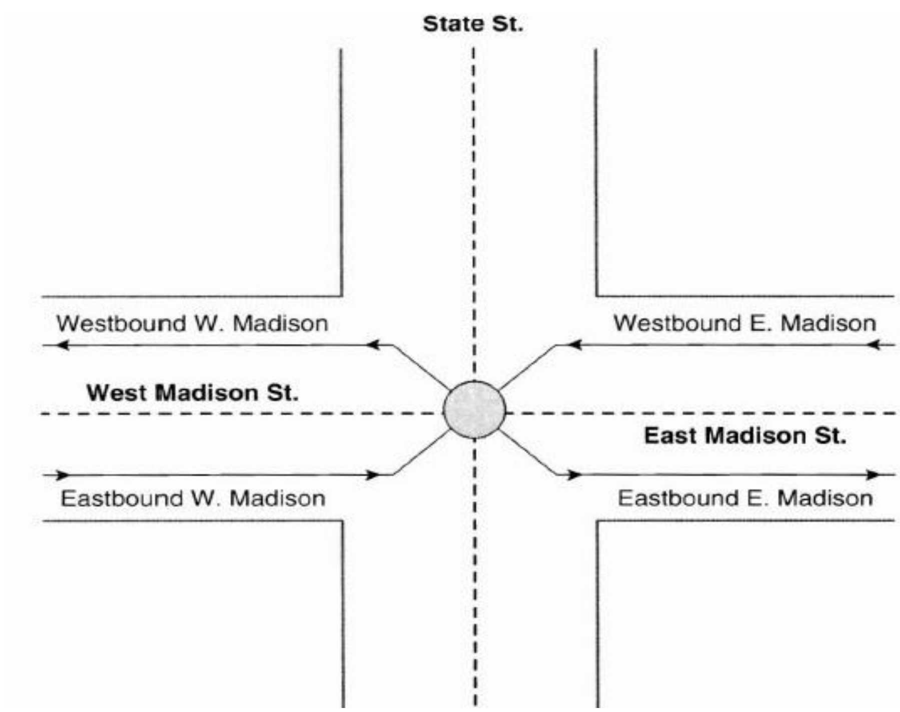


Figure (2.11): Defining Routs

### 2.7.3 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.

### 2.7.4 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.

### 2.7.5 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.

### 2.7.6 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.

### 2.7.7 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.

There are two primary data types that are used to implement linear referencing in ArcGIS:

1. Route feature classes
2. Event tables

Using dynamic segmentation, events from event tables are located on line features in a route feature class.

## Route feature classes

A **route feature class** is a line feature class which has a defined measurement system. These measurement values can be used to locate events, assets, and conditions along its set of linear features, figure (2.12).

In ArcGIS, the term route refers to any linear feature, such as a city street, highway, river, or pipe, that has a unique identifier and a common measurement system along each linear feature.

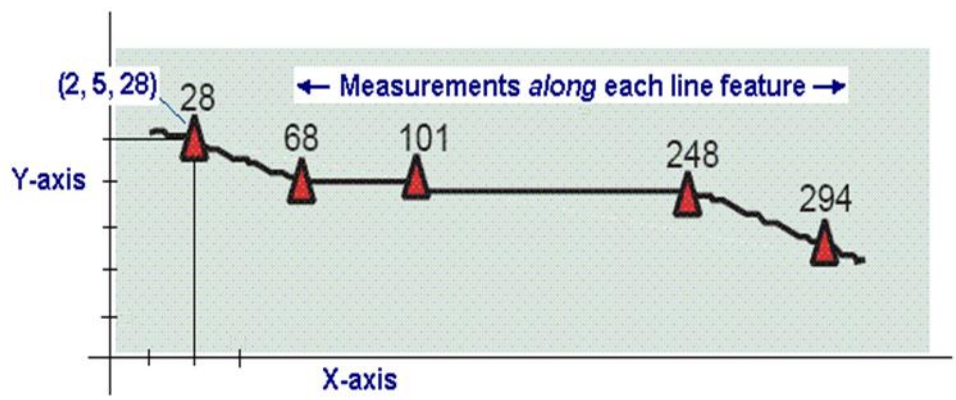


Figure (2.12): Measurement System along Each Linear Feature.

In simple terms, feature vertices in route feature classes include **m-values** (x,y,m or x,y,z,m). These measured coordinates form the building blocks for route features. In route feature classes, line features have their x,y (or x,y,z) coordinates that describe location as well as a measurement value (m) along the line.

A collection of routes with a common measurement system is a route feature class. Each route in the feature class will also have a unique identifier, figure (2.13). Line features with the same unique identifier are considered to be part of the same route:

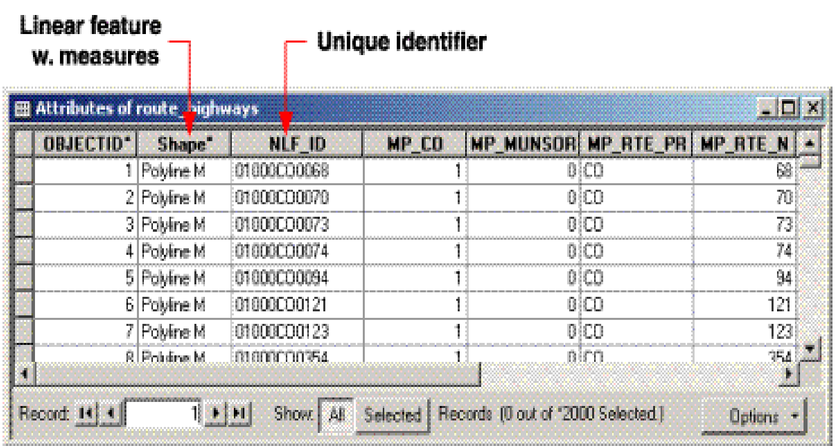


Figure (2.13): Feature Unique Identifier

Route feature classes are created and managed as line feature classes in the geodatabase. You can also use route feature classes from ArcInfo coverages and polyline shapefiles that include route identifiers and measured features.

## Route feature geometry

Route features have a measurement system stored with their geometry. Each measured line's segments have x-, y-, and m- (measure) or x-,y-,z-, and m-values. When a measure value is unknown for a particular vertex, its m-value is recorded as NAN (not a number) as illustrated in figure (2.14).

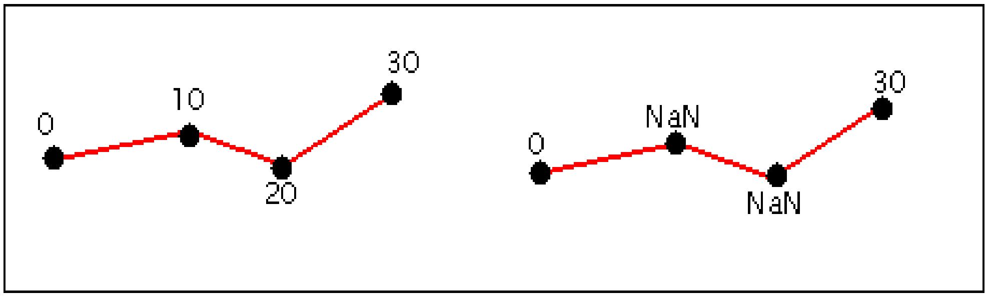


Figure (2.14): Measurement System Stored

Simple linear features are represented by lines with one path. Complex linear features are represented by lines with many paths, figure (2.15)

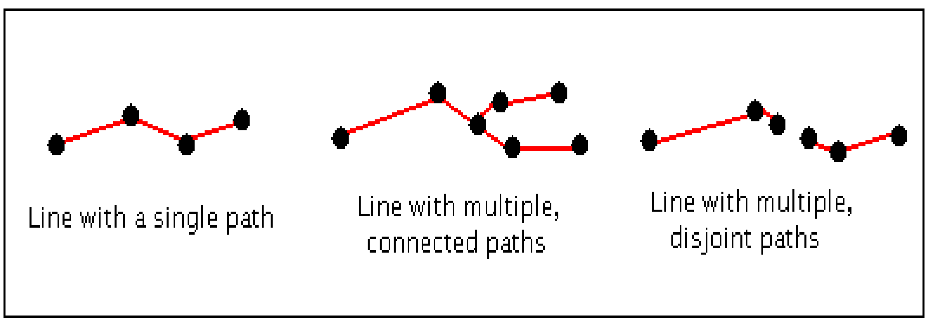


Figure (2.15): Lines with Many Paths

It is important to note that although most applications use measures to represent increasing distances along a linear feature, measure values can arbitrarily increase, remain constant, or decrease along line features.

Measure values are independent of the horizontal coordinate system of a feature class (and the vertical coordinate system, as well, if one is defined). That is, the measure values are not required to be in the same units as the feature class's x,y,z coordinates.

For example, features stored in a feature class whose coordinate system is Universal Transverse Mercator (UTM) meters might have their measure values stored in feet or miles or time.

## Event tables

Event tables contain information about assets, conditions, and events that can be located along route features. Each row in the event table references an event, and its location is expressed as measurements along named (identifiable) linear features.

There are two types of events: point events and line events. A point event describes a discrete location along a route (a point), whereas a line event describes a portion of a route (a line).

1. A point event location uses only a single measure value to describe a discrete location such as "Mile 3.2 on I-91."

2. A line event uses both from- and to-measure values to describe a portion of a route, for example, "Mile 2 to mile 4 on I-91."

Because there are two types of route event, there are two types of route event tables: point event tables and line event tables. All event tables must contain a route identifier and measure location field(s) containing measure information. A point event table uses a single measure field to describe its discrete location. A line event table requires two measure fields (a from- and to- measure) to describe its location.

Route locations and their associated attributes are stored in an event table based on a common theme. For example, four event tables containing information on speed limits, year of resurfacing, present condition, and accidents could be included and used to dynamically locate events on a route feature class.

An event table can be any type of table that ArcGIS supports. This includes INFO, dBASE, geodatabase, delimited text files, and database management system (DBMS) tables accessed via an Object Linking and Embedding database (OLE DB) connection.

## Event table example

Hydrologists and ecologists use linear referencing on stream networks to locate various types of events such as is illustrated in figure (2.16). The route feature class for streams provides measures along the streams using river reach mile. Point and line event tables record the route ID and location along each river reach. These event tables can be used to locate point and line events.

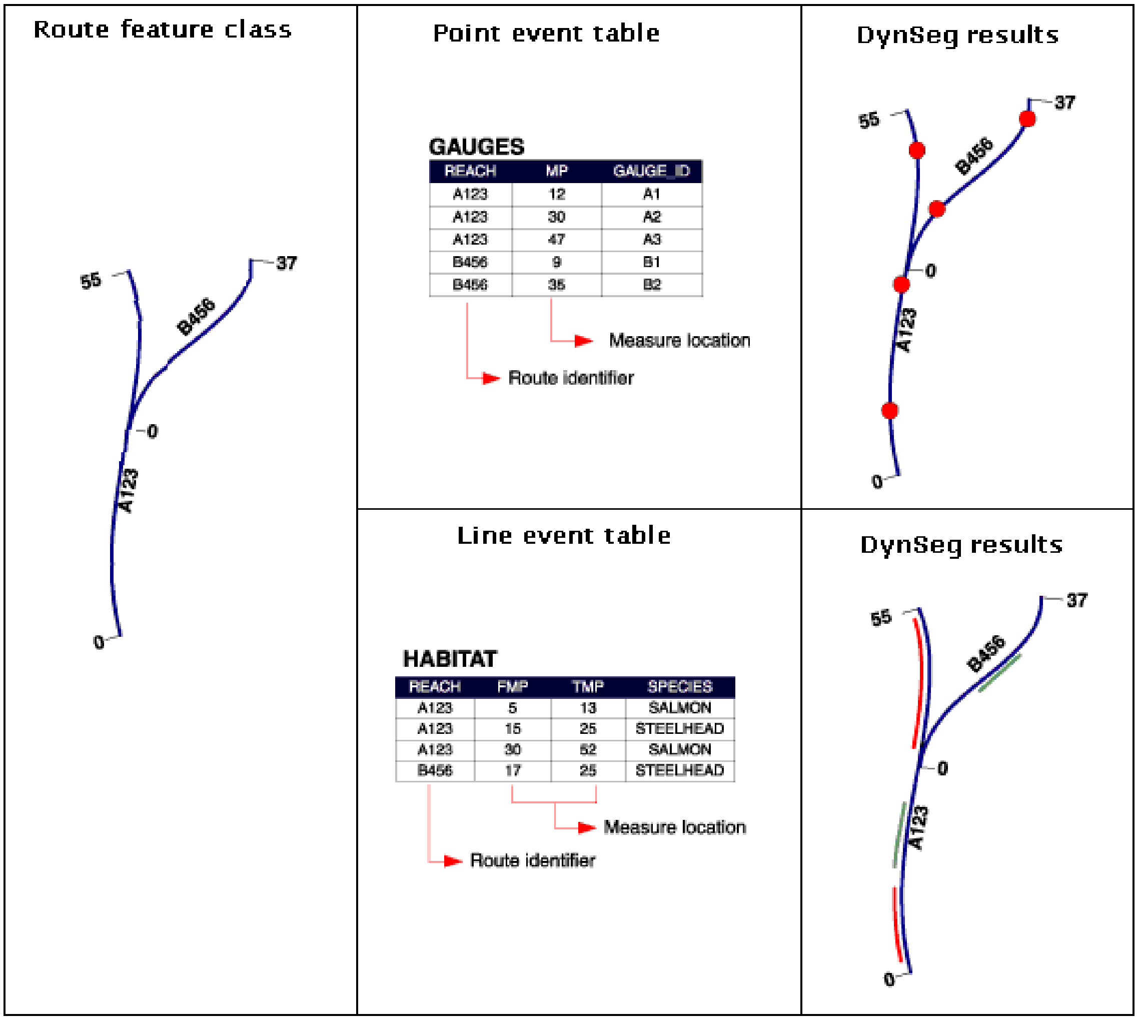


Figure (2.16): Various Types of Events

## Storing features using relative locations

With linear referencing, locations along linear features are referred to in terms of their route measure, or distance from a known point, figure (2.17). For example, it often makes sense to describe the location of an accident as occurring at "12 miles from the beginning of the interstate" rather than at a GPS coordinate such as at "1,659,060.25, 1,525,238.97".

To determine a location along a linear feature, a system of measurement is required. When a measurement system is stored along with a linear feature, any location along that linear feature can be expressed in terms of the measure values.

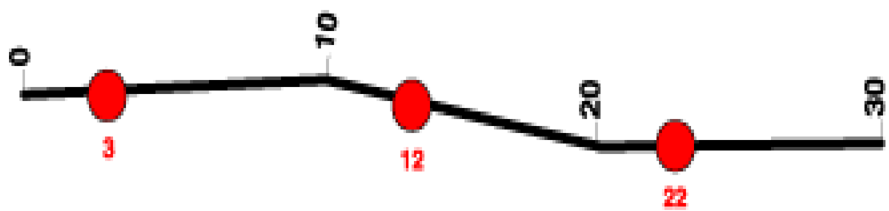


Figure (2.17): Storing Features Using Relative Locations

In addition to making data more intuitive, storing data as a relative location along a linear feature has the added benefit of ensuring that spatial phenomena you know to fall on a linear feature is located on the feature. For example, in the absence of a very accurate basemap, locating accidents using x,y coordinates may end up displaying accidents that do not fall on the road network as they should. This will not happen if the accidents are located using linear referencing.