Map Coordinates, GIS, and GPS for Enhanced 9-1-1

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Maps and coordinates are used to describe features and their locations on the Earth. Maps are also used for navigation, and efficient navigation is important for emergency response. Maps for 9-1-1 have historically been used to aid dispatchers and personnel in locating an emergency, but in the past decade, geographic information systems have also been used to automate the assignment of addresses and to manage the construction of master street address guides and computer-aided dispatch geofiles. Recently maturing navigation technologies, such as the Global Positioning System (GPS), have moved 9-1-1 mapping directly into the field and have made users aware of the importance of map coordinates.

The National Emergency Number Association (NENA) has proposed a 9-1-1-database exchange format that includes the use of map coordinates for each telephone record. This database standard has not been adopted for a variety of reasons, even though the additional information would be very useful for 9-1-1 emergency dispatch. One of the reasons this data standard has not been utilized is the lack of definition of which map coordinates should be utilized.

History of Mapping and Geometry

Most map features can be simply described with points, lines, and areas. The Greeks were among the first to seriously study how points, lines and areas are related mathematically. In 300 BC, the Greek mathematician, Euclid, defined rules of geometry which are still used today to make maps. The word geometry means "earth-measure."

Euclid created five basic rules that he felt could describe nearly all principles of geometry and these became known as Euclid's Five Elements. Euclid's "Elements" consisted of:

1) A straight line segment can be drawn joining any two points.
2) Any straight line can be extended indefinitely in a straight line.
3) A circle can be drawn from a straight line by rotating it on one endpoint.
4) All right angles are congruent (same shape and areas).
5) Two parallel lines can be extended and they will never intersect.

Euclid's rules greatly influenced mathematics and map coordinates for the next 2,000 years. A hundred years after Euclid, a Greek geographer named Eratosthenes represented the known world on a map that had a grid of lines to locate places. This map was the first with parallel lines to equal latitudes and meridians of longitude. Lines of longitude and latitude are used today to define mathematical coordinates for locations on the earth.

Around AD 150, the Egyptian scholar Ptolemy published a work containing maps of the world. These maps were the earliest to use a mathematical representation of the earth using the conic projection, which is a method of mapping that preserves certain measurement accuracies. Today, all maps are projected to minimize errors in measurement of length and area and to preserve the true shape of a region.

The accuracy of mapping improved as more was learned about the size and shape of the earth. But the most important influence on better mapping came about with better methods of determining latitude and longitude. By the mid 1700s, accurate maps of the known world were being produced. However, the serious understanding of the mathematics affecting the geometry of map making had not yet occurred.

In 1823, mathematical research occurring simultaneously refuted Euclid's most important postulate, the "Fifth." It was found that parallel lines could intersect, contrary to the Fifth Postulate. On a curved surface, such as a sphere describing the earth, parallel lines of longitude intersect at the poles. This led to the advent of non-Euclidean geometry, which today includes hyperbolic geometry (where the sum of the angles of a triangle is less than 180 degrees) and elliptic geometry (where the sum of the angles of a triangle is more than 180 degrees).

Map Coordinates

To represent the entire surface of the earth without any kind of distortion, a map must be a sphere and this type of map is known as a globe. Using a globe, accurate measurements of distance and area are possible, and the shapes of regions are true. But a globe is not a practical map for showing a great amount of detail for a small region.

For this reason, flat maps are created and used, but with flat maps, the spherical surface and coordinates of the earth cannot be accurately represented, except for very small areas where the curvature of the earth is negligible. Thus a map of the world on a flat sheet of paper does not have true shape for all regions and has cumulative measurement errors. This is because every map is a mathematical compromise among the distortions of area, shape, distance, and direction.

Spherical Coordinates

The spherical coordinates of a globe use a measurement grid composed of meridians of longitude and parallels of latitude. Longitude is marked 180 east and 180 west from 0 at Greenwich, England. Latitude is marked 90 north and 90 south from the 0 parallel of the equator. Any position in this location system can be accurately defined by providing degrees, minutes and seconds for both latitude and longitude.

Spherical coordinates are useful for mapping large areas and the coordinate system of latitude and longitude is excellent for measuring directions, but not distances. Distance calculations with spherical coordinate measurements in small areas are very complex. During World War I, it was necessary to simplify the coordinate measurements so that accurate azimuth (direction) and range (distance) could be easily calculated with Euclidean geometry and plane trigonometry. So, a series of local plane coordinate systems were developed. Today, there are plane coordinate systems for mapping all regions of the world.

The Global Positioning System (GPS) utilizes latitude and longitude to tell its user where they are on the earth, but GPS actually calculates its coordinates not in a spherical coordinate system, but rather in a Cartesian coordinate system with the origin found at the center of the earth. A GPS receiver calculates its position by measuring an x, y and z position on the earth using the earth centered earth fixed (ECEF) ordinate system and then translates these x, y and z coordinates into spherical latitude and longitude coordinates.

Plane Coordinates

Plane coordinate systems are flat surfaces that are tangential, or intersect a small portion of the surface of the earth. Planar coordinate systems are best used in small geographic areas and essentially treat land and water as level surfaces. To minimize mapping error in plane coordinate systems, the areas being mapped are intentionally kept small. As coordinates are measured away from the place where the flat map intersects the spherical surface of the earth, their accuracy decreases.

In the United States, the state-plane coordinate system (SPCS) is the most commonly selected choice for mapping areas the size of counties. However, plane coordinate systems accumulate error in distance measurements (because the meridians on a plane coordinate system are not truly parallel, but will eventually converge - remember the refuttal of Euclid's Fifth Postulate). Thus, plane coordinate systems require adjustments to "tie" the plane to the surfaces of the earth. Changes in the "ties" to the earth's surface (geoid) occurred in the 1980s, when the North American Datum of 1927 (NAD-27) was updated with the North American Datum of 1983 (NAD-83). In some regions of the US, mapped features "moved" tens of feet.

Larger areas covering many counties, or even states, are likely to be mapped with the Universal Transverse Mercator (UTM) system. Like SPCS, UTM is a plane coordinate system, but instead of the more than a hundred SPCS plane systems covering a the United States, there only a few UTM zones for the same region.

It is also much simpler for users to locate coordinates with UTM, as it was designed and adopted by the military, not specialized for surveying.

Map Projections

The models that may be selected in preparing a flat map of the earth are known as projections. Projections may be based on geometric surfaces on which the earth is depicted (i.e. cylindrical, conic, and planar). The UTM coordinate system is based on a cylindrical projection (which is an imaginary paper cylinder placed around the earth), while many state-plane systems are based on conic projections (an imaginary paper cone placed on the earth). Other projections that are determined by mathematical computation are known as analytic projections. The needs of the users must be determined to plan which advantages and limitations of the projection fulfill those specific needs to optimize the distortions of distance, direction, shape, and area.

New Technologies

Two new methods of mapping should be considered because of their inevitable impact on 9-1-1. Digital ortho photographs are aerial photographs that have been mathematically reshaped so that one can use them as maps. Perhaps of greater significance is the global positioning system which will be more commonly used to build maps and to serve as a navigation tool for 9-1-1 response.

Digital Ortho Photographs

Photogrammetry is the science of taking measurements from photographs to make maps. When a photo is taken, there are inherent distortions (scale and angle) in the image. These distortions were historically removed using a manual, optical process. Today, the inherent errors of a photograph are reduced with software that operates on the scanned image of the aerial photograph. The software moves and stretches the individual pixels in the scanned image to place them in their true positions with real earth coordinates. The resulting image is a photograph that has been fit and tied to plane coordinates so that measurements and mapping can occur without distortion. Each pixel in the photographic image thus has a known map coordinate.

Unlike other forms of photography, one can map directly from digital ortho photos. This results in every point on the ortho photo being a true map coordinate, usually a state plane coordinate.

Today, some communities are building 9-1-1 mapping databases directly from their digital orthos, with each mapped feature having true map coordinates.

Global Positioning System

GPS is a satellite-based navigation system created by the Defense Department. It was fully established in 1994 at a cost of more than 12 billion dollars. GPS provides positioning, velocity, and time information and is used by the military to immediately determine location anywhere on the earth. However, civilians cannot make use of the military version of the signals and must settle for less precise positions measured in tens of meters (though some specialized GPS equipment can yield accuracies of centimeters). But these civilian systems may require increased data collection time to gather GPS signals, as well as complex and expensive hardware, and additional software processing.

The coordinates collected directly by GPS receivers are not spherical or planar coordinates. GPS coordinates are in the WGS-84 ECEF system, which is a three-dimensional Cartesian coordinate system whose origin is based on the mathematical center of the earth. The WGS-84 coordinates are usually converted into the spherical coordinates of latitude, longitude and elevations automatically by the GPS receiver. The user must then translate the latitude and longitude into their choice of planar coordinates such as state-plane.

GPS will benefit 9-1-1 users in two fundamental ways. First, GPS will become a widely used tool to map communities for address assignment. Second, GPS will become a viable emergency service dispatch navigation aid as GPS systems improve and prices fall. Some communities have entirely skipped the addressing process for 9-1-1, dispatching directly to a map coordinate and using GPS for navigation.

Both digital ortho photography and GPS are becoming standard product and service offerings with some 9-1-1 mapping and addressing vendors.

A Case Study of Coordinate Choice

The following case considers how x, y and z coordinates could be included in an Enhanced 9-1-1 system via the NENA data format. In south Texas, three counties, Jim Hogg, Zapata, and Starr, were mapped with GPS to note road and house locations.

The choices of map projections was the State Plane Coordinate System (SPCS) because all three counties are in the same SPCS zone (Texas South) and the digital maps were to be used later as part of a regional geographic information system. Also, because the addresses being assigned are based on GIS distance measurements along each road, the choice of coordinate systems and projections had to be one that minimizes measurement error.

SPCS coordinates are measured from an x y grid with the y-axis corresponding to measurements termed Northings, and x-axis measurements termed Eastings. All measurements in SPCS are usually in feet. Meters are commonly used in other coordinate systems such as Universal Transverse Mercator.

Both the UTM and SPCS projections are based upon the known shape of the surface of the earth. As technologies improve, so does our knowledge of where the mathematical surface of the earth is located. This mathematical surface of the earth is termed the geoid and measurements from the geoid control how map measurements are made. A comprehensive survey that occurred prior to 1927 resulted in a map control system termed the North American Datum of 1927 (NAD 27). NAD 27 is the geoid referencing system found on the majority of the USGS 7.5" quadrangles. Another comprehensive survey to mathematically redefine the geoid occurred in the early 1980s, which resulted in NAD 83 being used as the standard referencing system for subsequent mapping measurements and coordinate systems.

This presents a slight dilemma because the source materials likely to be used in a county geographic information system will be the USGS 7.5" quads, the bulk of which are likely to be based on NAD 27 because of their vintage. Most high-end GIS application software can translate NAD 27 to NAD 83, but the user must be aware that this will be required, otherwise mapped data from the quads will not match the GPS data translated into NAD 83.

For the 9-1-1 work in these Texas counties, NAD 83 SPCS coordinates were selected. When Texas converted its State Plane Coordinate System from NAD 27 to NAD 83, they also changed the coordinate schemes for each SPCS zone in Texas. Because of the curvature of the earth, the SPCS in Texas is divided into several horizontal zones. The three counties, which are part of this project, happen to be in the South Zone of the Texas SPCS system. Each of these Zones, according to the 1927 system, has an origin to measure distances in Northings and Eastings. In 1983, Texas decided to go with a single origin for all zones instead of unique origins for each Zone. Thus the new coordinates in the 1983 system have greatly different numbers from the NAD 27 system. This means the NAD 83 coordinates that are produced in this project do not match the SPCS coordinates noted on the USGS quadrangles.

The following location is the same, but the coordinates vary.

Lat/Long	N 26º 53' 56.2555"	W 099º 15' 48.0942"
NAD27 SPCS	N 448,538.296	E 1,751,331.154
NAD83 SPCS	N 16,852,843.252	E 735,476.085

The same coordinates could also be represented in UTM, in WGS-84 ECEF, and a host of other coordinates systems.

Map Coordinates for 9-1-1

Maps and their coordinate systems have a variety of uses such as building new data, (i.e. addresses) to serving as dispatch and navigation aids. Ultimately, every 9-1-1 customer must have a logical address for 9-1-1 dispatch and map coordinates can help serve this purpose. Map coordinates can help locate callers in rural areas, especially where addresses are assigned from major roads, yet the structure from which a 9-1-1 call is being made may be some distance off of the major road, and possibly hidden in trees and hills.

The National Emergency Number Association has recommended that x, y, and z coordinates be included in the record format for telephone company data exchange. The inclusion of these coordinates could have the following benefits:

- The map coordinates could be another type of Automatic Location Information (ALI), which will assist dispatchers who possess digital maps in locating 9-1-1 calls. This is especially true for rural communities.
- The map coordinates could aid in the construction of Master Street Address Guides (MSAG) because

the coordinate of each customer could be automatically assigned Emergency Service Number (ESN) codes with a geographic information system.

- The map coordinates could be used by the serving telephone companies in determining accurate tax codes for each customer so that 9-1-1 surcharge monies can be correctly collected and distributed.
- In the future, GPS will likely be widely available on emergency service vehicles and GPS can be used as a navigation tool to navigate to the location in question.
- Map coordinates could also be used to more finely geocode crime and other public safety statistics than existing computer-aided dispatch geofiles and address-based geographic information systems.

The NENA recommended format for data exchange does not specify the type of coordinate that can be used in the reserved fields. Database fields of 9 bytes are reserved for each of the x, y, and z coordinates in the 512-byte record. To prevent future problems with database interchange compatibility, a choice must be made to determine standards for map coordinates and the formatting of these coordinates.

It will best serve the interests of communities to use a single coordinate system that will serve the broadest range of local users. NAD 83 would be an appropriate datum and the State Plane Coordinate System is a good choice for county-level geographic information systems. However, nearly all mapping by telephone companies is in the UTM system, thus the coordinate systems between the local users and the telephone companies will not match.

One possible solution that will help all organizations is to use a common coordinate system. Latitude and longitude can be translated into practically any coordinate systems used by local governments and utilities.

If latitude and longitude are used in the recommended data format, then there are several choices in denoting latitude and longitude:

N dd°mm’ss”	+dd°mm’ss”
N dd.mmss	+dd.mmss
N ddmm.mm	+ddmm.mm
N dd.dddd	+dd.dddd

If a choice other than latitude and longitude is to be used, such as SPCS or UTM, then more fields should be specified in the NENA Data Exchange Format. These fields will need to contain information describing the map projection, zone information, and other facts such as datums and geoids.

Summary

The inclusion of map coordinates with other 9-1-1 information can help save lives and property and shorten response time. As customer demands for this type of information increase, serving telephone companies will either have to begin incorporating the coordinate information or permit emergency service providers to more easily construct and maintain their own 9-1-1 databases.

To date, there are no telephone companies that have included map coordinate information into the 9-1-1 ALI database record, but this is likely to change as telephone companies begin to overhaul their database structures and begin to provide more responsive services to their customers. The impetus for this overhaul will also likely be a federal mandate similar to the FCC requirment to locate wireless 9-1-1 calls using location determination technologies (LDT).