Improving Spatial Accuracy of Base Maps for Wireless Enhanced 9-1-1

Map Improvements in the Texas Wireless Integration Project

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In 1996, the State of Texas 9-1-1 Advisory Commission, Harris County 9-1-1 Emergency Communications District, and Tarrant County 9-1-1 District, along with key partners from the Wireless and 9-1-1 industries, successfully demonstrated what we now refer to as Phase II Wireless E9-1-1. The trial was called the Wireless Integration Project, or the WIP trial. The result of the WIP trial was that a caller's location, along with their mobile directory number, was delivered to a PSAP and displayed on the Call Handler's digital map.

Before the actual trial demonstration and resulting map display ever took place, consideration was given to the quality of the base map as it compared to the physical locations that were being identified and collected in the field. This paper explains the process of "map accurizing" to improve accuracy for wireless call mapping. This paper also considers the concept of spatial synchronization between the map coordinates generated by the wireless LDT (location determination technology) and the digital maps to display those coordinates at the PSAP. An earlier version of the paper as co-authored with Beth Ozanich, Wireless Operations Manager, Intrado Corporation.

Introduction to WIP Mapping

An accurate and complete map is a critical component required for the implementation of any LDT to locate wireless 9-1-1 calls. The map serves as a positioning reference tool and graphically communicates the location of the person reporting an emergency. Thus, the map is the tool that interfaces the LDT to the dispatcher. An inaccurate or incomplete map will likely provide inaccurate and incomplete dispatch information. Producing an accurate map to support the Wireless Integration Project (WIP) was a requirement defined early in the project.

The science and art of mapping has undergone a tremendous change over the past decade. Digital mapping has been transformed from an esoteric science of photogrammetric engineering and computer programming into a layperson's toy popularized by off-the-shelf mapping systems and public domain mapping databases. This revolution in mapping access has allowed inexperienced map users to access mapping data and software without the education and training required only a few years ago. One result is that commercially available electronic maps are being used in applications for which they were never designed or intended. Although this has meant that public domain mapping data is used by a much broader base of user, the mapping data has been misunderstood and misused. The inappropriate use of these mapping data sources and their poor integration with LDT can become a problem for wireless 9-1-1 call tracking and especially for emergency dispatch.

Several issues must be considered in the integration of digital mapping with LDT. Perhaps the greatest and most overlooked issue is this: How does a dispatcher, who is not experienced with mapping, understand the visual information presented on the map? The cognitive interface of any mapping system requires the quick and unambiguous communication of information, especially with the high stress and the limited time of emergency dispatch.

Besides the cognitive or "human factors" relating to dispatch mapping and LDT display, other issues were realized. Circumstances involving multi-jurisdiction dispatch, real-time event geocoding, and dynamic call routing require investigation. Fundamental issues of map coordinate systems were also raised.

WIP Map Accurizing [1]

The mapping source for the Wireless Integration Project in Houston was delivered with the MapInfo software used by the Greater Harris County 9-1-1 Emergency Network. In Harris County, a region known as the Villages was selected as the pilot area because of the density of cellular towers and variety of geographies including subdivisions, shopping malls, buildings of various heights, parks and an interstate highway corridor.

The mapping data available to the WIP included with MapInfo, was derived from the Census Bureau's TIGER Line Files. TIGER (Topologic Integrated Geographic Encoding and Referencing) is a public domain digital mapping database created by the Census Bureau for the 1990 Census. The source materials used in the construction of TIGER was the USGS 1:100,000 series maps that have a nominal working scale of one inch representing the map equivalent of 1.578 miles. Obviously, at this working scale, there is not a lot of detail and any electronic representation of a map at this scale will have a significant amount of positional error. This positional error is often stated in terms of National Map Accuracy Standards (NMAS), which means that of the features digitized from source maps, 90 percent should be within 1/50th of the map's scale, or in the case of TIGER, 166.7 feet.

In urban areas, such as the WIP test area, the Census Bureau needed the attribute information, primarily address ranges, found in the cartographic data files compiled for previous decennial censuses, known as the GBF-DIME files. The GBF-DIME files were created to automate census questionnaire tabulation by matching census statistics to address ranges, street block sides and census blocks. The GBF (Geographic Base Files) used a two-address range approach (Dual Independent Map Encoding or DIME) to match census data to unique street sides. The positional accuracy of the GBF-DIME is actually coarser than the TIGER data, and often the information does not have the detail found in TIGER, because only streets with addressing were cataloged. Today, the information content found in the original GBF-DIME files for approximately 300 metropolitan regions is found in the TIGER files.

As an emergency dispatch tool, the TIGER files have both advantages and disadvantages. Among the advantages are low cost, a fair amount of completeness and accuracy, and often the scarcity of other readily available databases for a community. Due to these advantages, TIGER often finds its way into many emergency dispatch applications.

As noted, TIGER also has many shortcomings. In an urban area, the most obvious shortcoming is the lack of spatial accuracy, with many roads varying from true position by as much as 200 feet. TIGER also suffers from incomplete and inaccurate map features and supporting attribute information, such as road names and address ranges. It should be reiterated that TIGER was built to conduct a census, not dispatch emergency vehicles.

Several methods exist to update the source maps. To the layperson, perhaps the most obvious approach would have been to re-digitize the road network from the USGS quadrangles. However, the quads for the region of the pilot study were created in 1976, and edited in 1982. Thus 20 years of updates would be necessary. Another, more professional option would be the use of aerial photography to update the road locations. However, there are costs and delays in the acquisition of aerial photos as well as inherent distortions that would have to be reduced by photogrammetric techniques. If either of these methods of map update were used, the roads would still have to be field checked to update attribute information such as road names and addressing, because none of this information is present on the quadrangles or photogrammetry.

Since a field check was necessary, it was determined that differential GPS could be used to correct road locations. The use of differential GPS would also permit staff to immediately begin their work. The only limitation of the GPS approach was that the

[1] The term "map accurizing" was first coined by J. Ross Sherohman in early 1996.

positional data being collected dynamically may range in accuracies of two to five meters 95 percent of the time (double distance root mean square--2dRMS). These accuracies are about the same as the width of the roads being driven, thus the error was considered to be acceptable.

The Accurizing Process

Work commenced in the pilot area by setting up a GPS base station to collect GPS signals simultaneously with the GPS mounted on the vehicle used to drive and map the roads. The GPS data collected by the base station was used to reduce intentional error in positioning introduced by the military and other error generated by the atmosphere.

Each workday lasted between ten and fourteen hours and GPS positions were collected every two seconds. This data collection rate accumulated over 18,000 GPS positions in a long day. Four and a half days of fieldwork were conducted.

As each day's work was completed, the field data were differentially processed against the base station's observations to reduce positioning errors. Then the raw positions of latitude, longitude and heights were exported into an ASCII file for their eventual import into MapInfo.

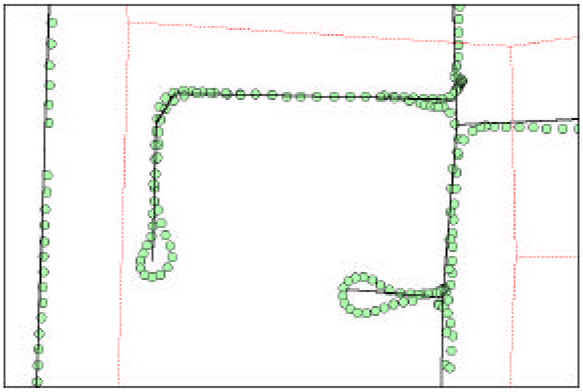

Figure 1 – GPS second-by-second positions.

At each recorded GPS position, a small circle was placed into a MapInfo workspace (see Fig. 1). The GPS positions generally followed the road locations found in the TIGER line files represented as the lighter colored roads above. Both the original road lines and the field collected GPS points can be displayed on the same map by opening each data set as a separate layer. This provided an opportunity to view the offset on the resulting map display.

Several types of map updates and corrections were required. The most commonly used map update method was to move a road intersection, which also updated most of the road network. Another type of update was an improvement in road geometry, thus improving the "shape" of the road to fit the GPS locations. A third update was the addition of new roads and connecting roads that did not connect with other road segments in the original maps.

Most of the updating consisted of moving road intersections that were offset from the recorded GPS locations. These were easily fixed by moving the road intersection node (the intersection of the roads) to the proper location. MapInfo maintained the connectivity of the road segments when making the adjustments.

The other common type of problem was inaccurately shaped roads. These problems included not enough bends or too many bends in a road. Most of the latter problems were corrected "for free" when the road intersection locations were adjusted. The other road shape problems were fixed by adding or deleting nodes and by moving nodes, thus changing the shape of the road.

In a few cases, a road segment not present in TIGER was added. Occasionally roads are shown to intersect by the GPS positions indicated by the vehicle's path of travel, but these roads did not connect in TIGER. These features were adjusted accordingly.

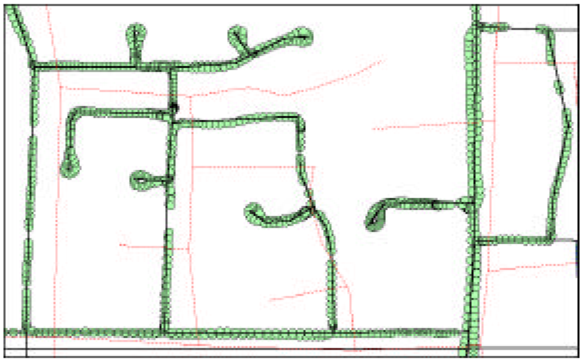

Figure 2 – GPS enhanced roads and original TIGER data.

The resulting maps (Fig. 2) showed the typical amount of position displacement between the original map and the GPS-enhanced road positions.

Displacement seen was often as large as 210 feet. Typically, however, positioning errors ranged from 70 to 110 feet, well within NMAS for digital data whose source is based on 1:100,000 scales sources. While some intersections and roads were found to be positionally accurate in the original data, these were very few.

Mapping Issues for LDT

A common problem associated with map use is the near reverence people have for mapped information. When the GIGO (garbage in, garbage out) phenomenon is applied to maps, people tend to interpret any "garbage" in the map as "gospel."[2] This is important to LDT and map-aided dispatch because dispatchers must understand the inherent errors present in all maps. It should also be understood that maps and their sources are always incomplete and out of date due to the changing real world. Most importantly, when a position is indicated on the map, the region where the LDT call could be located can be quite large, due to errors and uncertainties in the positioning technologies.

The technologies used in LDT can determine a position of a wireless call, but the accuracy of the position must be properly interpreted. Like all mapping and positioning technologies, the term accuracy means how closely repeated measurements of the same feature can be made. Accuracies in mapping are expressed in statistical terms that assume that position measurements fit a normal distribution (bell curve). Therefore, one may state that half of the observed positions may be within a specified accuracy. One standard deviation (root mean square or RMS), which represents about 65% of the observed positions is another statement of positioning confidence. The second standard deviation (double distance root mean square or 2dRMS) represents a 95% confidence in the accuracy of the positioning.

Presently, LDT positioning is estimated by manufacturers to be within 125 meters RMS. This means that one third of the 9-1-1 wireless calls may have positional accuracies worse than 125 meters. This level of positioning confidence is about the length of a city block. Because of the statistical nature of these measurements, there could be a percentage of locations for 9-1-1 wireless calls that could also be more accurate than a few feet. Thus, statistics can be used to predict accuracies, but should not be depended on as a guarantee of a result.

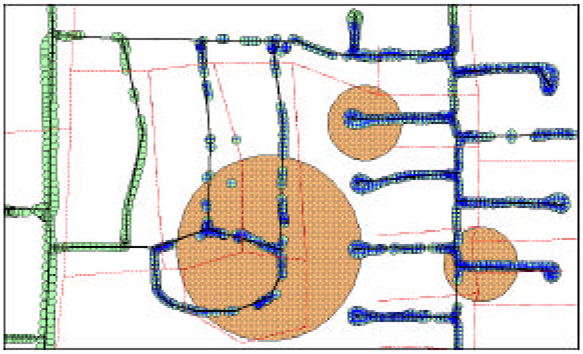

Figure 3 – Depicting 125 meter and 40 meter RMS circles.

Two types of positional accuracies should be considered when using an LDT to map emergency calls. The first is the positional accuracy of the map and the second is the positional accuracy of the location reported by the LDT. Mapping accuracies have been rapidly improving over the past ten years and LDT positioning is also likely to improve considerably with its use. LDT positioning of about 40 meters RMS seems to be quite possible with today's technology and will likely improve quickly.

The WIP Map and Human Factors

Several issues must be considered when displaying the computed position of the cellular 9-1-1 call. The most important issue is that the map is an information communication tool. The objective of the map is to unambiguously communicate information quickly to minimize human interpretation error.

One of the communication problems with the original TIGER data used in the trial was the poor positional accuracy and inaccurate shape of many roads. Reducing the geometric and spatial inaccuracies improves the human interpretation of the map.

Another key to the proper use and interpretation of the map should be a determination of the scale at which the map is to be presented. Many problems with map positioning are simply overcome by decreasing the scale of the map. Decreasing map scale presents a larger area for viewing and hides

[2] "Garbage In – Gospel Out" was coined in 1989 by Richard Friedman, of McKinley County, NM.

positioning error via the map symbolization process. This technique minimizes the apparent error in TIGER and its random road changes in the GBF-DIME areas. Remember that TIGER was derived from a map source whose presentation scale is one inch to 1.56 miles.

Elementary cartographic display for emergency dispatch is another issue that has not been researched. Basic information is needed to define cartography standards to improve human-map interaction, error abstraction, symbology, and eyestrain reduction.

Mapping Resolution and Error Budget

When building a map, especially a digital map, the scale (level of inherent mapping inaccuracy) of the mapping source must be remembered. The mapping accuracy of raw TIGER data used was approximately 166 feet for about 90% of the features and the accuracy of the GPS points dynamically collected to the WIP trial was 15 to 21 feet. Thus maps should not really be used for any applications requiring any greater degree of positional accuracy. Digital mapping technologies lure people ignorant of numeric and error analysis into believing that a map can be successively magnified while maintaining the same mapping accuracies and usefulness. This tends to be a problem with experienced map users and is certainly a difficult concept for mapping novices to understand.

The mapping resolution and error budget required for an efficient LDT are likely to be a few meters. This implies that the accuracy of the map should be about the same. However, when one considers that the typical 9-1-1 emergency call is likely to be made from a car or house, this requires resolution and mapping accuracy on the order of about three to five meters. Since emergency dispatch calls are being referenced to a road map, the required resolution then climbs to the width of the road or size of a home, which usually ranges from seven to twenty meters.

These accuracies are perfectly acceptable outdoors. More accurate mapping and LDT information may be required if one wishes to dispatch to a complex indoor location like an apartment, shopping mall or office. In these cases we are no longer dealing with a digital map, but with much more detailed drawings and floor plans, thus requiring much more expensive databases.

Maps created for LDT can thus have a mapping resolution ranging from five to ten meters which means the level of mapping error, or budget, which is acceptable can be on the same level.

Map Coordinate Systems

One of the most intriguing issues faced by the display of an LDT position on a map is the question of mapping projections. Mapping requires a coordinate system that is used to reference the locations of mapped features. Mapping coordinate systems are selected to minimize different types of mapping errors. Some types of mapping errors include coordinate systems designed to preserve the true shape of features, while others preserve true area and distance measurements of features.

The coordinate system to reference features on the Earth is a spherical coordinate system called latitude and longitude. However, when a map is made, the spherical coordinates must be translated into a planar coordinate system via a process termed projection. Planar coordinate systems are used for most mapping because the mathematics are simplified to plane trigonometry. Projecting spherical coordinates of latitude and longitude into a flat x,y coordinate system causes certain distortions to occur in the data being mapped. MapInfo uses latitude and longitude coordinates that are projected into a cylindrical projection called Mercator. This coordinate system causes distance measurement errors and distortion of shape the further the place being mapped is north of the equator.

When mapping small regions, such as a county or city, a local plane coordinate system is often preferred, such as the State Plane Coordinate System (SPCS). SPCS is well-suited for accurate distance measurements and is the choice of many surveyors. The map coordinate accuracy of SPCS is about one foot in 15,000 feet for distance measurements. However, SPCS is not easily extended over large regions because of the curvature of the Earth (one foot of drop in 300 feet of distance), which causes distance measurement errors to begin to accumulate. Therefore, the SPCS uses several zones to map larger regions such as a state. When one crosses from one zone to the next, the mapping coordinate system is likely to change, thus counties bordering a different zone will have different coordinate systems and different methods of projection. This adversely impacts dispatch based on LDT generated coordinates because the projection and coordinate system for each county or region must be known before coordinates can be projected.

Another commonly used map coordinate system is the Universal Transverse Mercator (UTM). UTM is similar to SPCS but the zones are larger, and more importantly, the coordinate system is continuous from zone to zone. Features mapped in one zone can thus be easily referenced to features mapped in another zone. The distance measurement accuracy is more coarse than SPCS (about one meter accuracy), but perfectly acceptable for 9-1-1 dispatch. UTM is a less popular coordinate system than SPCS among surveyors, but is much better suited to the layperson because of its superior human interface to determine map locations. UTM coordinates are also easier for a layperson to reference on a paper map than latitude and longitude.

The FCC's mandate for location display of wireless callers calls for the use of latitude and longitude as the standard coordinate system. National Emergency Number Association (NENA) standards have defined the size and format for these coordinates. Mapping software applications generally supply the capability to translate latitude and longitude to the locally preferred coordinate system. The user must be aware that all projections are not alike and should consider this when planning for display of the location information at the PSAP.

Summary

The Wireless Integration Project provided an opportunity to examine the interface between mapping and LDT to locate emergency calls. The first requirement of wireless mapping is improved base mapping accuracy.

The WIP has also indicated that many more directions of research are required before dispatch mapping standards can be specified for wireless call tracking. There should also be standards defined for acceptable levels of mapping accuracies (“error budgets”) for both LDT wireless call calculations and the digital mapping files. Human factors issues require research to determine how dispatchers can best utilize mapping for emergency call management.