SOUTHERN ILLINOIS GIS MAPPING FOR NEXT GENERATION 9-1-1

BASED ON NENA STANDARD DATA FORMAT

By

William Barrett

B.S., Southern Illinois University – Carbondale, 2010

A Thesis

Submitted in Partial Fulfillment of the Requirements for the

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Approved by:

Dr. Guangxing Wang, Chair

Dr. Matthew Therrell

Dr. Tonny Oyana

Graduate School

Southern Illinois University Carbondale

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William Barrett, for the Master of Science degree in Geography and Environmental Resources, presented on November 5th 2012, at Southern Illinois University Carbondale.

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MAJOR PROFESSOR: Dr. Guangxing Wang

Next Generation 9-1-1 (NG 9-1-1) will revolutionize how the public accesses emergency services and will alter the technological landscape within which existing public safety agencies operate. A lack of systematic methodologies exists for quality control of the required geospatial data layers for NG 9-1-1 systems. The primary objective of this study was to develop and systematize a highly accurate NG 9-1-1 GIS database for Counties of Southern Illinois (CSI). The project goals included mapping relevant geospatial data layers required by and based on NENA standard data formats; conducting data quality control and standardization; and providing standardized spatial datasets for NG 9-1-1 to relevant stakeholders. The approach was developed using a conceptual model for error and uncertainty analysis of the GIS-based NG 9-1-1 system. This included the identification of various sources of input uncertainties often associated with spatial data layers; modeling the accumulation and propagation of errors; analyzing their impact on the quality of the spatial data layers; and correcting the errors. Modeling uncertainty propagation focused on positional errors and was conducted through a simulation procedure. The results showed that the original spatial datasets possessed a large account of uncertainties, especially location errors of railroads and roads. The errors had different sources, including input map errors, the use of different map projection and coordinate systems, a lack of topological structures, etc. In addition, they varied from county to county. From the error propagation simulation, it was also found that the location errors measured as root mean square error (RMSE) fluctuated when the perturbed distance of the ground control points (GCP) was less than 15 m. After that, the RMSE increased as the perturbed distance of GCPs increased. This relationship was significantly linear. In addition, the location errors from railroads were larger than those from roads.

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LIST OF ACRONYMS

NG	Next Generation
ESN	Emergency Service Numbers
PSAP	Public Safety Answering Points
CSI	Counties of Southern Illinois
NENA	National Emergency Number
APCO	Association of Public Safety Communications Officials
USDOT	U.S. Department of Transportation
IETF	Internet Engineering Task Force
ACN	Automatic Crash Notifications
GPS	Global Positioning System
UTM	Universal Transverse Mercator
ETSB	Emergency Telephone System Board
CAD	Computer Aided Dispatch
UTM	Universal Transverse Mercator
GPS	Global Positioning System
USGS	United States Geological Survey
SDTS	Spatial Data Transfer System
ALI	Automatic Location Information
MSAG	Master Street Address Guide
ESZ	Emergency Service Zones

CHAPTER 1

INTRODUCTION

BACKGROUND

For the last few decades, 9-1-1 has been known as the number to dial in emergency situations across America. This number has provided an invaluable service to numerous citizens who have found themselves in need of fire, police, or medical assistance. In the last few years, communications technology has become more and more sophisticated and has offered users a wide variety of methods in which to stay connected (e.g. voice, text, video, & picture). Emergency service agencies must keep up and be able to respond to these technologies. Next Generation 9-1-1 (NG 9-1-1) will revolutionize how the public accesses emergency services and will alter the technological landscape within which existing public safety agencies operate. NG 9-1-1 requires specific address information in the form of spatially geo-referenced datasets or maps, typically including Emergency Service Numbers (ESN), Public Safety Answering Points (PSAP), structures (9-1-1 information address point layer), cell towers, roads, railroads, mile markers, lakes/streams, city and county boundaries, etc. In Southern Illinois, several county agencies have begun taking steps necessary to ensure that they are prepared to receive communications in these various formats. These counties have formed a not-for-profit organization, known as Counties of Southern Illinois (CSI), and are working together to establish a Next Generation system with multiple redundancies. Each county has developed the required datasets mentioned above, but many are incomplete. In addition, many have different map projections and coordinate systems. They also contain different data format standards with inconsistent data quality controls that are not compatible with National Emergency Number Association (NENA) standards. These differences will lead to uncertainties within NG 9-1-1 systems. The standardization, accuracy assessment, and quality control of the geospatial datasets is thus critical in the development of NG 9-1-1 systems so that the information is accurate and can be shared between counties, allowing it to come together seamlessly to ensure public safety.

SIGNIFICANCE OF THE STUDY

Today's 9-1-1 systems in the state of Illinois are built, operated, and maintained locally, usually by counties. Only recently has there been any federal involvement in 9-1-1 matters, and there has never been any interconnection among 9-1-1 systems to allow the transferring of calls. Experts in the 9-1-1 community have realized that today's systems need a considerable advance in order to continue to efficiently handle today's level of traffic and to meet the new technological requirements of the future. The system will need to handle video, photos, and text, and have the ability to transfer 9-1-1 calls among communication centers. There are several major agencies who are working on NG 9-1-1, including NENA, the Association of Public Safety Communications Officials (APCO), the U.S. Department of Transportation (DOT), and the Internet Engineering Task Force (IETF). It is imperative that these agencies share the standards, methods, communications, and datasets.

The overall project for improvement, Next Generation 9-1-1, involves many aspects and topics. These include: i) Standardizing the underlying technology of the group called CSI, LLC using IP technology and Internet-based communication links; ii) Creating two mirrored data centers for handling calls--one in Jackson County and the other in Saline County; iii)

Interconnecting PSAPs to allow the unlimited transfer of calls, the distribution of overflow 9-1-1 calls, and other call-handling features; iv) Allowing the system to accept and handle advanced information from citizens, including video, photos, text messages, etc. There also needs to be a component that allows for interconnecting with private services, such as telematics providers, to handle automatic crash notifications (ACN) and other similar data.

The significance of this project is that it works to integrate and standardize geospatial data from each 9-1-1 entity's GIS. In addition, it provides quality assurance of this data to meet accuracy standards and makes it possible to bridge the gaps that currently exist so that the NG 9-1-1 system will be greatly advanced, both theoretically and practically.

RESEARCH STATEMENT

New communications devices that are wireless and IP-based are being produced at a rapid rate. These devices offer text and video messaging capabilities that provide the potential for emergency agencies to accelerate responses to incidents. Unfortunately, the existing 9-1-1 system was never intended to receive calls and data from these types of technology. As a result, it must experience a significant overhaul in order to remain effective.

Scientifically, a lack of systematic methodologies exists for quality control of the required geospatial data layers for NG 9-1-1 systems. This study will develop a conceptual methodology and thus, to some extent, bridge some of the significant gaps that currently exist. Through this study, the author intends to answer the following questions:

RESEARCH QUESTIONS

i) What are the minimum map quality requirements for a NG 9-1-1 system?

ii) What are the major uncertainty sources of the existing geospatial data layers?

iii) How do location errors affect the quality of the maps, and is there a threshold value of location errors that significantly decrease map accuracy?

iv) What is the best systematic methodology for conducting quality control of data layers across the 9-1-1 system created by CSI?

CHAPTER 2

LITERATURE REVIEW

QUALITY CONTROL & ERROR SOURCES

Data quality control and standardization are critical for the development of geospatial datasets within GIS and for their application in environmental management, transportation, and emergency response systems such as 9-1-1. The decisions that 9-1-1 system managers make are often based on "maps" which show spatial information, spatial patterns, and distributions of relevant objects and variables, including the relationships between them. The data should be accurately geo-referenced and positioned, clearly visualized, and easily updated. However, GIS map products are frequently generated using a variety of different methods and multiple sources of data. Among these are field measurements and derived data sets, including those taken from remotely sensed images. This means that most of the values used are estimates of the variables, and therefore, have associated errors and uncertainties (Crosetto and Tarantola, 2001; Goodchild and Gopal, 1992; Gertner et al., 2002a; Heuvelink et al., 1989; Lanter and Veregin, 1992; Lilburne and Tarantola, 2009; Lunetta et al., 1991; Wang et al., 2005). The map products thus possess multiple sources of uncertainty that may vary spatially and temporally. When management decisions are made using the maps, the users potentially face risks because of these uncertainties. Quality control and standardization of the map products are both critical for decision-making.

Error means the difference of a measured or computed value from its true or theoretically correct value of a variable (Longley et al. 2011). Uncertainty implies the lack of certainty and is considered as a measure of the difference between the contents of a dataset and the real phenomena. Uncertainty is usually represented using a set of possible states with probabilities assigned to each possible outcome. In practice, the correct value is known in very few cases and a value that has higher accuracy is thus often used as its reference.

Errors in GIS products can be grouped into inherent and operational errors or into position and thematic errors (Khorram et al., 1999; Pontius, 2000 and 2002; Walsh et al., 1987). The inherent errors include those related to source data (e.g. the use of different map projections and coordinate systems, different data formats, etc.) Operational errors are often introduced during data collection or during its input, processing, manipulation, and analysis. Additionally, editing errors, errors due to map overlap, and merging or mosaic-ing, as well as sampling errors, and other measurement errors are common.

On the other hand, thematic errors mean the differences between the map values and observations of an interest variable, while position errors deal with the movement of true locations of objects caused by incorrect positioning of a global positioning system (GPS), map projections, geometric referencing of images or maps, etc. (Pontius, 2000 and 2002). The position errors in turn result in thematic errors. The inaccuracy from ground control and geometric rectification of map coordination leads to position errors (Wang et al., 2009 and 2011). Position errors can be caused by inaccurately locating the field plots used to collect ground data and the ground control points used to geo-reference remotely sensed images using global positioning system (GPS) technology. Geometric errors often occur when images and maps are geo-referenced to projected coordinate systems such as Universal Transverse Mercator (UTM). Incorrect transformations of map projection and coordinate systems result in position errors. Position errors are also due to the inaccurate digitizing of thematic maps. Position errors shift the maps in GIS and result in serious problems in 9-1-1 emergency systems.

Lunetta et al. (1991) systematically discussed the sources of the errors and uncertainties, and suggested priorities for error quantification research topics. Moreover, Davis et al. (1991) developed a flow chart for analysis of potential errors and uncertainties from ground and survey measurements to a map. GIS mapping is a complex process including data collection and processing, geo-referencing, symbolization, data representation and generalization, model development and prediction, etc. During the operations, subjective and objective errors and uncertainties are inevitably created and propagated into the final maps. Some of them may accumulate in the maps and others may be cancelled out. The accuracy of the output map can only be as accurate as the least accurate individual layers.

ERROR AND UNCERTAINTY ANALYSIS

Quality assessment of GIS maps can be conducted using uncertainty analysis and sensitivity analysis (Arbia et al., 1998; Crosetto and Tarantola, 2001; Heuvelink et al., 1989; Heuvelink and Burrough, 1993; Heuvelink, 1998; Lanter and Veregin, 1992; Lilburne and Tarantola, 2009). In uncertainty analysis, the uncertainty propagation from inputs to outputs through mapping systems is modeled and assessed, while in sensitivity analysis, the output uncertainties of the mapping system are apportioned into different components of the input uncertainties.

Several authors have proposed methods that can be used to improve data quality control through error and uncertainty analysis, including identifying error sources, modeling error propagation, and calculating contributions of input errors to the uncertainties in the output maps (Congalton and Green, 1999; Goodchild and Gopal, 1992; Heuvelink, 1989 Walsh et al., 1987; Wang et al., 2005). For example, Pontius (2000, 2002) proposed a method to identify and quantify location and quantity errors for a categorical map. Lanter and Vergin (1992) suggested a research paradigm for error and uncertainty propagation in layer-based GIS. Wang et al. (2005) proposed a general uncertainty analysis framework in which the accumulation and propagation of input errors are modeled and their contributions to the output uncertainties are calculated. Crosetto and Tarantola (2001) and Heuvelink (1998), and Lilburne and Tarantola (2009) also emphasized the general framework of uncertainty and sensitivity analysis. Especially, Gertner et al. (2002) and Wang et al. (2011) developed a polynomial regression in which the relationship of the uncertainties of an output map with various input errors is modeled and apportioning of the output uncertainties into the input components is then conducted. These methods can be applied to the quality control of the geospatial datasets required by a NG 9-1-1 program.

STANDARDIZATION & GIS IN EMERGENCY SERVICE

NENA has published national standard data formats that can be used as guidelines for the designers and manufactures of systems for processing emergency calls from any device (9-1-1). The goal of this standard is to give every Emergency Telephone System Board (ETSB) in the nation the ability to develop new map products that they are able to share with other public safety agencies.

GIS is a computer-based system that is designed and used to collect, store, analyze, manage, and display spatially geo-referenced data and their attributes (Lonley et al. 2005), and it provides great potential to accurately position objects and standardize spatial data layers. Using GIS in emergency service has been a major topic of discussion for many years. Remembering that new products drive changes in the 9-1-1 world (Innes 1992), planners that are working toward NG 9-1-1 must understand GIS. There will be a major investment in GIS over the next few years. It is a powerful tool for emergency management (Ertug 2000). The future of 9-1-1 has many things to do with GIS, including disaster forecast, vulnerability analysis, damage assessment, and personnel resources deployment, etc. With GIS, there is a way to understand and manage the size of the data, and there is a method by which a standard operating procedure (SOP) can be put into place. GIS technology gives people the ability to have much more data than before. The State of Vermont was able to put a statewide 9-1-1 system in place in 1994 (Westcott 1999). GIS was a big part of the project. The manner in which they were able to implement their 9-1-1 system on a large scale should provide valuable insight to this project.

Ontology plays an important role in how standardization and GIS in emergency service is managed. Inter-operability is a concern in emergency service. Geographic information that is processed from different information sources must be able to work together. Ontology began as a philosophical tradition but has found widespread application in many diverse disciplines (Agarwal 2005). Ontology is used in one way to give a clear understanding of vocabulary. If sharing geospatial information across disparate systems and designs is going to be successful, an in-depth study of the current research on metadata and semantics needs to be conducted. One way to look at this is through ontology. (Arpinar et al 2006)

CHAPTER 3

MATERIALS AND METHODS

STUDY AREA & DATASETS

The proposed CSI study area consisted of 23 counties in Southern Illinois, including Alexander, Clay, Edwards, Franklin, Gallatin, Hamilton, Hardin, Jackson, Jefferson, Johnson, Marion, Massac, Perry, Pope, Pulaski, Randolph, Richland, Saline, Union, Wabash, Wayne, White, and Williamson (Figure 1).

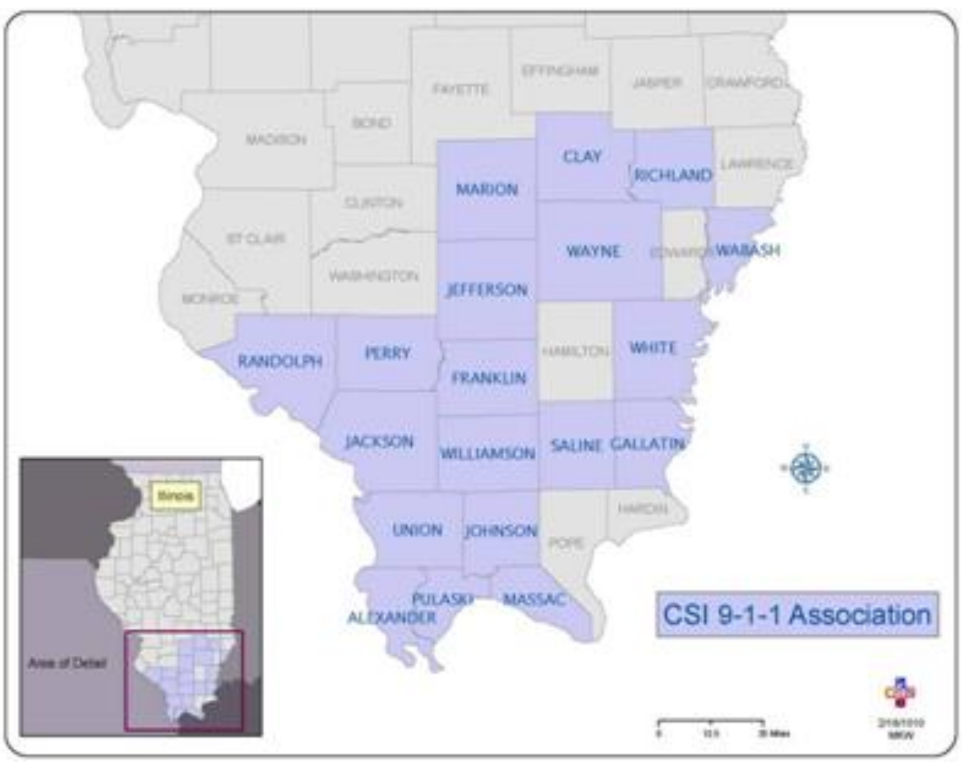

Figure 1: Study Area: 23 Counties of Southern Illinois.

Existing datasets included the necessary map layers of ESN, PSAP, structure, cell tower, road, railroad, mile marker, lake/stream, and city and county boundary for all of the counties. Table 1 shows, in tabular format, sample data which can be represented and used in Figures 1-3.

Table 1: Emergency Service Number (ESN) Data for Williamson County, Illinois

ESN	NAME	FIRE	LAW	MEDICAL
751	Rural Makanda	LAKE /MAKANDA-S	WCSO	LAKE
756	Prison	WCFPD /LAKE	PRISON	LIFELINE
755	Primex	HERRIN/ LAKE /WCFPD	WCSO	LAKE
753	SIU	CARTERVILLE	SIU /WCSO	CARTERVILLE
734	John A Logan College	CARTERVILLE	LOGAN	CARTERVILLE
729	Rural Cambria	WCFPD/CAMBRIA	WCSO	CAMBRIA
750	Lake of Egypt	LAKE/ WCFP-S	WCSO	LAKE
748	Rural Creal Springs	WCFPD/ LAKE-S	WCSO	LAKE
761	Primex Test Range	WCFPD MARION	WCSO	WCA
747	Rural Stonefort	WCFPD/ STONE-S	WCSO	WCA
726	Hurst	HURST	HURST	HURST
727	Bush	BUSH/HURST	WCSO	HURST

Figure 2 provides information regarding the datasets that are important to emergency management agencies. The ESN is a polygon layer showing who the appropriate responder would be for that area. For example, if there was a fire in the northern right corner of Figure 2, the New Burnside Fire Department would respond. Many of the datasets belonging to the aforementioned counties were incomplete.

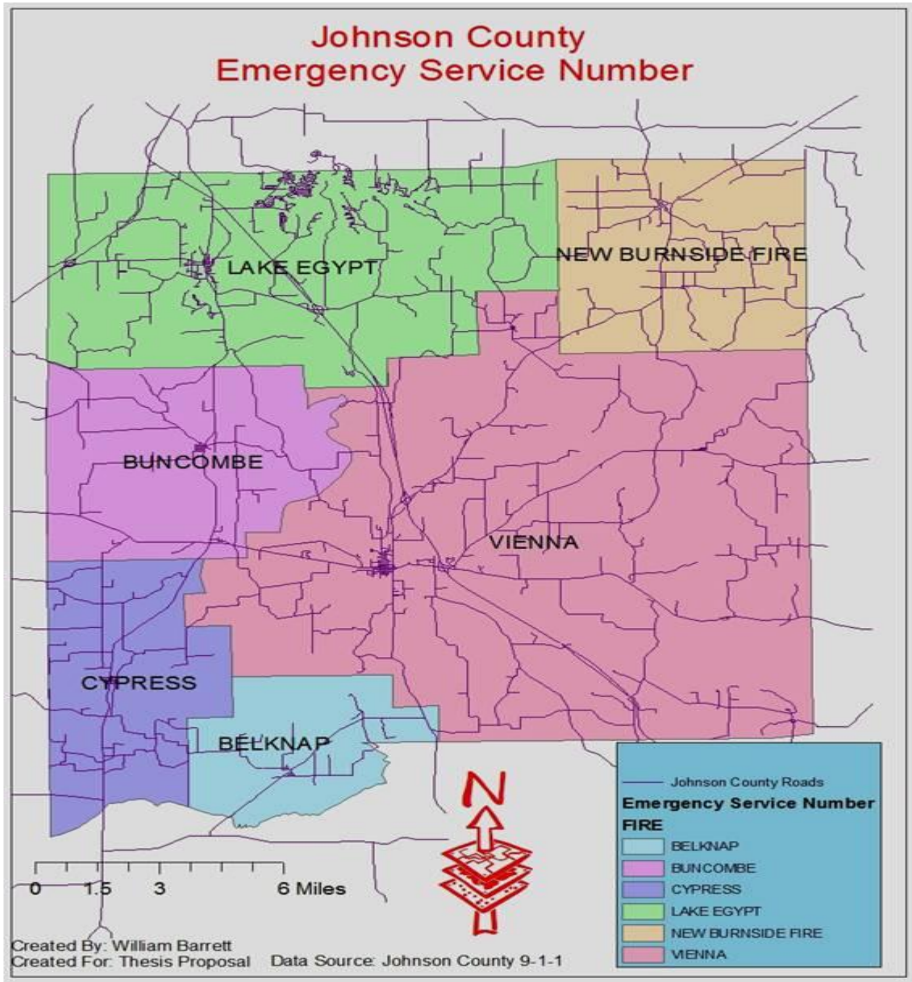

Figure 2: Emergency Service Number Map for Johnson County, Illinois

For example, in Franklin County, there were significant location errors of the roads due to different map projections (Figure 3). The community field was incomplete, and many 9-1-1 address points were missing. In Gallatin County, some roads were not split at intersections. In Saline County, ESN and community fields needed to be populated. White County needed GIS data and ESN layers. In Williamson County, roads were not split at intersections (Figure 4). The NENA standards and data format were used to standardize the spatial datasets required for NG 9-1-1.

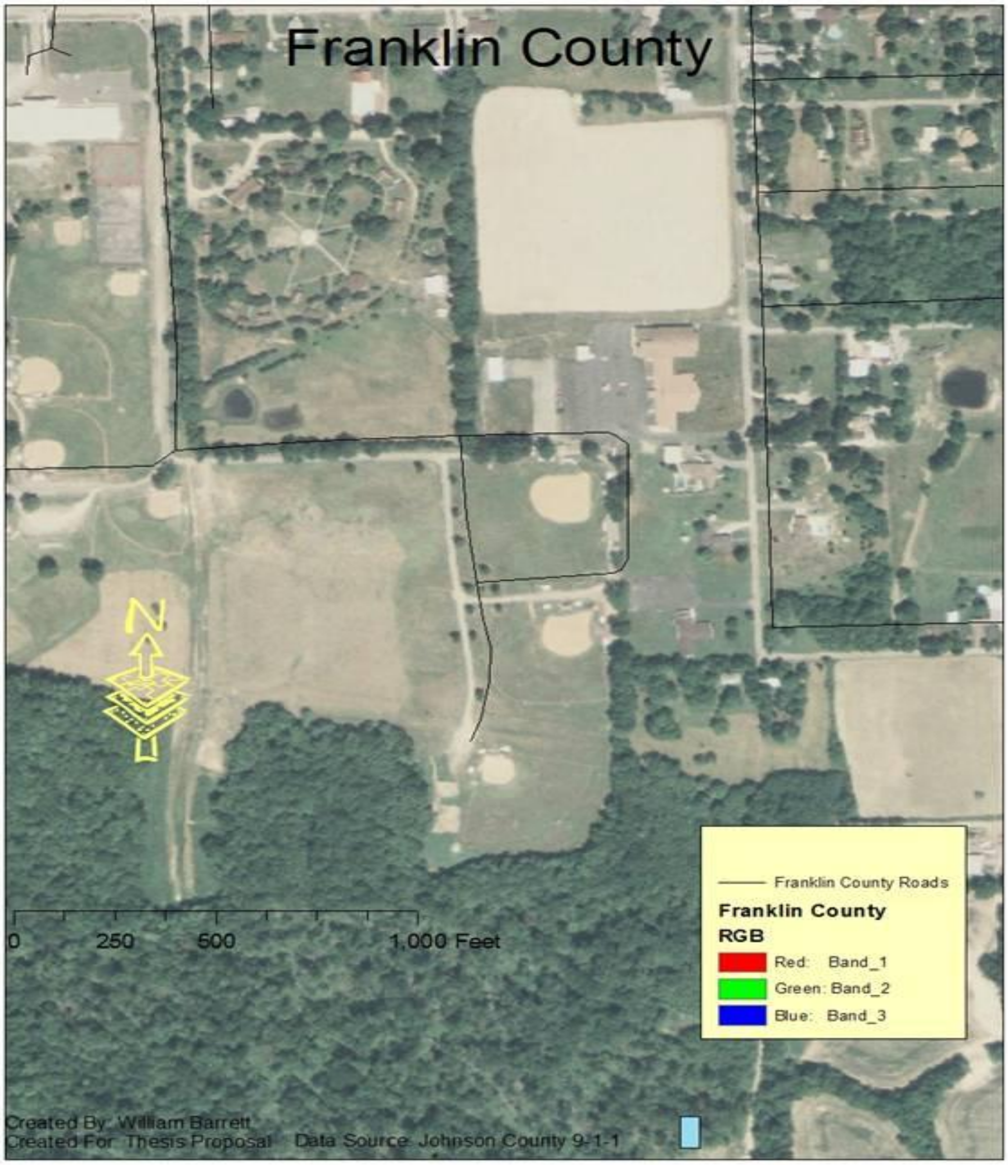

Figure 3: Road Location Errors Due to Different Map Projections for Franklin County, Illinois

The aerial photo (Figure 4) shows Jackson County. This digital photo consists of three bands including blue, green, and red with a spatial reference of NAD 1983 UTM Zone 16N and a

1 meter spatial resolution. An aerial photo was used for each county in this study and all the aerial photos came from the same source and were taken in 2007 by USGS (Geological Survey).

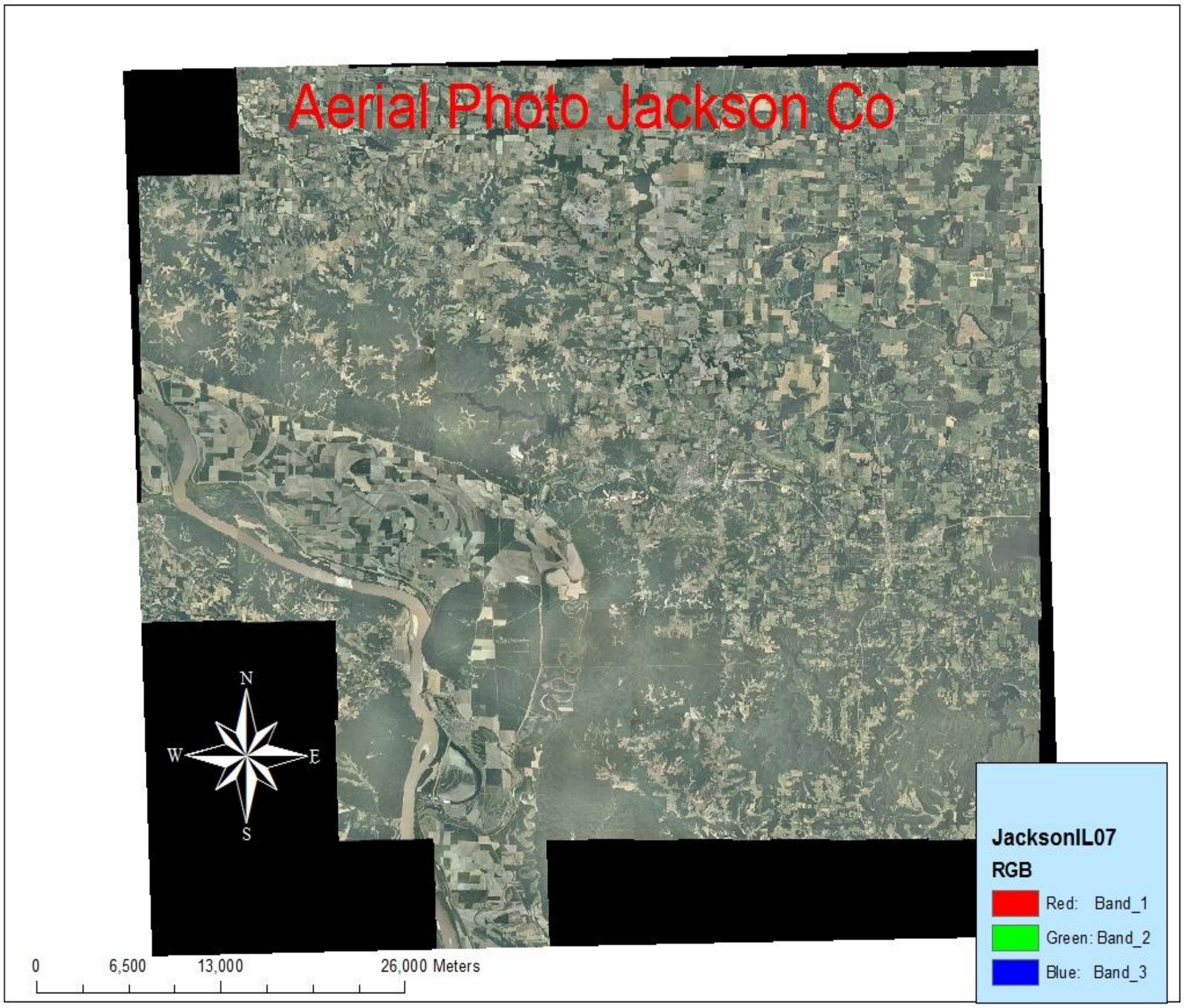

Figure 4: Composite Image from Three Bands (Blue, Green, and Red) of an Aerial Photo in NAD 1983 UTM Zone 16N with a 1 Meter Spatial Resolution

A total of more than 200 ground control points (GCPs) (road intersections) were collected using a Global Positioning System (GPS) within the study area (Figure 5). The GCPs were evenly distributed within the study area. At least 5 GCPs were measured for each county. These points were used to geo-reference the spatial datasets, including images and maps, to WGS84 UTM and were also employed for assessment of the geometric correction. The GPS unit used for this study was a Magellan eXplorist XL. The receiver on this device has a 14 parallel channel that tracks up to 14 satellites to compute and update information. The update rate is 1 second continuous with an accuracy of 7 meters, 95% 2D RMS (root mean square) w/WAAS/EGNOS < 3 meters, 95% 2D RMS. The accuracy of the GPS unit was tested in the field by collecting the x- and y-coordinates of 30 GCPs with a time of at least 3 minutes and it was found that there was an average of a 4 meter error.

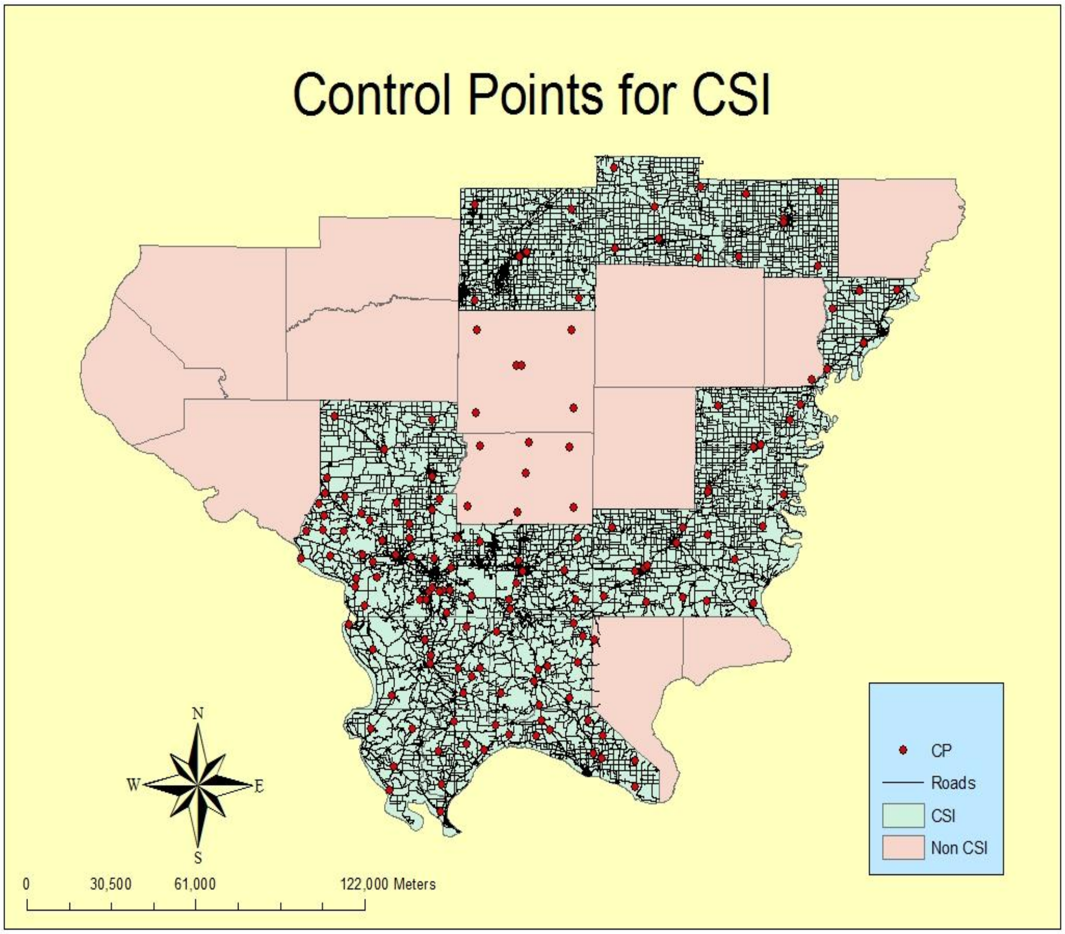

Figure 5: Ground Control Points Collected Using GPS for the Study Area

METHODS

In this study, a conceptual model for error and uncertainty analysis of the GIS-based NG 9-1-1 system was proposed (Figure 6). This model outlined the procedure and methods of error and uncertainty analysis. These included the identification of various sources of errors that are associated with the spatial data layers; modeling the error propagation; analyzing their impacts on the quality of the spatial data layers; and correcting the errors.

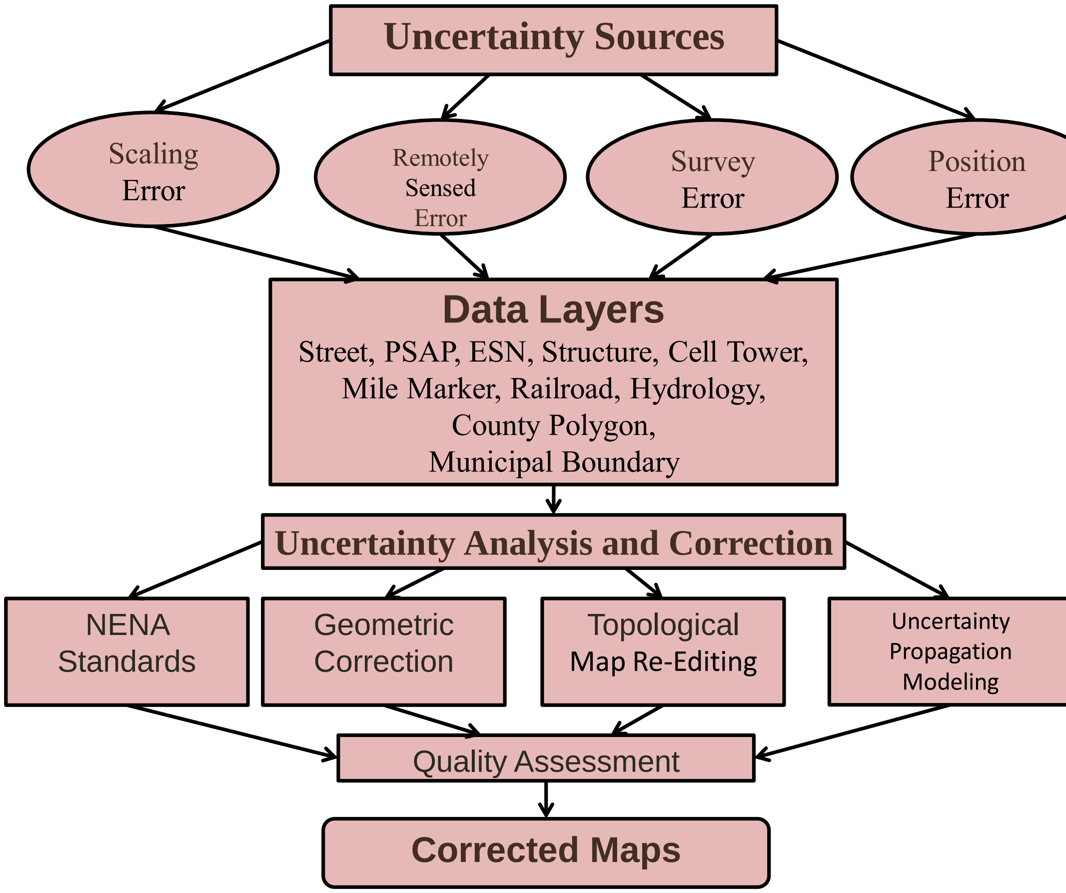

Figure 6: A Conceptual Model for Error and Uncertainty Analysis of a
NG 9-1-1 GIS System

Many sources of errors exist (Figure 7) including errors in sampling, measurement, map projection, data conversion, digitizing, overlapping, classification, geometry, etc. These errors were divided into inherent errors and operation errors or into positional errors and attribute errors. Because a NG 9-1-1 system requires that object locations are significantly accurate, this study concentrated on positional errors. In addition, focus on the consistency and standardization of geospatial data was a requirement for data and information sharing, exchange, and merging.

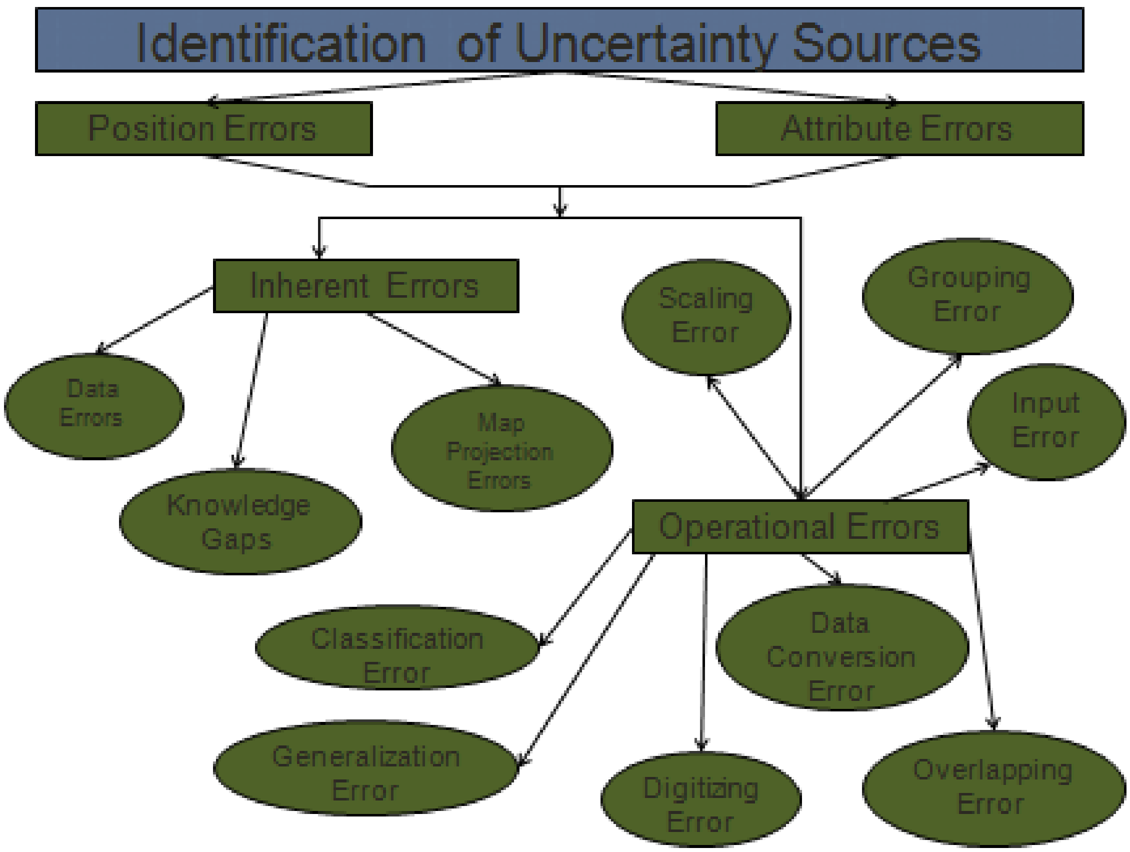

Figure 7: Error and Uncertainty Sources of Geospatial Data Layers for a NG 9-1-1 System

The positional errors led not only to the incorrect location of objects on the surface of the Earth, but also to uncertainties of attributes. Some of the errors may be cancelled out, and others may accumulate and be propagated to the output maps. The uncertainties may be minor or very large depending on the amount of the input errors. The output uncertainties can result in mistakes in decision-making and possibly delay responses to emergency calls.

In this study, an uncertainty and error analysis was conducted. That meant that particular steps were followed, including the identification of various sources of input uncertainties, the modeling their accumulation and propagation, and quantification of their impacts on the quality of output maps. (Figure 7) (Wang, 2011). The uncertainty analysis looked at the quality assessment of maps with a focus on errors that result from such things as the inconsistency of definitions, data structures and formats, map coordinate systems, and positional errors. NENA standards and data formats were then used to standardize the spatial datasets required for the NG 9-1-1 system. This study followed the defined GIS data formats and models to define geospatial variables, create data structures, and produce geospatial data layers. The standards included minimal attributes, attribute structures, data types and precision, consistent map projections and coordinate systems, datum, geocoding method, etc. Following these formats greatly mitigate map errors and improve opportunities for data sharing, exchange, and merging. The map quality assessment was conducted, and the results were compared before and after the standardization.

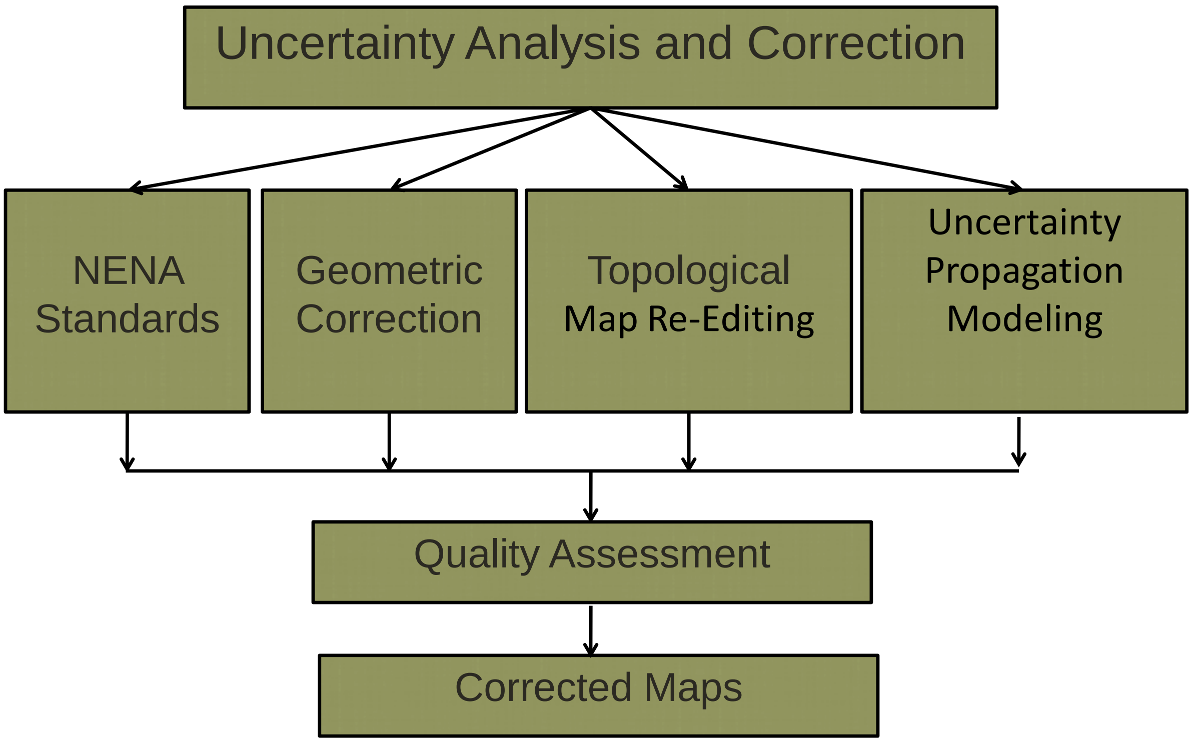

Figure 8: Uncertainty Analysis and Quality Control of Geospatial Data Layers for the NG 9-1-1 System

The positional errors of geospatial data layers deal with shifts of objects (points, lines, and polygons) from their true locations and are mainly caused by such things as different map projections and coordinate systems, digitizing errors, mismatches, etc. The reduction and correction of positional errors can be made by geometric correction and topological editing of geospatial data layers, respectively. (Figure 8) For geometric correction and the assessment of location errors, a large sample consisting of more than 200 locations was surveyed within the study area using GPS technology. This included 85 PSAPs, 9-1-1 information address points, and 115 road intersections used as GCPs. There were 5 GCPs within each county. This study utilized WGS84 UTM as the base for map projection and the coordinate system. The 115 GCPs, or road intersections, were used to geo-reference all the geospatial data layers. The 85 PSAP 9-1-1 information address points were employed to assess the quality of the data layers.

The root mean square error (RMSE) of X- and Y-coordinates was calculated for the assessment of location errors using the following equation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left\{(x_i - x_{io})^2 + (y_i - y_{io})^2\right\}}{2n}} \quad (1)$$

Where x_{io} and y_{io} are the column and row coordinates of original input maps or those before geometric correction. The x_i and y_i are true x- and y-coordinates of information address points or GCPs (Jensen 2005).

Moreover, topological editing of the geospatial data layers was conducted after the geo-referencing of images and maps using different perturbed distances. The topological editing process included corrections of overshoots, undershoots, dangling segments, sliver polygons, etc., through rubber-sheeting. The idea behind the editing was to use the topology to create a vector data model (including no duplicated nodes and line segments), unique identification of all polygons, defined adjacency relationships between polygons, and the use of a geo-relational model.

Modeling uncertainty propagation focused on positional errors and was conducted through a simulation procedure. Jackson County was used as a case study for this modeling. The simulation procedure consisted of two parts: the simulation of different GCP location errors for the geometric correction of maps and topological editing. Several perturbed distances for the location errors, including 1m, 2m, 5m, 10m, 20m, 30m, 40m, 50m, 100m, 300m, 500m, and 1000m, were used for geometric editing (Figure 9). For each given perturbed value, the map editing and error corrections were done and the quality of the resulting map was assessed using GCPs.

In Jackson County, 30 GCPs were collected using GPS. Out of them, 10 were used for geometric corrections of maps and the other 20 were employed for an assessment of map quality. The locations of 10 GCPs were randomly moved within each of thirteen different distance intervals including 1m, 2m, 5m, 10m, 15m, 20m, 30m, 40m, 50m, 100m, 300m, 500, and 1000m (Figure 9). Randomly moving the location of a GCP within a given distance interval meant that the X- and Y-coordinates of the GCP were changed. The amounts of the changes were determined using random numbers with the maximum amount corresponding to the given distance interval. Furthermore, the changes in direction of the X- and Y-coordinates were determined by randomly choosing -1 and 1. For a given moving distance of the GCPs, the geometric correction of maps was conducted and the quality of the resulting map was assessed using the 20 GCPs.

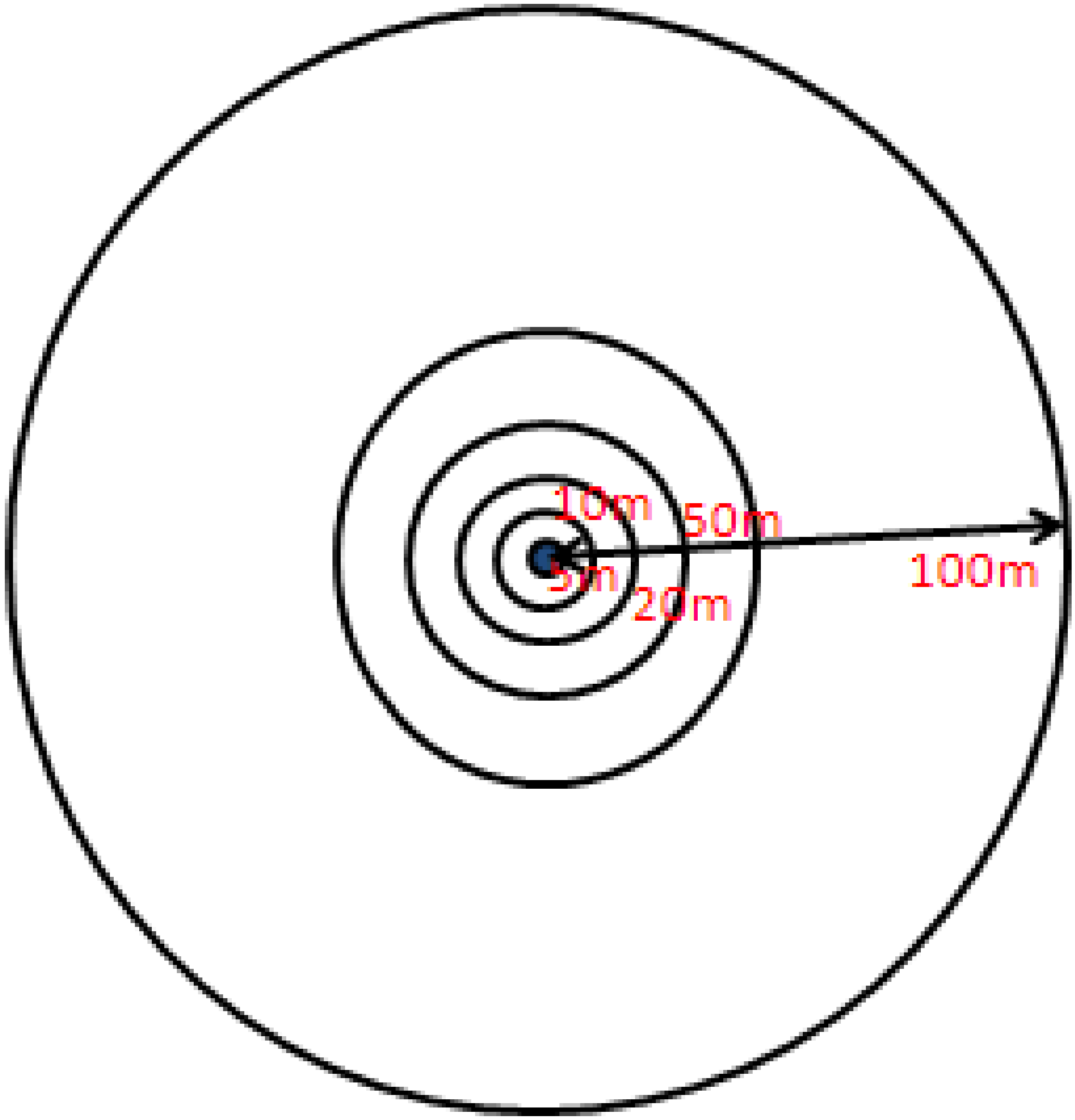

Figure 9: Simulation of Location Errors for Ground Control Points by Randomly Moving Their Locations at Different Distances

The above thirteen perturbed distances were used for topological editing and geometric correction to model. The propagation of location errors formed various combinations of input uncertainties. It was assumed that the errors in the input were propagated to the output maps. For each combination, the map quality assessment was done and the corresponding RMSE was obtained. A polynomial regression model was then developed and used to build the linkage of the input location errors with the output uncertainties (RMSE):

$$OU_{map} = f(IU_{GCP}, IU_{TDT}) \tag{2}$$

Where OU_{map} is the output uncertainty of the resulting maps, IU_{GCP} and IU_{TDT} are the input uncertainties of GCPs' locations and geometric editing of perturbed distances. Modeling error propagation means measuring the impact of uncertainty from input errors on the results of GIS operations. The relationship of the input location errors from GCPs and perturbed distances, with the uncertainty of the output maps, was built. The statistical significance of the models was tested based on the student's distribution $r_\alpha = \sqrt{t_\alpha^2 / (n - 2 + t_\alpha^2)}$ where α is the risk level (5%) and *n* is the number of sample plots used. Furthermore, the relative contribution of each type of location error to the output uncertainty was calculated. Together with map quality assessment for standardization, the main error sources were identified.

The standardization of geospatial data will greatly improve the quality of GIS map products and promote data sharing and exchange.Therefore, standardized geospatial data becomes an important component of a NG9-1-1 system. For example, the U.S. National Map Accuracy Standard is defined as 0.5mm for map distance with the ground distance allowed to vary depending on map scale (e.g., the allowed ground distance is 2.5 m for maps at a scale of 1:5,000). In 1992, the United States Geological Survey (USGS) set up and approved the Spatial

Data Transfer System (SDTS) to promote and facilitate the transfer and sharing of digital spatial data (http://mcmcweb.er.usgs.gov/sdts/). The SDTS increases the users' potential for access to and sharing of spatial data. It reduces loss of information in data exchange, eliminates the duplication of data acquisition, and improves the quality and integrity of spatial data. Thus, the standards in SDTS are of significant interest to users and producers of geospatial data. NENA has published national standard data formats used as a guide for the designers and manufacturers of systems for processing emergency calls from any device.

After standardization, topological editing, and geometric correction, all the data layers of the same type of map from all the counties were then merged in ArcMap. The complete and accuracy-improved maps of the study area, having consistent standards and quality controls, were output.

CHAPTER 4

RESULTS

GEO-REFERENCING AND UNCERTAINTY PROPAGATION MODELING

The original images were geo-referenced with the 10 GCPs, and the corresponding RMSE values were obtained. Table 2 shows the results (RMSE) of the geometric correction using the 10 GCPs. The residual error ranges from 10.85 m through 44.50m.

Table 2: An Example of the Results (RMSE) of Geometric Correction Using 10 GPS for Jackson County, Illinois

X Source	Y source	X Destination	Y Destination	Residual (m)
284041.90	4167523.43	283981.91	4167522.36	26.49
283798.49	4196699.05	283792.09	4196690.59	22.07
274604.56	4183565.33	274577.40	4183601.66	17.71
306421.27	4171802.85	306459.47	4171747.36	44.50
297682.44	4182741.36	297692.57	4182742.62	10.85
297426.47	4193100.15	297424.15	4193101.32	27.06
286761.64	4181208.53	286779.26	4181228.65	32.82
311042.27	4188463.19	311055.76	4188465.22	37.23
271839.69	4200043.07	271842.06	4200056.42	16.36
306137.66	4200970.82	306205.88	4200942.30	23.02

Location errors were simulated using the random function in Microsoft Excel. For example, in Jackson County, a total of 10 GCPs were randomly moved by changing their X- and Y- coordinates within the intervals of 1, 2, 5, 10, 15, 20, 30, 40, 50, 100, 300, 500, and 1000 meters. The moving directions of the points were also determined using random numbers. Given a moving distance such as 100 m, the new X-coordinate of each GCP was obtained by selecting one random number times 100 and moving directions (-1 or 1) plus the original GPS X-coordinate. Using the same method, the new Y-coordinate was calculated. Table 3 shows the random numbers, moving directions, and X- and Y- coordinates that were obtained after the points were randomly moved within the interval of 100m.

Table 3: An Example of the Method Used to Obtain New X- and Y-Coordinates for 10 GCPs by Randomly Moving Their Locations at an Interval of 100 m

X GPS	Y GPS	Random X	Random Y	Sign X	Sign Y	New X- coordinate	New Y- coordinate
271842.59	4200055.43	0.07	0.61	-1	1	271835.79	4200116.00
274577.73	4183600.79	0.41	0.55	-1	1	274536.51	4183655.32
283791.79	4196689.67	0.14	0.79	-1	1	283778.10	4196768.99
297424.28	4193100.82	0.70	0.17	-1	1	297354.29	4193117.67
306206.42	4200941.05	0.74	0.15	-1	1	306132.50	4200955.78
311054.53	4188464.00	0.54	0.88	-1	-1	311000.69	4188376.20
297693.40	4182742.73	0.12	0.22	-1	1	297681.06	4182764.44
306459.38	4171747.20	0.61	0.17	-1	1	306398.53	4171764.63
283982.84	4167522.67	0.34	0.38	-1	-1	283949.12	4167484.50
286779.40	4181228.69	0.64	0.33	-1	1	286715.33	4181262.00

Once the new X- and Y- coordinates were produced for the 10 GCPs, they were used to geo-reference the images and maps. Table 4 shows the residual when the moved or perturbed 10 GCPs (with an interval of 100 m) were used for geometric corrections of the image for Jackson County. The residual error range was from 15.18 to 63.69 m, and the average was 33.83 m.

Table 4: An Example of Residuals and RMSE for the Geometric Correction of Image Using 10 GCPs After Randomly Disturbing Their Locations

ID	X Map	Y map	X for 100 m interval	Y for 100 m interval	Residual Error	X difference	Y difference
1	271842.26	4200042.47	271780.11	4200112.59	35.44	62.15	-70.12
2	274603.78	4183563.87	274567.03	4183626.27	28.41	36.75	-62.40
3	283796.57	4196696.11	283752.12	4196778.40	15.18	44.45	-82.29
4	297423.90	4193099.61	297418.14	4193163.57	25.40	5.76	-63.96
5	306139.40	4200967.22	306167.64	4201036.51	33.38	-28.24	-69.29
6	311043.79	4188464.21	311022.47	4188412.93	63.69	21.32	51.28
7	297685.22	4182739.64	297612.37	4182771.14	38.08	72.85	-31.50
8	306416.92	4171801.44	306374.43	4171799.52	17.57	42.49	1.91
9	284036.21	4167523.24	283962.23	4167504.53	24.75	73.98	18.71
10	286763.70	4181211.46	286716.07	4181274.96	31.10	47.63	-63.50
						37.91	-37.12
RMS Error	33.83						

Once all the images had been geo-referenced, a total of 20 GCPs were used to assess the accuracy of the corrected images and maps. The resulting values of RMSE were listed against the moving distances in Table 5. This table shows all the values of RMSE and the distance for 10 GCPs and 20 reference points. The GCPs were shown in Figure 10. There is a fluctuation of RMSE when the perturbed distance was less than 15 m. After that, the RMSE started to slightly increase. Two big jumps of RMSE took place from the perturbed distance from 50 m to 100 m and from 100 m to 300 m. The RMSE increased from 26 m to 37 m and then to 125 m if the perturbed distance increased from 50 m to 100 m and then to 300 m. After 300 m, the RMSE became huge.

Table 5: Values of RMSE for Geo-referenced Images Using 10 GCPs and for the Assessment of Their Accuracy Using 20 GCPs for Jackson County, Illinois

ID	RMSE 10 Points	RMSE 20 Points
No Change	26.26	14.81
Perturbed 1 M	26.28	19.79
Perturbed 2 M	25.87	22.57
Perturbed 5 M	27.84	22.91
Perturbed 10 M	26.21	21.96
Perturbed 15 M	25.14	23.24
Perturbed 20 M	27.91	24.56
Perturbed 30 M	24.09	24.01
Perturbed 40 M	26.27	24.23
Perturbed 50 M	28.09	26.12
Perturbed 100 M	33.83	37.16
Perturbed 300 M	119.30	125.36
Perturbed 500 M	274.24	290.92
Perturbed 1000 M	302.90	291.35

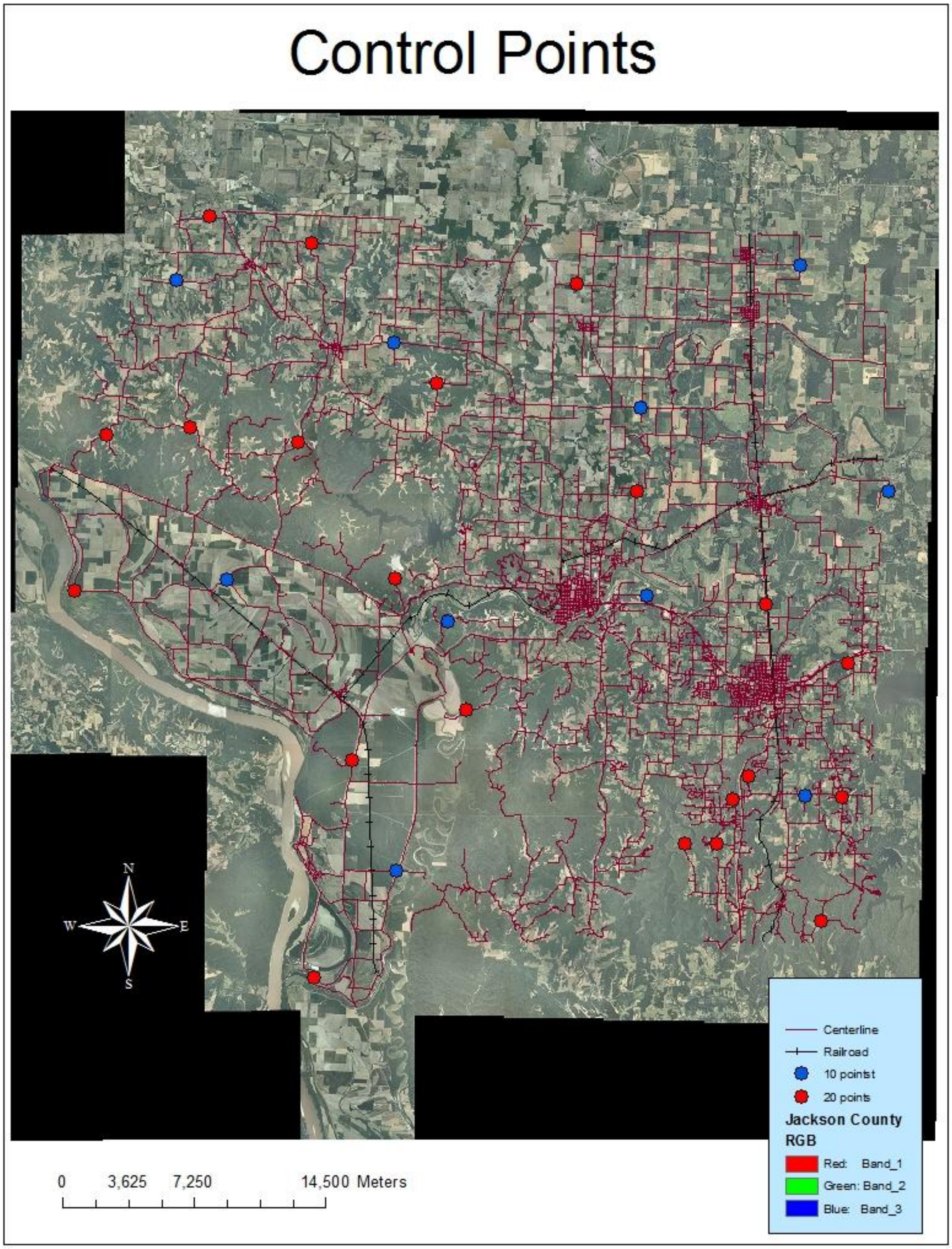

Figure 10: Jackson County, Illinois: Original Image with GCPs

Obviously, the RMSE increased as the moving distance increased. Based on the values of RMSE from 20 GCPs in Table 5, a regression model was obtained, and it accounted for the relationship of the RMSE with the perturbed distance (Equation (3) and Figure 11). The coefficients of determination, that is, R squared values, for the location error is 0.8784, and it is significantly different from zero at a risk level of 5%.

$$RMSE_{Geo\_ref} = 21.369 + 0.3231 Location\_error_{GCP} \quad (3)$$

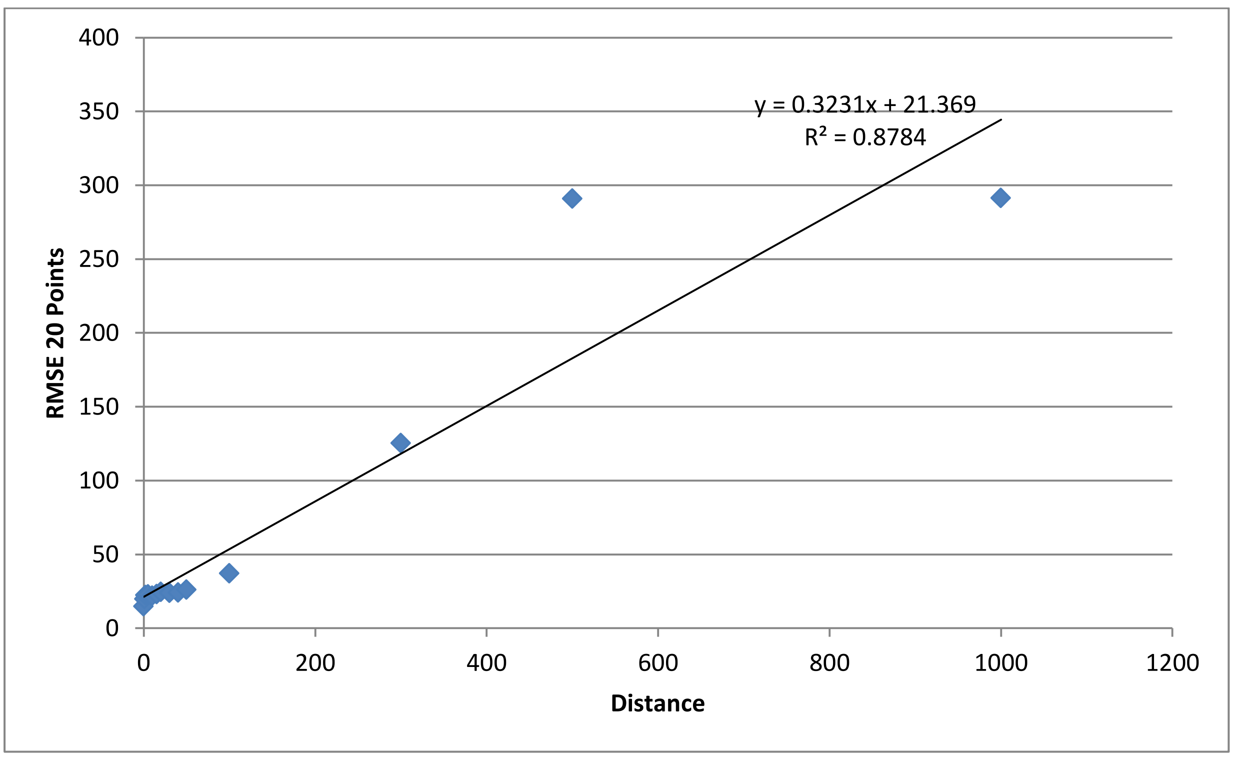

Figure 11: Linear Regression Model that Accounts for the Relationship of the Input Location Errors (Perturbed Distance in Meters) for the 10 GCPs with the Output Location Errors (RMSE) of the Geo-referenced Image, Obtained Using 20 GCPs, for Jackson County, Illinois

GEOMETRIC CORRECTIONS AND UNCERTAINTY PROPAGATION MODELING

Once the images have been produced, the railroad and road layers from Jackson County were used to check for uncertainty in the datasets. The railroads were divided into 6 segments and then adjusted to the images. Table 6 shows the values of RMSE for the railroads under different perturbed distances from 0 to 1000 m. The RMSE fluctuated under the perturbed distance of 100 m and ranged from 14 m to 22 m. The RMSE increased rapidly from 16 m to 26 m when the perturbed distance increased from 100 m to 300 m. After that, the RMSE was huge. When the original image was geo-referenced with GCPs and their locations were not perturbed, the RMSE of the railroad locations was 18.55 m. Figure 12 shows an example of this offering a good look at how closely the railroad lines up with the image. When the original image was geo-referenced with the GCPs whose locations were perturbed at a distance interval of 500 m, the RMSE of the railroad locations was 55.10 m. Figure 13 shows an example of the errors of railroad locations when the locations of the GCPs were perturbed at a distance interval of 500 m.

Table 6: Values of RMSE of Railroad Locations Between the Geo-referenced Image and the Road Map for Jackson County, Illinois

ID	RMSE 1	RMSE 2	RMSE 3	RMSE 4	RMSE 5	RMSE 6	RMSE Avg
No Change	19.24	16.71	16.16	17.20	32.89	9.09	18.55
Perturbed 1 M	25.14	15.01	14.33	10.48	14.82	8.24	14.67
Perturbed 2 M	27.12	15.10	13.43	10.86	26.27	13.52	17.72
Perturbed 5 M	28.42	14.92	11.55	19.83	28.90	13.41	19.50
Perturbed 10 M	29.04	14.36	11.95	11.10	27.61	13.12	17.86
Perturbed 15 M	28.97	14.36	19.56	14.31	28.85	13.39	19.91
Perturbed 20 M	28.90	14.94	12.99	11.25	27.28	13.78	18.19
Perturbed 30 M	23.47	13.99	12.89	11.54	27.88	11.60	16.90
Perturbed 40 M	18.46	15.96	11.98	11.68	29.06	8.32	15.91
Perturbed 50 M	32.26	15.94	28.99	17.83	28.83	8.91	22.13
Perturbed 100 M	18.43	15.96	12.60	11.68	29.17	8.32	16.03
Perturbed 300 M	33.97	21.75	16.44	33.60	41.22	7.15	25.69
Perturbed 500 M	78.13	51.92	35.52	115.75	41.71	7.58	55.10
Perturbed 1000 M	91.37	51.09	88.43	114.46	87.18	20.11	75.44

Figure 12: Example of the Errors of Railroad Locations When the Original Image was Geo-referenced with the GCPs Whose Locations Were Not Perturbed for Jackson County, Illinois

Figure 13: Example of the Errors of Railroad Locations When the Original Image was Geo-referenced with the GCPs Whose Locations Were Perturbed at a Distance of 500 m for Jackson County, Illinois

The linear regression model shown in Figure 14 and equation (4) accounted for the relationship of the location errors (RMSE) of railroads with the input location errors (perturbed distance) when the locations of railroads were compared to the geo-referenced image and the road map for Jackson County. Overall, the RMSE of the railroads increased as the perturbed distance increased. The R squared value was 0.9417 and significantly differed from zero at a risk level of 5%.

$$RMSE_{railroad} = 16.3302 + 0.0602 Location\_error_{Tolerance} \quad (4)$$

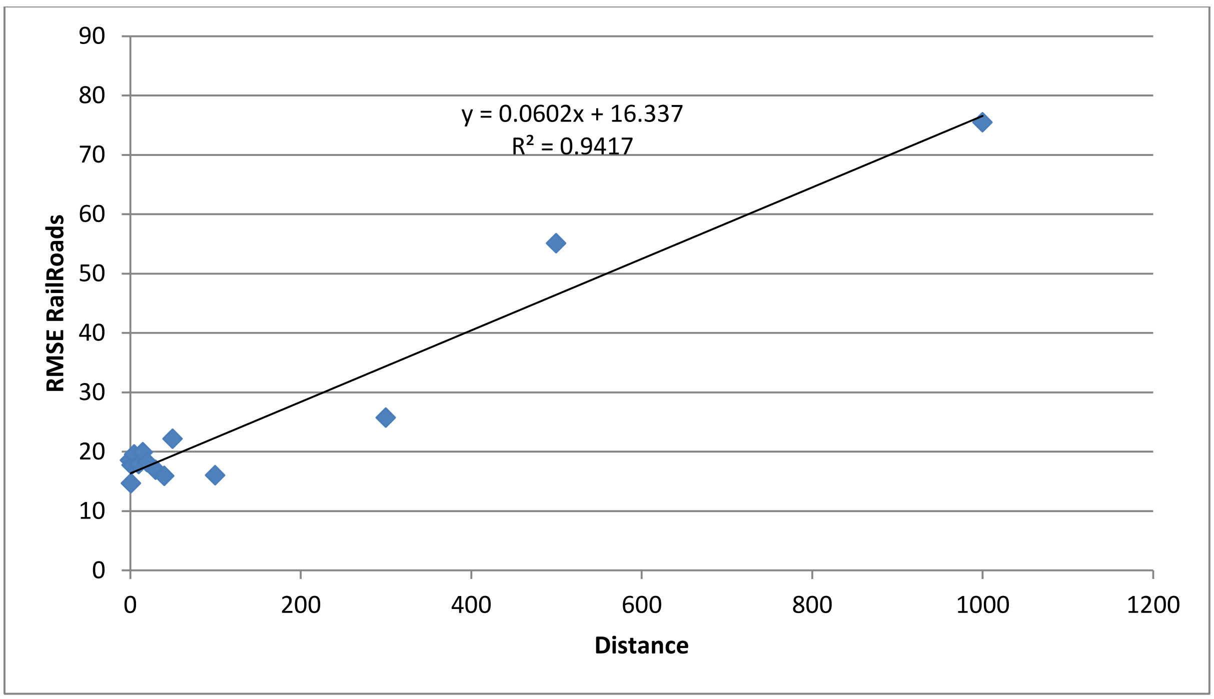

Figure 14: Linear Regression Model That Accounts for the Relationship of the Input Location Errors (Perturbed Distance) with the Location Errors of Railroads When These Locations Were Compared Between the Geo-referenced Image and the Road Map for Jackson County, Illinois

Once the images were geo-referenced, the road maps from Jackson County were used to check for uncertainty in the datasets. The roads were divided into 8 segments and then adjusted to the images. The RMSE values were obtained for each segment and each perturbed distance, and the average RMSEs were then calculated. Table 7 shows the values of RMSE for these roads when the locations of roads were compared between the geo-referenced image and the road map. When the perturbed distance was less than 300m, there were no big differences in terms of RMSE. After that, the RMSE increased quickly. But, overall, the values of RMSE were relatively smaller when compared to those from the railroads and geo-referenced images and maps. As shown in in Figure 15, the RMSE of road locations for Jackson County was 10.17. The image was geo-referenced with the GCPs whose locations were not perturbed. When the locations of the GCPs were perturbed at a distance interval of 300 m, the RMSE of the road locations for Jackson County was 12.94. Figure 16 shows how far apart the road layer is from the road image.

Table 7: Values of RMSE of Road Locations When Compared Between the Geo-referenced Image and the Road Map for Jackson County, Illinois

ID	RMSE 1	RMSE 2	RMSE 3	RMSE 4	RMSE 5	RMSE 6	RMSE 7	RMSE 8	RMSE Avg
No Change	21.40	16.01	7.26	17.96	1.71	8.40	5.98	2.60	10.17
Perturbed 1 M	21.63	16.20	7.55	17.97	2.00	8.16	6.13	2.96	10.33
Perturbed 2 M	21.50	17.25	7.54	18.03	2.00	9.05	6.09	2.96	10.55
Perturbed 5 M	21.50	15.09	7.54	17.98	2.00	8.04	6.09	3.30	10.19
Perturbed 10 M	21.48	17.29	7.92	20.43	2.00	9.61	5.71	2.78	10.90
Perturbed 15 M	21.48	14.80	7.55	18.58	2.00	8.03	5.71	2.68	10.10
Perturbed 20 M	21.63	18.80	7.55	17.82	2.00	8.09	6.13	2.68	10.59
Perturbed 30 M	21.63	16.12	7.28	18.00	2.00	8.39	6.09	2.96	10.31
Perturbed 40 M	18.36	16.29	7.95	18.27	2.80	8.41	6.09	2.57	10.09
Perturbed 50 M	21.34	16.78	7.78	18.12	2.85	8.42	5.92	2.57	10.47
Perturbed 100 M	29.19	8.10	6.80	19.84	2.92	9.06	5.26	3.38	10.57
Perturbed 300 M	33.35	28.12	8.14	10.80	3.11	9.88	6.38	3.73	12.94
Perturbed 500 M	24.88	21.59	8.79	14.09	3.32	7.77	7.68	4.05	11.52
Perturbed 1000 M	25.31	28.88	11.51	25.43	5.27	11.31	9.42	4.74	15.23

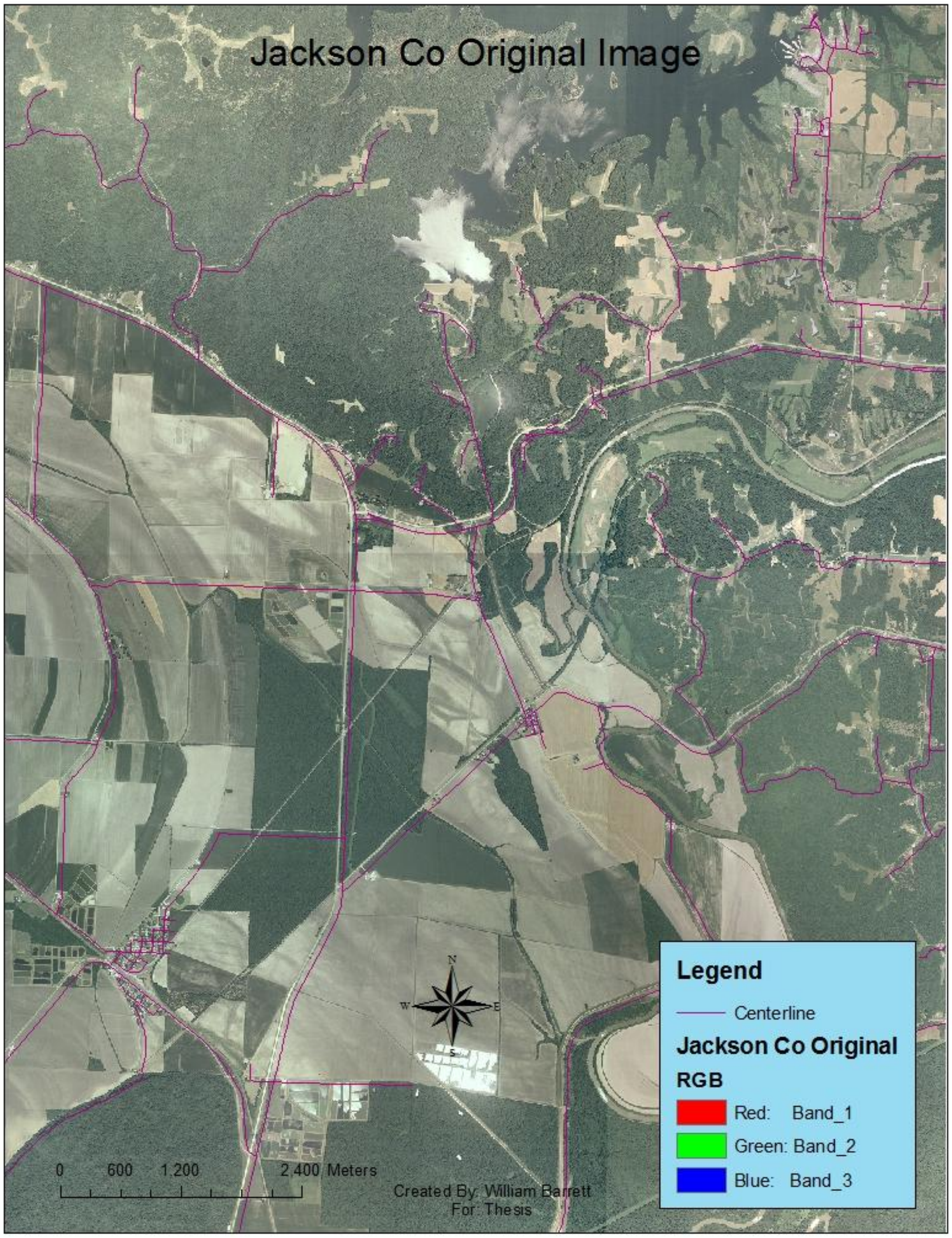

Figure 15: An example for the errors of road locations when the original image was geo-referenced with the GCPs whose locations not perturbed for Jackson County, Illinois

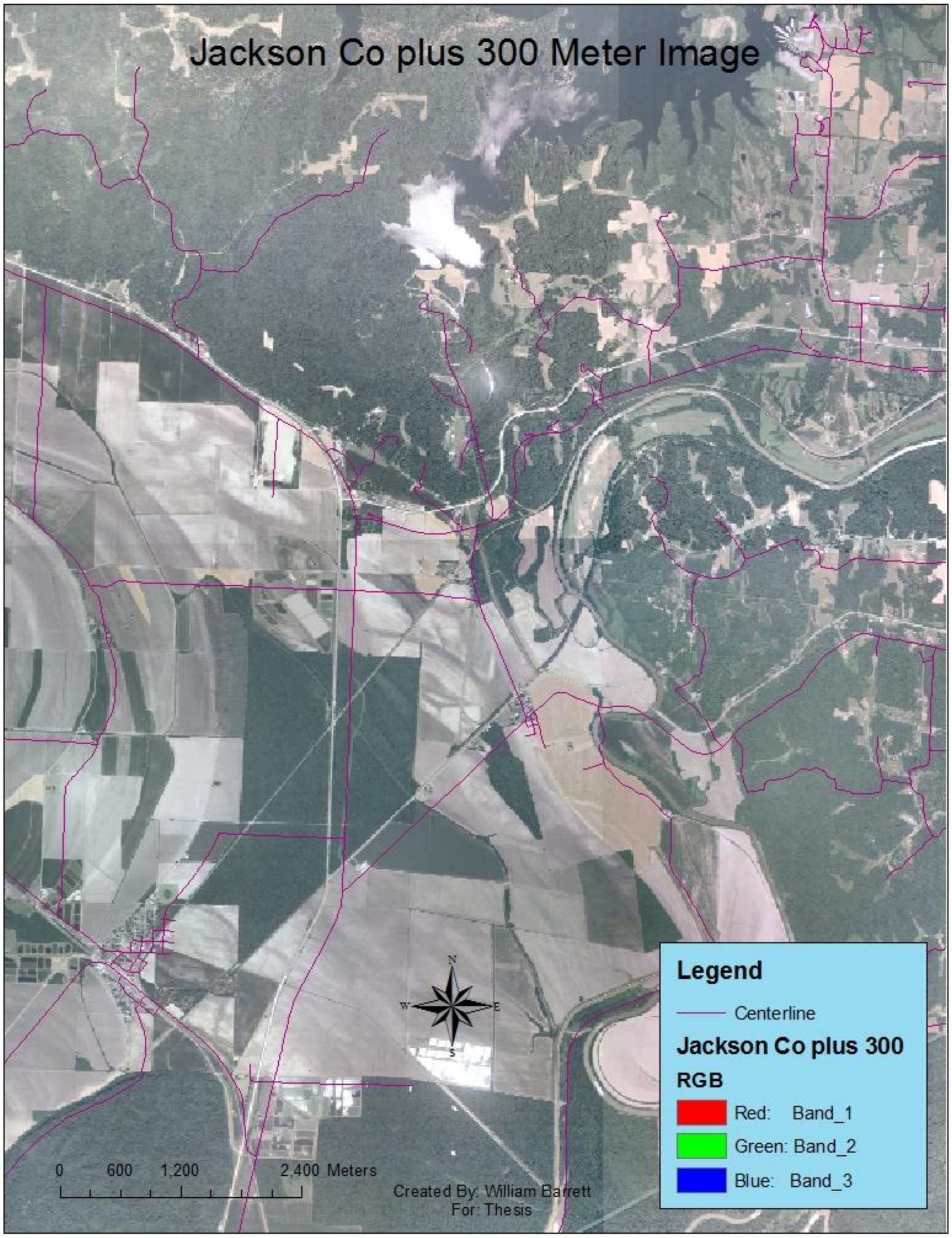

Figure 16: Example of the Errors of Road Locations When the Original Image was Geo-referenced with the GCPs Whose Locations Were Perturbed at a Distance Interval of 300 m for Jackson County, Illinois

In Figure 17 and equation (5), the linear relationship of the input location errors (perturbed distance) with the location errors of roads were compared to the geo-referenced image and the road map for Jackson County. Overall, the RMSE of the roads increased as the perturbed distance increased. The R squared value was 0.8664, and it significantly differed from zero at a risk level of 5%.

$$RMSE_{road} = 10.302 + 0.0047 Location\_error_{Tolerance} \quad (5)$$

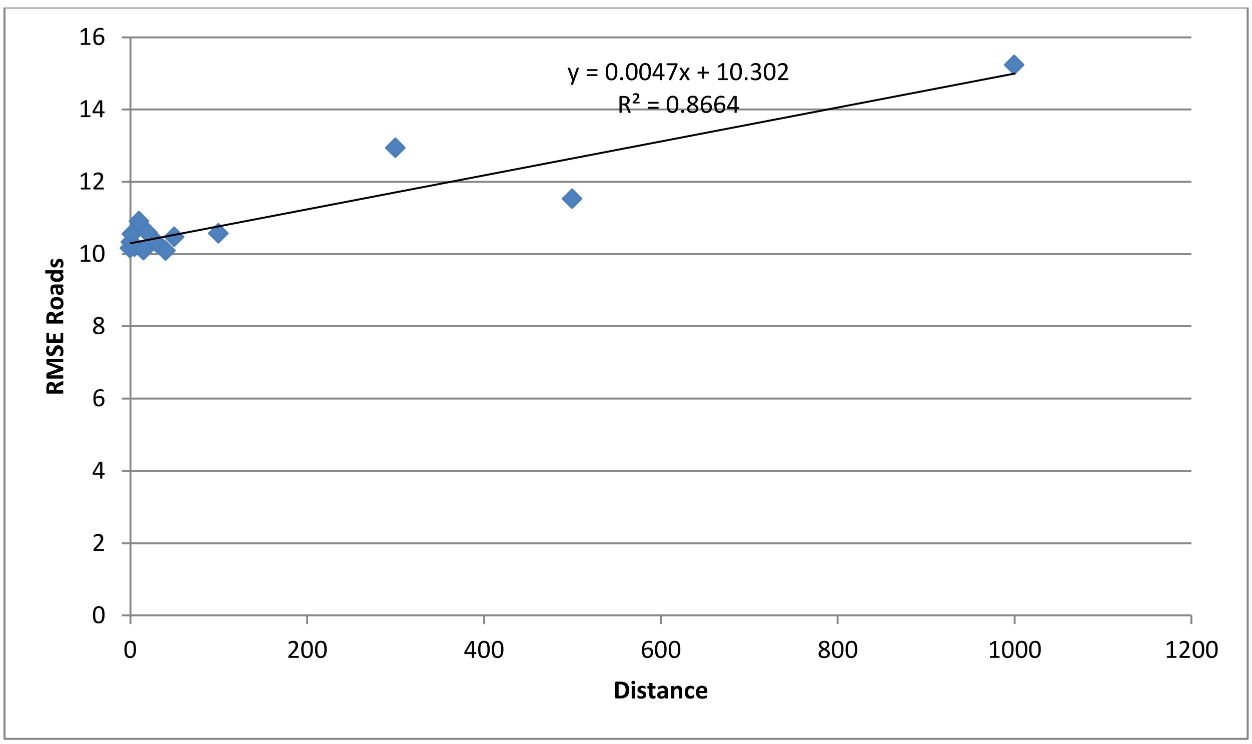

Figure 17: Linear Regression Model That Accounts for the Relationship of the Input Location Errors (Perturbed Distance) with the Location Errors of Roads When They Were Compared Between the Geo-referenced Image and the Road Map for Jackson County, Illinois

A lot of time was spent conducting the topological corrections for the whole study area, including topological structures, rubber sheeting, overshoot, undershoot, and dangling segments, etc. But, the results were ignored here because of space and time limits. In addition, it should be noted that modeling the error propagation for topological corrections was not made in this study.

DATA STANDARDIZATION

Standardization of the GIS road centerline data incorporated the following: North, South, East, West, Northeast, Northwest, Southeast, or Southwest. These are the only prefix and suffix directional abbreviations which were used, when a prefix and / or suffix directional was present. All punctuation was avoided. Special characters were removed (dash, underscore, apostrophe, quotes or any other special characters that could cause problems in any of the software or databases). Only whole numbers were used in the house number fields (fractional house numbers were placed in the House Number Suffix field). Complete spelling of legal street names was assigned by the addressing authority (e.g. Saint Albans versus St Albans). It was important to spell out the complete MSAG and postal community names. The prefix directional was only abbreviated when it was not part of the actual street name (North Drive would not be abbreviated to N Dr). Post directions were abbreviated when they were not part of the actual street names. (Lone Pine Dr South would be abbreviated to Lone Pine Dr S, but Loop West Dr would not be abbreviated to Loop W Dr).

The attribute fields within the centerline data included high and low address ranges along each segment of the road. The high and low addresses were further broken down into left and right side addresses, so that each centerline segment had a left-side low address, a right-side low address, a left-side high address, and a right-side high address. It is strongly recommended that actual addressing be used in the GIS street centerline. Using actual address ranges for the GIS street centerlines improved the location accuracy of the geocoding process. Table 8 provides an example of the NENA standard for the centerline data of Jackson County.

All the county datasets used the same naming conventions. This allowed for consistent ontology across the counties. The first step for the standardization was to get all the datasets from the 9-1-1 coordinators for each of the 15 counties. The next step was to export the attribute table to Excel. After the table had been changed to meet the NENA standards, it was joined back to the layer. The final step was to use Xtools Pro, an extension for ArcMap, to do table restructures for each of the datasets for each of the counties. The final product was a standardized dataset for centerline, railroad, ESN, hydrology, and cell tower information for each county. The process of standardizing all the datasets for the 15 counties took around 480 hours of work to complete.

Once the data was standardized it was given back to the counties for quality control purposes so that confirmation could be provided that all the information was transferred correctly to the new standard. In the NG 9-1-1 environment, all calls will be routed using GIS data. The importance of the quality of the data cannot be overstated.

Table 8: Example of the Attribute Table of Centerline Dataset After Standardization Based on NENA Standards

COUNTRY	STATE_L	STATE_R	LLO	LHI	RLO	RHI	LABEL
US	IL	IL	2841	3839	2842	3840	GENTRY RD
US	IL	IL	3301	3799	3300	3800	N MCGEESVILLE RD
US	IL	IL	11654	12194	11655	12195	DEER RUN RD
US	IL	IL	13560	16684	13561	16685	CANAVILLE RD
US	IL	IL	220	810	221	811	HIDDEN BAY LN
US	IL	IL	2000	2500	2001	2501	W DEVILS KITCHEN RD
US	IL	IL	1025	1499	1024	1498	DIMING BLVD
US	IL	IL	985	1499	984	1498	SKELCHER BLVD
US	IL	IL	2494	2954	2495	2955	VENUS AVE
US	IL	IL	2494	2952	2493	2951	ROBLEY AVE
US	IL	IL	1140	1420	1139	1421	PINE RIDGE LN
US	IL	IL	2071	2805	2070	2806	S MCGEESVILLE RD
US	IL	IL	2021	2149	2022	2150	APACHE DR
US	IL	IL	2071	2143	2070	2144	SIOUX LN
US	IL	IL	573	849	572	850	MCKINNEY CHAPEL RD

CHAPTER 5

CONCLUSIONS AND DISCUSSION

RESEARCH QUESTIONS REVISITED

Overall, the results of this study showed that the research questions were well answered. Below, we will discuss these questions and the answers from this study.

The first question was: *What are the minimum map quality requirements for a NG 9-1-1 system?*

The ultimate quality of the GIS data is dependent on the source data and the methods used to incorporate the data into the GIS. Whether new GIS datasets are being compiled onto a base map or old maps are being recompiled onto a new database, certain procedures need to be addressed. Precise procedures, although very important, will not improve the inherent source of map data. The quality of input data and maps is very critical for NG 9-1-1 systems. Geo-referenced maps, rectified photographs and images, as well as vector base maps may serve as sources of GIS data for a NG 9-1-1 system. As the data, maps, and images are input into the database of a NG 9-1-1 system, the errors are also propagated into the system. In this study, researchers found that the existing data and maps were associated with a large account of uncertainties, and the uncertainties were greatly reduced by geo-referencing, topological structure construction, and standardization. This study also led to the map data standards: i) GIS maps and vector data at a scale of 1:24,000 or larger are acceptable; and ii) Digital

Orthophotograph data, or raster data, shall have a spatial resolution of 15 m or finer based on the values of RMSE obtained with different perturbed distances of ground control points. Moreover, the RMSE for geo-referencing the maps and images should also be smaller than 15 m. After that, the quality of the spatial data will decrease.

This study shows that based on the minimum map quality requirements obtained in this study, the standards of NENA GIS data collection and maintenance (NENA July 2007) are adequate. These requirements are also close to the US National Map Accuracy Standard: 12 m derived based on the 0.05 mm standard for map distance and the scale 1:24,000. Compared to the datasets that are used for NG 9-1-1 for the whole USA, the datasets that are used in this study are limited. More work and examination should be conducted to see how the data and map quality requirements react to responses in the NG 9-1-1 systems.

The second question was: *What are the major uncertainty sources of the existing geospatial data layers?*

With Jackson County being used as an example, Figures 9 through 11 showed that the output uncertainties had linear relationships with the input errors regardless of geo-referencing of maps and images and locations of railroads and roads. The linear relationships were significantly different from zero at a risk level of 5%. Overall, the values of RMSE for both geometric errors and location errors of the shifted railroads and roads increased as the perturbed distance increased. However, the geometric errors of the maps and images due to the location errors of ground control points were significantly larger than the position errors of railroads and roads.

The third question was: *How do location errors affect the quality of the maps, and is there a threshold value of location errors that significantly decrease map accuracy?*

When the perturbed distance was less than 15 m, the geometric errors of the spatial datasets, due to the location errors of the ground control points, did not significantly change. The errors started to increase after the perturbed distance of 15 m, and big increases took place from the perturbed distance of 50 m to 100 m and 100 m to 300 m. After that, the spatial maps and images would be shifted to more than 100 m away. Until the shift reached the 100m threshold value, the map accuracy was not significantly decreased.

The final question was: *What is the best systematic methodology for conducting quality control of data layers across the 9-1-1 system created by CSI?*

Taking into account the nature of static resources, attributes and spatial features of the GIS data shall be validated at a minimum of once a year against one or more of the following data resources: Attribute Validation, Automatic Location Information (ALI) Data Base and Master Street Address Guide (MSAG,) Tax Assessment Information, and Spatial Validation. The map data that reside in mapping software require updates on a regular basis. The call taker interacts with the map data on a daily basis and can serve as a good reference when determining the accuracy of this data. If a street is missing or an address range is incorrect, the call taker can be the first line of defense. Therefore, there must be a means in place for the call taker to communicate mapping issues as they arise so that they can be corrected expediently. GIS data of any worthwhile size contain errors. Eliminating all errors is an unrealistic expectation. The goal is to quickly correct any discrepancies found. What is expected is a consistently applied program to identify and correct these errors. The longer GIS data goes without an update, the less accurate the information will become, and its integrity therefore diminishes. There are several options for the entity that may be responsible for performing GIS data maintenance. These include such personnel as the PSAP staff of Local GIS department(s) (i.e. government, police, utilities, etc).

MAP QUALITY AND RESPONSE OF NG 9-1-1 SYSTEMS

NENA data standards aim to bringing 9-1-1 agencies together in NG 9-1-1 by building consistent standards and requirements and providing the potential to share and access data and maps. This study was conducted based on NENA data standards. The results that were obtained thus met the NENA data standards. Among the standards, location errors are the most critical because the errors have large impacts on the responses to calls in the NG 9-1-1 system. Generally, a location error of 15 m may not seriously impede the search for and location of the NG 9-1-1 system user. It may also not greatly delay making a response to the call whether in a downtown city or rural area. But, a location error of more than 100 m may seriously delay the response because the search of the NG 9-1-1 for the call may be problematic.

In addition, for an agency to begin to apply NG 911 their GIS data must be clearly defined. Discrepancies between the GIS, MSAG, and ALI data can cause call routing and dispatching problems. Inaccuracies in the databases could lead to a delayed or improper response. By comparing GIS data to the MSAG, identifying the problems, creating discrepancy reports, and working to correct the discrepancies, problems can be minimized.

LIMITATIONS AND FUTURE STUDIES

Future study in GIS for NG 9-1-1 purposes is very important. A gap still exists with regard to what each 9-1-1 center is currently using for GIS and what NENA says is needed. For the purpose of this study, Jackson County was the focus. It provided an informative look at one county's data set. The method used to complete this work could be used to check the accuracy of the data sets for each of the other counties in Southern Illinois. Maintaining data integrity within the GIS and keeping the data synchronized with existing tabular files, MSAG, and ALI files requires high levels of coordination. Much work is needed in the study of ontology in GIS datasets for NG 9-1-1 to better streamline the efficiency of data usage.

Another future study could be to use the perturbed images that were produced for the railroad and road layer to check for uncertainty in the structure points of actual 9-1-1 calls. By using the structure points the RMSE from this information could reveal if the data produced from the railroad and road maps are adequate. A linear regression model could be built that would account for the relationship of the input location errors (perturbed distance) with the location errors of structures. This could add one more piece to the puzzle of uncertainty.

Moreover, in thus study we compared the geometric errors of the geo-referenced maps and images with the location errors of the railroads and roads. However, we did not conduct a systematic apportioning of the output uncertainties into various input errors because of time limitations. In addition, because of limited space, we did not report the results for other counties.

RECOMMENDATION

The main purpose of this project was to help provide accurate spatial data for the PSAPs of CSI to properly locate 9-1-1 calls. Spatial information can be used for a map display which includes, among other functions, a display of the location of each emergency call, alternative means of determining emergency locations, and spatial query tolls. Computer Aided Dispatch Systems (CAD) may require spatial data in order to acquire the information needed for CAD emergency responses and operations.

Pinpointing emergency locations with a high degree of accuracy is one very important reason for the proper maintenance of GIS data. To properly represent the ever-changing real world, the underlying spatial data layers are required to have constant maintenance and updating within the GIS environment.

GIS data of any worthwhile size are associated with uncertainty and error. Eliminating all the uncertainties and errors is an unrealistic expectation. What is expected, however, is a consistently applied program to identify and correct any existing errors. If a spatial database is used for a long time without being updated, its information will become less accurate and the integrity of its data will diminish. Thus, the maintenance of the spatial database for a Next Generation 9-1-1 system becomes very important. This statement brings to bear the question of who should take responsibility for performing the maintenance of the spatial database. There are several options:

1) PSAP staff;
2) Local GIS department(s) (i.e. police, fire, utilities, etc.);
3) GIS mapping vendors;

4) Database management vendors

Further, maintaining data integrity within a GIS environment and keeping the data synchronized with existing tabular files, MSAG, and ALI files require high levels of coordination. The MSAG coordinator, PSAP personnel, and GIS personnel should work closely together to resolve MSAG and GIS discrepancies.

Moreover, creating updated timelines for the spatial data will be critical to maintaining accurate map data layers within a PSAP. It is important that the users of the map data retain confidence in its accuracy. When discussing these updates, a jurisdiction needs to remember that it is not only important for the data to be updated with the newest information, but also that these updates are made available to the telecommunicators within the system. Without these precautionary steps in place, the primary goal of the NG 9-1-1 system is not being served. This is why a long-term solution for the maintenance and updating of the map data within the system is so important.

It is also recommended that the spatial data updates be processed within five business days of the receipt and verification of an address. The updated data layer should be provided to CSI in a timely manner. The updates must be submitted in an electronic format according to the GIS Data Model in NENA 02-010.

In the real world, roads are renamed, added, relocated, and occasionally removed. Such changes must be accommodated for in the spatial database. As structures are built or demolished, geo-coding should also be updated on the road centerline layer to accommodate for these changes. In order to geocode accurately, the road centerline layer requires maintenance of coordinate locations, name changes, new roads, and address range changes. Changes in the road centerline layer may affect the Emergency Service Zones' (ESZ) topology. Adjustments to the ESZ information should reflect those changes. It is recommended that the ESZ boundary be joined to the road centerline where the road forms the boundary between two different ESZs.

A structure point layer should match the ALI Data Base. As buildings are constructed or demolished, these points need to be added or deleted. Information may be received from the addressing authority, ALI discrepancy, or as a determined part of the spatial audit process. The Emergency Service Data Layer is a combination of the Point Layer, the Emergency Service Agency Location Layer and the ESZ Polygon Layer. This layer is used to route emergency service calls from the correct emergency service provider to the emergency location. Emergency Service Agency Location updates are performed in a manner similar to site updates.

Background data layers including Hydrology, Railroad, Mile Marker Location, Electric Line, Petroleum/Natural Gas Line, and Water Main, etc., are optional layers used to help PSAPs' call handling capabilities. The background data layers need to be maintained as individual PSAP jurisdiction layers. As new information becomes available from the agency responsible for its creation, it should be integrated.

REFERENCES

Agarwal, P. "Ontological consideration in GIScience." *International Journal of Geographical Information Science* 19, no. 5 (2011): 501-536.

Arbia, G., D. Griffith, and R. Haining. 1998. Error propagation modelling in raster GIS: overlay operations. International Journal of Geographical Information Science 12:145–167.

Arpinar, Budak I., Amit Sheth, Cartic Ramakrishnan, Lynn E. Usery, and Molly Azami. "Geospatial Ontology Development and Semantic Analytics." *Transactions in GIS* 10, no. 4 (2006): 551-575.

Congalton, R.G., Green, K. 1999 Assessing the Accuracy of Remotely Sensed Data: Principles and Practices.CRC press, FL: Lewis Publisher.Crosetto, M., and S. Tarantola. 2001. Uncertainty and sensitivity analysis: tools for GIS-based model implementation. International Journal of Geographical Information Science 15(5):415-437.

Crosetto, M., and S. Tarantola. 2001. Uncertainty and sensitivity analysis: tools for GIS-based model implementation. International Journal of Geographical Information Science 15(5):415-437.

Data Technical Committee, Data Management Subcommittee. NENA 02-014, Issue 1, July 17, "GIS Mapping Working Group, NENA GIS Data Collection and Maintenance Standards. 2007." National Emergency Number Association (NENA).

Davis, Frank W., Dale A. Qualtrochi, Merrill K. Ridd, Stephen J. Walsh, and Joel C. Michaelsen. "Environmental Analysis Using Integrated GIS and Remotely Sensed Data: Some Research Needs and Priorities." Photogrammetric Engineering & Remote Sensing 57, no. 6 (1991): 689-697.

Fisher, Peter F. "Knowledge-based approaches to determining and correcting areas of unreliability in geographic databases." In The accuracy of spatial databases, Michael Goodchild and Sucharita Gopal, 45-54. New York: Taylor & Francis, 1989.

Gertner, George, Guangxing Wang, Shougan Fang, and Alan B. Anderson. "Mapping and uncertainty of predictions based on multiple primary variables from joint co-simulation with Landsat TM image and polynomial regression." Remote Sensing of Environment 83 (2002): 498-510

Goodchild, Michael F. "Modeling error in objects and fields." In the accuracy of spatial databases, Michael Goodchild and Sucharita Gopal, 107-114. New York: Taylor & Francis, 1989.

Goodchild, M.F., Uncertainty: The Achilles heel of GIS?, Geo Info Systems, 8 (11), 50-52, 1998. (Academic Pursuits column)

Goodchild, M., and S. Gopal. 1992. Accuracy of Spatial Databases. Taylor & Francis Ltd., Bristol, PA 19007.

Gunes, Ertug A., and Jacob P. Kovel. "Using GIS in Emergency Management Operations." Journal of Urban Planning and Development 126, no. 3 (2000): 136-149.

Heuvelink, Gerard B. Error Propagation in Environmental Modeling with GIS. Bristol, PA: Taylor & Francis, 1998.

Heuvelink, G.B.M., and P.A. Burrough. 1993. Error propagation in cartographic modelling using Boolean logic and continuous classi. cation. International Journal of Geographical Information Systems 7:231–246.

Heuvelink, Gerard B., Peter A. Burrough, and Alfred Stein. "Propagation of errors in spatial modeling with GIS." International Journal of Geographical Information Systems 3, no. 4 (1989): 303-322.

Horan, Thomas A., and Benjamin L. Schooley. "Time-Critical Information Services." Communications of the ACM 50, no. 3 (2007): 73-78.

Innes, J, and D Simpson. "Implementing GIS for planning." Journal of the American Planning Association 59, no. 2 (1993): 230-235.

Jensen, John R. *Introductory digital Image processing A Remote Sensing Perspective*. 3rd ed. Upper Saddle River, NJ: Pearson, 20005.

Karssenberg, D, and De K. Jong. "Dynamic environmental modeling in GIS: 2. Modelling error propagation." International Journal of Geographical Information Science 19, no. 6 (2005): 623-637.

Lanter, David P., and Howard Veregin. "A Research Paradigm for Propagation Error in Layer-Based GIS." photogrammetric Engineering & Remote Sensing 58, no. 6 (1992): 825-833.

Liburne, L., and S. Tarantola. 2009. Sensitivity analysis of spatial models. International Journal of Geographical Information Science 23(2):151-168.

Longley, Paul A., Michael F. Goodchild, David J. Maguire, and David W. Rhind. *Geographic Information Systems and Science*. 2ndnd ed. England: John Wiley & Sons Ltd., 2005.

Lunetta, Ross S., Russell G. Congalton, Lynn K. Fenstermaker, John R. Jensen, and Kenneth C. McGwire. "Remote Sensing and Geographic Information System Data Integration: Error Sources and Research Issues." Photogrammetric Engineering & Remote Sensing 57, no. 6 (1991): 677-687.

Mansor, Shattri, Mohammed A. Shariah, Lawal Billa, Iwan Setiawan, and Fisal J. Malaysia. "Spatial Technology for Risk management." TS10-Geoinformation for the Public FIG Working week 2004 Athens, Greece.

Mowrer, Todd and Congalton G. Russell. 2000. Quantifying Spatial Uncertainty in natural Resources: Theory and Applications for GIS and Remote Sensing. Chelsea, MI: Sleeping Bear Press.

Newsom, Donald E., and Jacques E. Mitrani. "Journal of Contingencies and Crisis management." Geographic Information System Applications in Emergency Management 1, no. 4 (1993): 199-202

Pontius, Gil R. "Quantification Error versus Location Error in Comparison of Categorical Maps." Photogrammetric Engineering & Remote Sensing (2000): 1011-1016.

Pontius, Gil R. "Statistical Methods to Partition Effects of Quantity and Location During Comparison of Categorical Maps at Multiple Resolutions." Photogrammetric Engineering & Remote Sensing 68, no. 10 (2002): 1041-1049

Smith, Barry, and David M. Mark. "Ontology and Geographic Kinds." International Symposium on Spatial data Handling, Vancouver, Canada. 12-15 July.

Veregin, Howard. "Error modeling for the map overlay operation." In The Accuracy of Spatial Databases, Michael Goodchild and Sucharita Gopal, 3-18. New York: Taylor & Francies, 1989.

Walsh, Stephen J, Lighfoot, Dale R, and Butler, David R. "Recognition and assessment of error in Geographic Information Systems." Photogrammetric Engineering and Remote Sensing 53, no. 10 (1987): 1423-1430.

Wang, Guangxing, George Z. Gertner, Shougan Fang, and Alan B. Anderson. "A methodology for Spatial Uncertainty Analysis of Remote Sensing and GIS Products." Photogrammetric Engineering & Remote Sensing 71, no. 12 (2005): 1423-1432

Wang, Guangxing, Maozhen Zhang, George Z. Gertner, Tonny Oyana, and Ronald E. McRoberts. "Uncertainties of mapping aboveground forest carbon due to plot locations using national forest inventory plot and remotely sensed data." *Scandinavian Journal of Forest Research* (2011): 1-14.

Wang, Guangxing, Tonny Oyana, maozhen Zhang, Samuel Adu-Prah, and Siqi Zeng. "Mapping and spaital uncertainty analysis of forest vegetation carbon by combining ntional forest inventory data satellite images." *Forest Ecology and Management* (2009): 1275-1283.

Westcott, Bruce. "GIS and GPS - The Backbone of Vermont's Statewide E911 Implementation." Photogrammetric Engineering & Remote Sensing 65, no. 11 (1999): 1269-1276.

APPENDICES

CSI GIS datasets by County

Alexander County

Roads, ESN, Address, hydrology, railroads, cities

Clay County

Roads, ESN, hydrology, railroads, cell towers

Franklin County

Roads, ESN, Address, hydrology, railroads, cities, cell towers

Gallatin County

Roads, ESN, Address, hydrology, railroads

Jackson County

Roads, ESN, Address, hydrology, railroads, cites, cell towers

Johnson County

Roads, ESN, cites, hydrology, railroads, cell towers, mile markers

Marion County

Roads, address, ESN, cites, hydrology, railroads

Marion City

Roads, address, ESN, city, hydrology, railroads, cell towers

Massac County

Roads, address, cites, hydrology, railroads

Perry County

Roads, Address, cities, ESN, hydrology, railroads

Pulaski County

Roads, Address, cities, ESN, hydrology, railroads

Richland County

Roads, Address, ESN, hydrology, railroads, cell towers

Saline County

Roads, Address, ESN, hydrology, railroads

Union County

Roads, Address, ESN, hydrology, railroads, cities, cell towers

Wabash County

Roads, ESN, hydrology, railroads, cities

Williamson County

Roads, address, hydrology, railroads, cities

VITA

Graduate School

Southern Illinois University Carbondale

William L Barrett

wb911coordiantor@cityofmarionil.gov

Southern Illinois University Carbondale

Bachelors of Science, Geography and Environmental Resources, Fall 2010

Special Honors and Awards:

Outstanding Student in Geography 2009
CDM Student Award 2011

Thesis Title:
Southern Illinois GIS Mapping for Next Generation 9-1-1 Based on NENA Standard Data Format

Major Professor: Dr. Guangxing Wang