A Comparative Analysis and Evaluation of Actual Emergency Incident Response Times and GIS Modeled Incident Response Times Using Network Analysis and Geographic Information Systems

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Abstract

The most important aspect for fire departments and emergency services is response. Demand for emergency services in the Winona area continues to grow and for emergency responders to continue to effectively respond to emergencies new resources are required. The analysis of emergency response times has been used for years in developing statistical data for the fire services. GIS analysis of that statistical data provides the ability to create service areas, calculate closest facilities, examine attributes and visualize the data. The findings of this work illustrate travel times, service areas and the most effective routing for these services by using a street network and various network analysis methods. The comparative analysis of yearly data illustrates how effective emergency services are responding, areas of concern, and the potential improvements gained by using GIS in the response process.

Introduction

According to the City of Winona (2011), the first attempt to give the City of Winona, Minnesota USA, fire protection was in 1857, a few months after the city was incorporated. Currently, the Winona Fire Department responds to over 2,000 calls a year for help ranging from medical to fire response calls.

The fire department also protects 24 square miles in the city that consists of 27,592 people, which includes student populations for approximately 8,500 Winona State University students, 1,372 Saint Mary's University undergraduate students and 2,600 students at Minnesota State College Southeast Technical (Winona Fire Department, 2012).

There are three important reasons for looking closely at emergency response data: (1) it provides insights into fire problems, (2) it identifies improvement areas for resource allocation for combating fires and (3) it identifies training needs. Probably the most compelling reason is that analysis provides insight into fire problems which in turn can affect operations and emergency response within the department (U.S. Fire Administration, 2004).

This type of analysis must be accomplished at several scales. The first is to apply the evaluation methodologies based on the actual responses for the individual demand zones. The process should then be used for analyzing an entire first-in district. The second step is to apply the study to a citywide perspective prior to making the final overall assessment (Commission on Fire Accreditation International, 2005). It is best to evaluate

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each station's ability to respond to the workload individually and then combine the results to evaluate the citywide performance as a whole for the department (Commission on Fire Accreditation International, 2005).

GIS analysis can effectively illustrate the problem areas as well as proposed solutions. It provides the ability to show various data for simulated responses to specific locations including apparatus and personal on a time-arrival sequence, response to multiple alarms, and travel time to each street segment in the system. This provides the information needed for crucial decision-making by incident commanders and includes the ability to predict the time needed to assign resources for various emergency operations (ESRI White Paper, 2007).

Analysis of response data in GIS can show both the efficiencies and deficiencies of current fire station coverage for a specified travel time and provide a model for future fire station coverage using the specified or other travel time standards (ESRI White Paper, 2007).

Project Scope

This project involves using emergency response data to map incident locations, identify new emergency service areas for current fire stations based on travel times, identify routes to incidents locations, identify areas of concern within service areas, provide an in-depth comparative analysis of response times and demonstrate the advantages of using GIS in emergency services.

The study area focused on current emergency coverage areas for the City of Winona. The City of Winona is located in Winona County in the southern part of Minnesota next to the Mississippi River. The fire department services and responds to calls within the city limits. It also has mutual aid contracts in Minnesota with Wilson, Goodview, Lewiston, Pickwick, and in Wisconsin with Fountain City and the Town of Buffalo.

To provide protection to the community the fire department responds from two fire stations: the central station and the west station. Current station responses hinge on incident addresses with the service areas divided by a single street (Figure 1). Although stations have specified service areas, emergency calls such as motor vehicle accidents, structural fires and hazmat incidents often require both stations to respond.

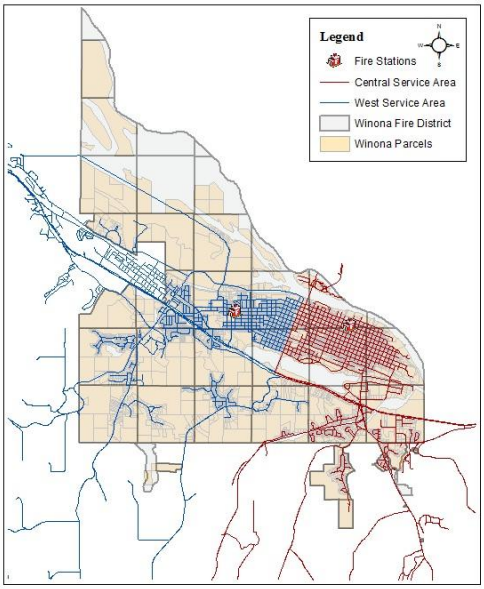

Figure 1. This map of the City of Winona identifies the current city parcels, current fire station locations (red point symbols), the current fire station service areas for the central station (red lines) and the west station (blue lines) and illustrates the current Winona Fire Departments fire district (grey grid) that covers 23.881 square miles.

The analysis uses a street network dataset along with the ESRI Network Analyst extension to calculate four minute service areas for station locations. It also

calculates the fastest route times to incident locations using emergency vehicle speed limits.

The comparative analysis of actual response times to the GIS modeled response times are examined at three levels: (1) overall analysis of department incidents, (2) station incident response analysis and (3) detailed service area incident analysis. The statistical data are selected through queries and analyzed to calculate specific time components required for a detailed response analysis.

The analysis identifies the advantages the GIS model can provide in the response process, areas where response times can be reduced and how times can be improved. It also identifies areas of concern for incidents within the four minute service areas.

The significance of the analysis and purposes for the comparative analysis are addressed in the following questions:

- Are current service areas providing an accurate depiction of station response times or are GIS modeled service areas more accurately illustrating response coverage?
- To what extent will the comparative analysis of actual response times to GIS derived response times indicate service improvements for: (1) an overall analysis of department incidents, (2) a station incident response analysis, (3) a detailed service area incident analysis?
- What are the advantages GIS can provide in the response process and to what extent can response times be improved?
- Are there any areas of concern within the service areas where incident response times are over four minutes?

Methods

Technology

The software used in this study includes Esri's (Environmental Systems Research Institute) ArcGIS 10.0 Suite including the Network Analyst extension. SPSS 16.0 was used for calculating dataset statistics. Microsoft Excel was used to clean and format the data for ArcGIS.

Data Collection and Preparation

Project data were acquired from the Winona County Planning Department and the City of Winona Fire Department. The incident data from the Winona Fire Department included emergency response times for each incident for 2011. This included the response code, emergency code and the units responding.

The Winona Fire Department also provided data on station locations, station apparatus, station service areas, department response protocols and emergency vehicle response policies. The data acquired from the Winona County Planning Department included a street dataset which included street addresses, a fire districts dataset and a city parcels dataset.

The incident data obtained from the fire department were provided in a PDF format and included the incident address, incident time and date, response and emergency codes, responding unit, notified time, arrival time and response time for all calls in 2011.

The PDF was converted to Excel where the project data were cleaned and formatted. This process involved inspecting the data and manually copying it to a new document using the paste

special tool to preserve the original data format. The text-to-columns tool was used to convert the data from single to multiple columns to develop individual incident records. This resulted in a total of 2,102 incidents responded to for the year.

Additional fields were added to facilitate importing data into ArcMap. These included feature ID and object ID numbers. Fields were also added for total response minutes and total response percent and converted to specific units. These data fields were required for the statistical analysis. In addition, fields were added for city, state, zip code, longitude and latitude. An address to longitude and latitude tool was used to geocode incident locations to XY coordinates, converted to decimal degrees and added to the longitude and latitude fields. These fields were needed for mapping the incident locations in ArcMap

The data were imported into ArcMap and queried for emergency incidents. A total of 1609 incidents were identified and exported as a feature class named Incidents81512. The data were then queried based on responding apparatus to create feature classes for station incidents. The results were 597 incidents for the west station, 803 incidents for the central station and 209 incidents for both stations responding.

The street dataset contained attribute fields for speed limits (required for calculating emergency speed limits, emergency travel times and regular travel times), road class, distance (in feet) and road names. Additional fields were added for distance in miles, emergency speed limits, regular travel time, emergency travel time and street segment elevations. These attributes were needed to properly design and build the street network for calculating travel times. The study area was then extracted from the dataset using the Extract by Clip tool and saved as a new dataset called streetsclip.

The parcel dataset provided building footprints and contained fields for parcel addresses. An additional street address field was added to convert multiple fields into a single field needed for identifying address locations.

The fire district dataset included the required attributes and provided the overall service area the department protects. The fire station locations were developed by querying the parcel dataset and exporting the selected parcels into new feature classes. New point feature classes were created and plotted on the street network for the central, west and both fire station locations.

GIS Analysis

Street Network

The analysis began with constructing the street network dataset using the Network Analyst extension in ArcCatalog. The streetsclip dataset was used as the source to develop the new network dataset. The Network Analyst extension provided the tools to calculate the best route, find the closest facility and to identify service areas around station locations.

The design of the network required parameters to be set for connectivity using the end point policy and elevation using the street elevation fields. Network attributes were added for road class, which used default values for establishing the road hierarchy. In addition, cost attributes were added for distance (in miles) and time (in minutes), with evaluator fields set to correspond with attribute fields from the streetsclip dataset. This dataset accounted for the emergency vehicle response policy that allows emergency vehicles to travel at speeds of up to 10 mph over the posted

speed limit. The parameters were verified and the final dataset was built as an emergency street network.

After building the street network dataset it was added to ArcMap. The incident data for the central station, west station, both stations and all emergency incidents were geocoded to the map using the longitude and latitude fields. The longitude and latitude attribute fields were used instead of an address locator to map the data for several factors: (1) a large portion of the incidents were located at non-address locations such as intersections and mile markers, and (2) many incident locations were spelt incorrectly, recorded as building names or were referenced by landmarks. The parcel and fire district datasets were added to the map along with the fire station locations (Figure 2).

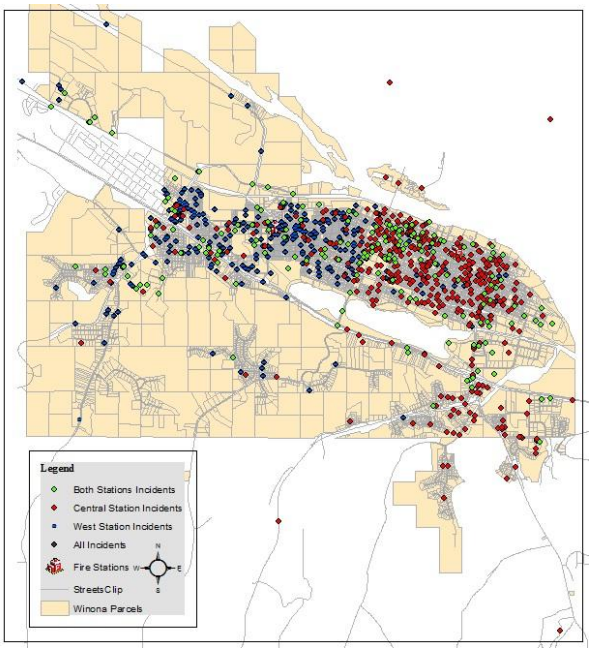

Figure 2. All actual emergency incidents, central station response incidents (red points), west station response incidents (blue points) and both stations response incidents (green points).

Service Areas

The network analysis involved using the emergency street network dataset and the Network Analysts Service Area tool to calculate four minute response service areas. The fire station locations were loaded as the facilities and analysis settings were set to have time serve as the impendence value, default break value set as four, direction set as away from facility and u-turns allowed. Additional settings were set to return detailed polygons, line generations and accumulation attributes for time and distance.

This analysis was used to determine individual and joint station service areas using four minutes as the service area based on the national standards NFPA 1221 and NFPA 1710 time objectives. The standards state that after receiving a call for assistance the fire department shall respond with a unit to that location within four minutes to 90 percent of the area served (ESRI White Paper, 2007).

Closest Facility

The network analysis also used the Closest Facility tool to calculate route times to incident locations. The station locations were loaded as the facilities and the station incidents were loaded as the incident locations. The analysis settings were set for time to serve as the impendence, travel from set as facility to incident and u-turns allowed. In addition accumulated attribute settings were set to return time and distance. Using these settings the analysis generated the best route from each station to each incident location.

The results determined the fastest route to each incident and developed an attribute table that included time and distance for each incident. These results only indicated the travel times to incident locations so a new field was created to add one minute to the travel times to account

for turn out time. This resulted in new GIS modeled incident response times and routes for the central station (Figure 3), west station (Figure 4) and both stations (Figure 5).

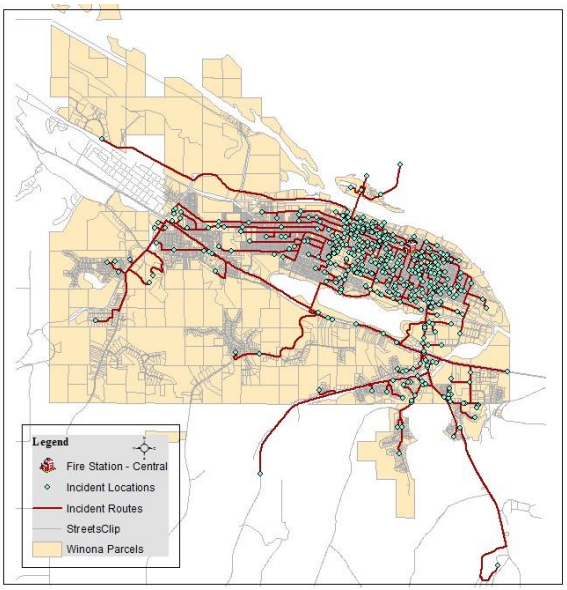

Figure 3. In this map are the GIS Network incident locations (green points) and routes (red lines) for the 803 incidents responded to by the Central Fire Station.

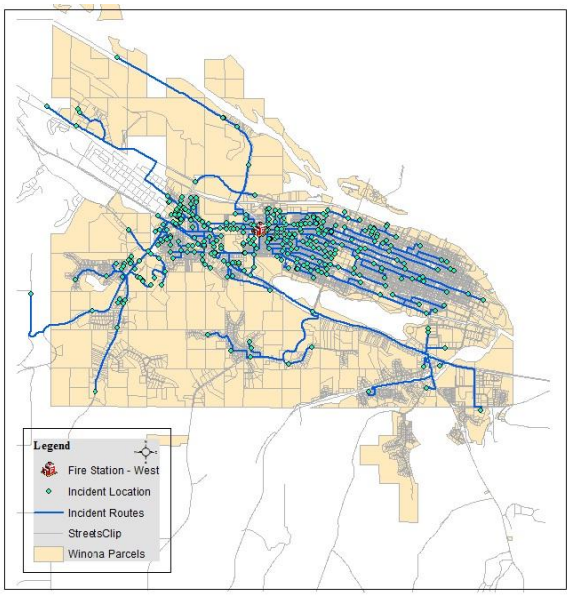

Figure 4. In this map are the GIS Network incident locations (green points) and routes (blue lines) for the 597 incidents responded to by the West Fire Station.

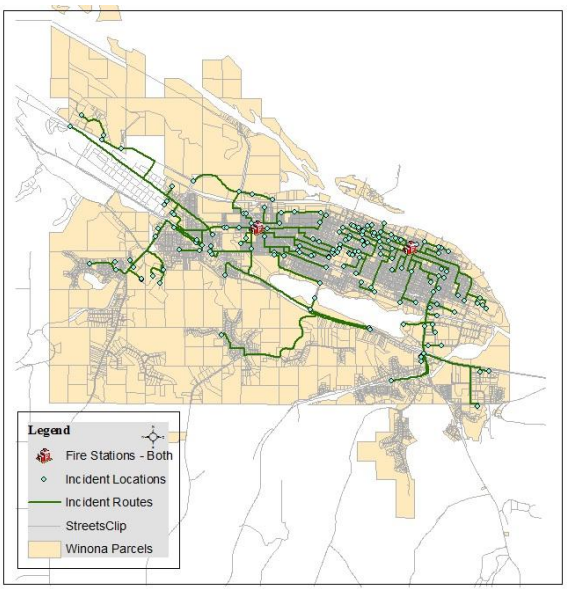

Figure 5. In this map are the GIS Network incident locations (green points) and routes (green lines) for the 209 incidents responded to by both fire stations.

Detailed Service Area Incident Analysis

This analysis used the GIS service areas and the Select by Location tool to query incidents within the corresponding service areas. The process selected the actual incidents and the GIS modeled incidents for the central station, west station and both stations responding that the service areas contained.

This was performed as an overall analysis of department incidents and as a station incident analysis. The results were exported as feature classes where the Select by Attributes tool was used to query for response times over four minutes. These incidents were then export again as new feature classes. This analysis was important because it identified the locations of incidents within the service areas as well as those greater than four minutes. Using this data, areas of concern were developed to illustrate areas where expected response times are not being met.

Areas of Concern Analysis

This analysis involved examining the feature class data for incident response times over four minutes. The analysis identified areas where incidents were concentrated and illustrated high density call areas. The results identified the areas of concern at the overall analysis level, station analysis level, and the detailed service area level. The results at these levels indicated areas where multiple incidents occurred with response times greater than four minutes.

Statistical Analysis

This analysis began by exporting feature class attribute tables for the actual emergency response times recorded by the fire department and the theoretical GIS modeled incident response times. This data was statistical analyzed using SPSS where the frequency analysis method calculated the average response time and the 90th percentile value of the response times.

The 90th percentile was used as a time measurement because it ranks data to identify the response time value for 90% of the data. This indicates whether the performance measures for responding to 90% of all incidents within four minutes are being accomplished.

The overall statistical analysis examined all emergency incidents that the department responded to (Table 1). The station response analysis examined the emergency incidents responded to by the central station, west station and both stations (Table 2). The detailed service area analysis examined incidents in the four minute service areas for all incidents and incidents responded to by each station (Table 3). The statistics identify the total number of incidents, average response times, 90th percentile times and the total incidents in the service area.

Table 1. The overall department statistical analysis results for the actual and GIS data.

	Actual Data
Total # of Incidents	1609
Average Response Time	3:31
90th Percentile	6:00
	GIS Data
Total # of Incidents	1609
Average Response Time	2:35
90th Percentile	4:00

Table 2. The station incident statistical analysis results for the actual and GIS data.

Actual Data	**Central**	**West**	**Both**
Total Incidents	803	597	209
Average Time	3:22	3:44	3:32
90th Percentile	5:00	6:00	6:00
GIS Data	**Central**	**West**	**Both**
Total Incidents	803	597	209
Average Time	2:47	2:51	2:37
90th Percentile	4:56	4:11	4:10

Table 3. The detailed service area statistical analysis results for the actual and GIS data.

Actual Data	**Central**	**West**	**Both**	**All**
Total Incidents	803	597	209	1609
Service Area	719	569	202	1542
Average Time	3:10	3:37	3:30	3:25
90th Percentile	5:00	6:00	6:00	6:00
GIS Data	**Central**	**West**	**Both**	**All**
Total Incidents	803	597	209	1609
Service Area	733	570	203	1554
Average Time	2:29	2:44	2:32	2:29
90th Percentile	3:50	4:10	3:54	3:52

Comparative Analysis

This analysis was performed at a detailed level and required more statistical data. The response time attributes were examined, queried, and selected to calculate the total incidents for specific

time intervals.

The analysis compared the actual incident data against the GIS incident data to identify the differences between the datasets. The results produced an in-depth analysis and a more accurate depiction of the response times versus the current emergency response performance.

Results

Comparative Analysis Results

Incorporating GIS into the response process provided the ability to examine emergency data at multiple scales. The results of the comparative analysis reveal opportunities for significant response time and service improvements. This analysis was important because it analyzed and compared the response time data at the following levels: (1) overall analysis of department incidents, (2) station response analysis and (3) detailed service area incident analysis.

Overall Comparative Analysis of Department Incidents

The results for this analysis are illustrated in (Table 4) and indicate the GIS average response time as 2:35 minutes an improvement of 56 seconds, the 90th percentile time as 4:10 minutes an improvement of 1:50 minutes, the total four minute calls as 1424 an improvement of 181 calls and the department service as 89% an improvement of 11% to calls responded to in four minutes.

The results of this analysis also identified the differences for the total number of incidents for specific response time intervals, the percentage of calls responded to in four minutes and the overall department service performance improvements.

Table 4. The overall comparative results are identified in the CR (Comparative Results) column.

Overall	Actual Data	GIS Data	CR
Total # of Incidents	1609	1609	0
Average Response Time	3:31	2:35	0:56
90th Percentile	6:00	4:10	1:50
< 1 Minute	9	0	9
1-2 Minute	75	493	418
2-3 Minute	397	742	345
3-4 Minute	760	189	571
> 4 Minute	366	185	181
4-8 Minute	346	185	161
> 8 Minute	20	0	20
Total within 4 Minute	1241	1424	181
% Calls < 4 minutes	78%	89%	11
% Calls < 8 minutes	99%	100%	1

Station Response Comparative Analysis

The station analysis compared the response times among the actual incidents and the GIS modeled incidents for the central station, west station and both stations responding. The results identify key time components, incident totals for various time intervals and the difference between the datasets. The results are shown in Table 5 and reveal the following:

- The central station results indicate the GIS average response time as 2:47 minutes an improvement of 35 seconds, the 90th percentile time as 4:56 minutes an improvement of 4 seconds, the total four minute calls as 668 an improvement of 9 calls and the department service as 83% an improvement of 1% to calls responded to in four minutes.

Table 5. The station incidents comparative results for Central, West, and Both Stations. The results are identified in the CR (Comparative Results) columns.

Station Analysis	Central Station			West Station			Both Stations		
	Actual	GIS	CR	Actual	GIS	CR	Actual	GIS	CR
Total Incidents	803	803	0	597	597	0	209	209	0
Average Time	3:22	2:47	0:35	3:44	2:51	0:53	3:32	2:37	0:55
90th Percentile	5:00	4:56	0:04	6:00	4:11	1:49	6:00	4:10	1:50
< 1 Minute	0	0	0	4	0	4	5	0	5
1-2 Minute	42	231	189	26	152	126	7	56	49
2-3 Minute	205	345	145	148	230	82	45	95	50
3-4 Minute	412	92	320	245	111	134	103	36	67
> 4 Minute	144	135	9	174	104	70	49	22	27
4-8 Minute	137	132	5	164	104	60	46	22	24
> 8 Minute	7	3	4	10	0	10	3	0	3
Total in 4 Min	659	668	9	423	493	70	160	187	27
% of Calls 4 Minutes or Less	82	83	1	71	83	12	77	90	13
% of Calls 8 Minutes or Less	99	99	0	98	100	2	98	100	2

- The west station results indicate the GIS average response time of 2:51 minutes an improvement of 53 seconds, the 90th percentile time as 4:11 minutes an improvement of 1:49 minutes, the total four minute calls as 493 an improvement of 70 calls and the department service as 83% an improvement of 12% to calls responded to in four minutes.
- The results for both stations indicate the GIS average response time as 2:37 minutes an improvement of 55 seconds, the 90th percentile time as 4:10 minutes an improvement of 1:50 minutes, the total four minute calls as 187 an improvement of 27 calls and the department service as 90% an improvement of 13% to calls responded to in four minutes.

Detailed Comparative Analysis

This analysis examined the detailed service area incident response times for the central station, west station, both stations and all incidents within the service areas, along with the incidents with response times greater than four minutes.

The complete results identify key time components, incident totals for various time intervals and the difference between the datasets. In addition, the results identify the total number of incidents residing in the service area with response times over four minutes. The analysis results were separated by station but to view the complete statistical analysis attribute table refer to (Appendix A).

The results for the central station (Table 6) indicate the GIS average response time as 2:29 minutes an improvement of 41 seconds, the 90th percentile time as 3:50 minutes an improvement of 1:10 minutes, the total four minute calls as 668 an improvement of 9 calls and the department service as 91.13% an improvement of 3.79% to calls responded to in four minutes.

The results also identified that the total number of incidents over four minutes were reduced by 26 calls totaling only 65 calls over four minutes in the service area.

Table 6. The Central Station detailed service area comparative analysis; the results are identified in the CR (Comparative Results) column.

Detailed	Central Station		
	Actual	GIS	CR
Total # of Incidents	803	803	0
Total Calls in Service Area	719	733	14
Average Response Time	3:10	2:29	0:41
90th Percentile	5:00	3:50	1:10
< 1 Minute	0	0	0
1-2 Minute	41	231	190
2-3 Minute	198	345	147
3-4 Minute	389	92	297
> 4 Minute	91	65	26
4-8 Minute	86	65	21
> 8 Minute	5	0	5
% of Calls 4 Minutes or Less	87.34	91.13	3.79
% of Calls 8 Minutes or Less	99.3	100	0.7
% of Calls in Service Area	89.539	91.282	1.743
Total # of Calls in 4 Minutes	628	668	40
Total # of Calls Over 4 Minutes	91	65	26
% of Calls over 4 Minutes	12.656	8.867	3.789

Table 7. The West Station detailed service area comparative analysis; the results are identified in the CR (Comparative Results) column.

Detailed	West Station		
	Actual	GIS	CR
Total # of Incidents	597	597	0
Total Calls in Service Area	569	570	1
Average Response Time	3:37	2:44	0:53
90th Percentile	6:00	4:10	1:50
< 1 Minute	4	0	4
1-2 Minute	26	152	126
2-3 Minute	146	230	84
3-4 Minute	238	111	127
> 4 Minute	155	77	78
4-8 Minute	148	77	71
> 8 Minute	7	0	7
% of Calls 4 Minutes or Less	72.759	86.49	13.731
% of Calls 8 Minutes or Less	98.76	100	1.24
% of Calls in Service Area	95.309	95.477	0.168
Total # of Calls in 4 Minutes	414	493	79
Total # of Calls Over 4 Minutes	155	77	78
% of Calls over 4 Minutes	27.24	13.508	13.732

The results for the west station (Table 7) indicate the GIS average response time as 2:44 minutes an improvement of 53 seconds, the 90th percentile time as 4:10 minutes an improvement of 1:30 minutes, the total four minute calls as 493 an improvement of 79 calls and the department service as 86.49% an improvement of 13.73% to calls responded to in four minutes. The results also identified the total number of incidents over four minutes were reduced by 78 calls totaling 77 calls.

The results for both stations (Table 8) indicate the GIS average response time as 2:32 minutes an improvement of 58 seconds, the 90th percentile time as 3:54 minutes an improvement of 2:06 minutes, the total four minute calls as 187 an improvement of 30 calls and the department service as 92.57% an improvement of 14.85% to calls responded to in four minutes. The results also identified the total number of incidents over four minutes were reduced by 29 calls totaling 16 calls.

Table 8. Both stations detailed service area comparative analysis; the results are identified in the CR (Comparative Results) column.

Detailed	Both Station		
	Actual	GIS	CR
Total # of Incidents	209	209	0
Total Calls in Service Area	202	203	1
Average Response Time	3:30	2:32	0:58
90th Percentile	6:00	3:54	2:06
< 1 Minute	4	0	4
1-2 Minute	7	56	49
2-3 Minute	45	95	50
3-4 Minute	101	36	65
> 4 Minute	45	16	29
4-8 Minute	42	16	26
> 8 Minute	3	0	3
% of Calls 4 Minutes or Less	77.72	92.57	14.85
% of Calls 8 Minutes or Less	98.514	100	1.486
% of Calls in Service Area	96.65	97.129	0.479
Total # of Calls in 4 Minutes	157	187	30
Total # of Calls Over 4 Minutes	45	16	29
% of Calls over 4 Minutes	22.277	7.881	14.396

Table 9. The detailed service area comparative analysis for all incidents; the results are identified in the CR (Comparative Results) column.

Detailed	All Incidents		
	Actual	GIS	CR
Total # of Incidents	1609	1609	0
Total Calls in Service Area	1542	1554	12
Average Response Time	3:25	2:29	0:56
90th Percentile	6:00	3:52	2:08
< 1 Minute	7	0	7
1-2 Minute	75	493	418
2-3 Minute	396	742	346
3-4 Minute	747	189	558
> 4 Minute	316	130	186
4-8 Minute	300	130	170
> 8 Minute	16	0	16
% of Calls 4 Minutes or Less	79.44	91.63	12.19
% of Calls 8 Minutes or Less	98.89	100	1.11
% of Calls in Service Area	95.835	96.581	0.746
Total # of Calls in 4 Minutes	1225	1424	199
Total # of Calls Over 4 Minutes	316	130	186
% of Calls over 4 Minutes	20.492	8.365	12.127

The results (Table 9) for all incidents indicate the GIS data's average response time as 2:29 minutes an improvement of 56 seconds, the 90th percentile time as 3:52 minutes an improvement of 2:08 minutes, the total four minute calls as 1424 an improvement of 199 calls and the department service as 91.63% an improvement of 12.19% to calls responded to in four minutes. The results also identified the total number of incidents over four minutes were reduced by 186 calls totaling 130 calls.

Service Area Results

The results developed through the GIS analysis calculated new service areas for the central fire station, west fire station and both stations responding. The results illustrate the coverage areas that emergency apparatus can respond to within four minutes and the accessible streets. These results provided more accurately depicted service areas for the central station (Figure 6) and the west station (Figure 7).

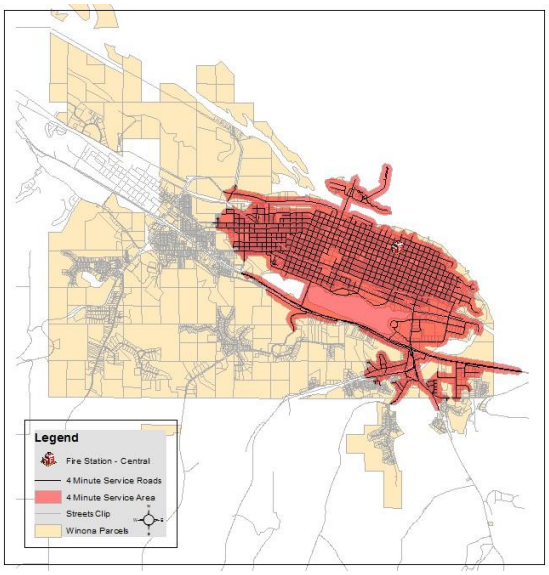

Figure 6. This map illustrates the Central Fire Stations service area (red polygon) and service roads. This service area allows adequate response cover for 5.468 square miles in four minutes.

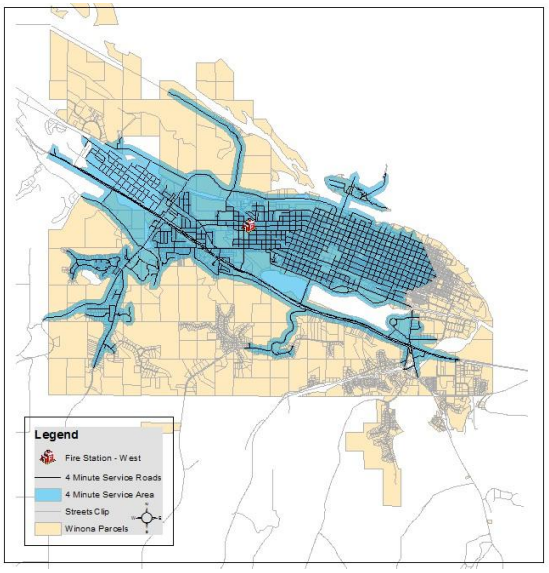

Figure 7. This map illustrates the West Fire Stations service area (blue polygon) and service roads. This service area allows for adequate response cover for 7.6808 square miles in four minutes.

The service area results for both stations (Figure 8) illustrate the total coverage area for both stations responding and the full department response capability in four minutes.

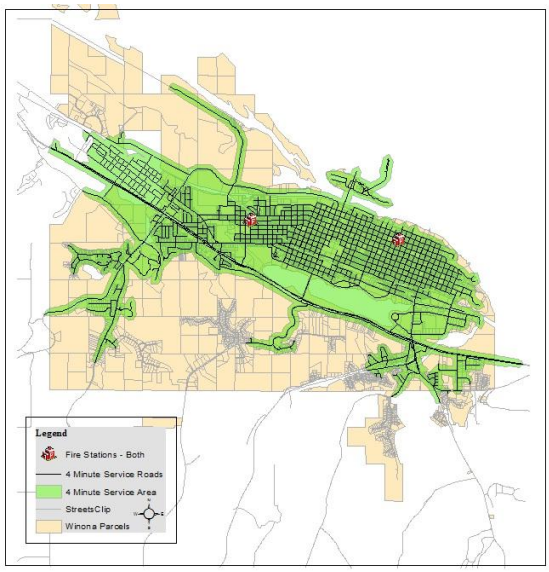

Figure 8. This map illustrates the department service area for both fire stations (green polygons) and service roads. This service area allows adequate response cover for 9.3901 square miles in four minutes.

Detailed Service Area Results

This analysis identified the incidents contained in the service areas and those with response times over four minutes. These results were used to determine the areas of concern (Figure 9).

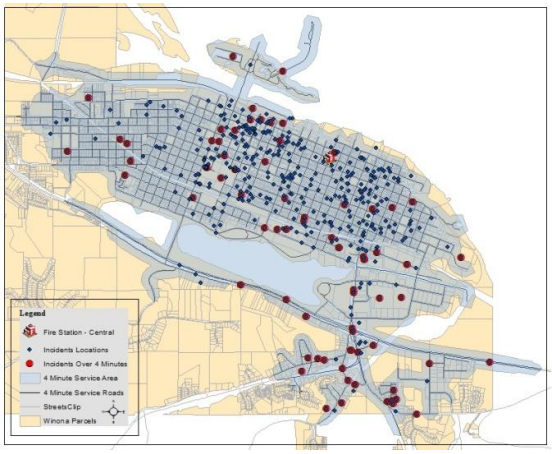

Figure 9. An example of the service area incident analysis used for developing areas of concern in service areas. This map illustrates the central stations service area, actual incidents in the service area (blue points) and the actual incidents over four minutes (red points).

Areas of Concern Results

This analysis identified areas where incidents continually occurred with response times over four minutes.

Central Fire Station

The results for the GIS modeled data identified 50 of the 65 incidents were highly concentrated in the areas of concern (Figure 10). The results for the actual data indicated that 52 of the 91 incidents were highly concentrated in the areas of concern (Figure 11).

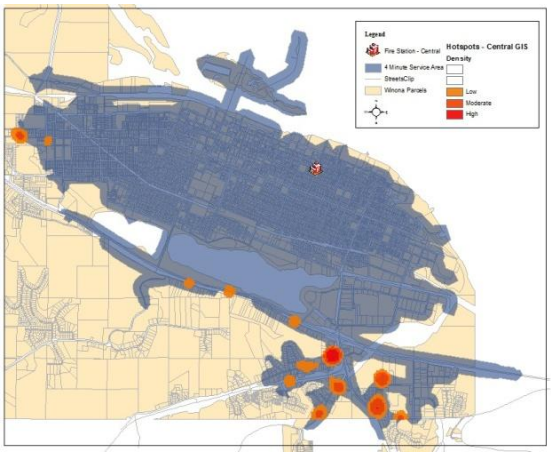

Figure 10. This map illustrates the Central Fire Station service area and the GIS areas of concern with response times over four minutes.

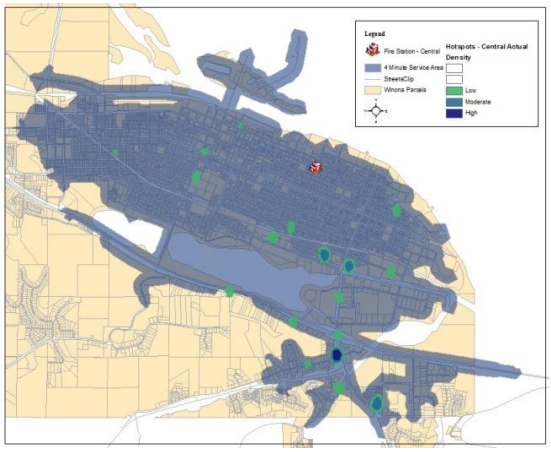

Figure 11. This map illustrates the Central Fire Station service area and the actual areas of concern with response times over four minutes.

West Fire Station

The results for the GIS modeled data identified 51 of the 77 incidents were highly concentrated in the areas of concern (Figure 12). The results for the actual data indicated that 93 of the 155 incidents were highly concentrated in the areas of concern (Figure 13).

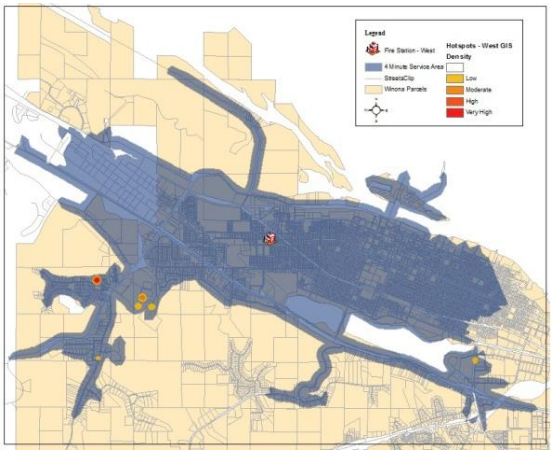

Figure 12. This map illustrates the West Fire Stations service area and the GIS areas of concern with response times over four minutes.

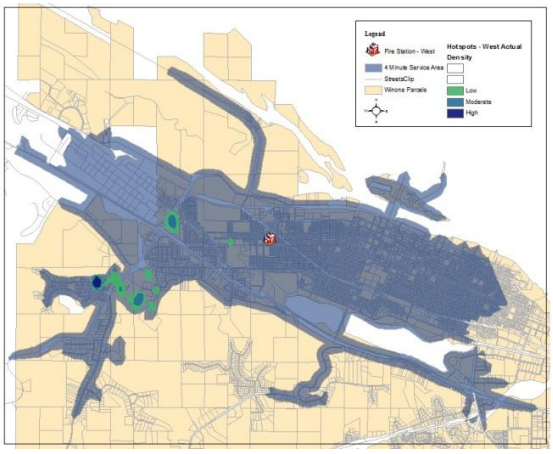

Figure 13. This map illustrates the West Fire Stations service area and the actual areas of concern with response times over four minutes.

Both Fire Stations

The results for the GIS modeled data identified 7 of the 16 incidents were highly concentrated in the areas of concern

(Figure 14). The results for the actual data indicated that 7 of the 45 incidents were highly concentrated in the areas of concern (Figure 15).

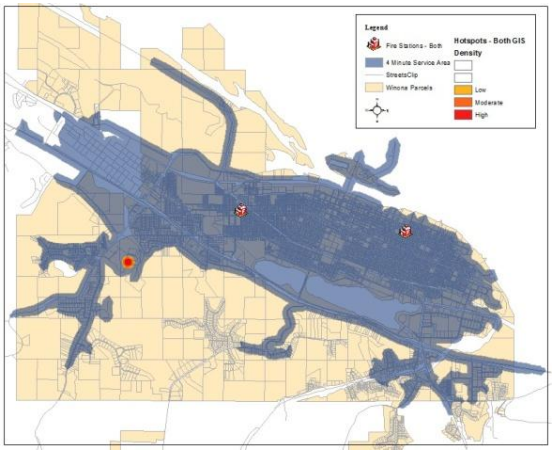

Figure 14. This map illustrates the service area for both fire stations and the GIS areas of concern with response times over four minutes.

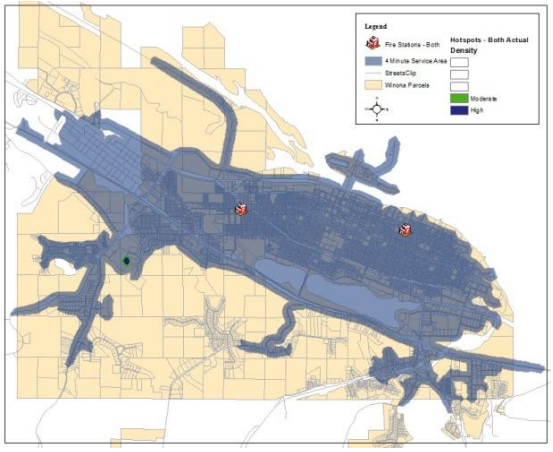

Figure 15. This map illustrates the service area for both fire stations and the actual areas of concern with response times over four minutes.

All Department Incidents

The results for the GIS modeled data identified 116 of the 130 incidents were highly concentrated in the areas of concern (Figure 16). The results for the actual data indicated that 169 of the 316 incidents were highly concentrated in the areas of concern (Figure 17). This indicates the areas of concern of all incidents the department responded to that are within the department's service area.

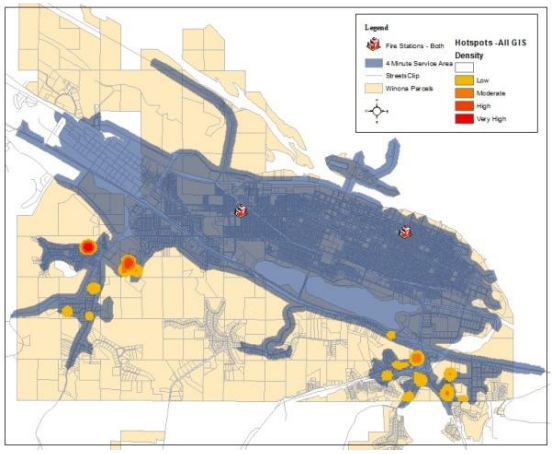

Figure 16. This map illustrates the service area for all incidents and the GIS areas of concern with response times over four minutes.

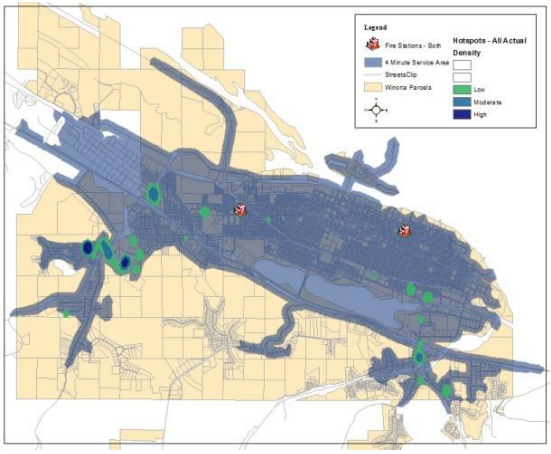

Figure 17. This map illustrates the service area for all incidents and the actual areas of concern with response times over four minutes.

Discussion of Results

This project is merely a theoretical analysis of emergency response time data where the results indicate potential improvements that GIS may be able to provide to the City of Winona emergency services.

The analysis implemented actual emergency incident locations and response times to calculate theoretical GIS modeled response times. This allowed for a

comparative analysis between the actual and GIS modeled response times where the results indicated significant response improvements by using GIS in the response process.

The traditional method for responding to incident locations involves using the primary city streets as response routes. The GIS model moved beyond the traditional method by calculating the travel time of each road segment, determined the fastest route to each incident, in turn reduced incident response times and increased the effectiveness of the overall department emergency services.

The analysis indicated current service areas for stations only illustrate the total coverage area for each station and the department as a whole. The GIS model calculated theoretical service areas based on response times and illustrated the potential coverage areas at a detailed level. The results of the potential service areas provide an improved understanding for service capabilities to the community based on response times.

The comparative analysis of actual and GIS response times demonstrated that the theoretical GIS model response times were able to significantly improve response times for each station and all department incidents. Results indicated potential improvements for: average response times, 90^{th} percentile times, total incidents responded to at various time intervals and service performance.

Analysis results for the areas of concern indicated that both datasets contained areas of concern within the service areas, shared similar locations and through using GIS some of these areas were eliminated. Overall, the GIS data eliminated areas of concern that shared a close proximity to station locations but increased them along the perimeter of the service areas. The results also identified similar locations between the datasets displaying the potential areas of concern where response times over four minutes continually occurred.

Limitations of Results

Possible limitations and sources of error for this project could be due to several factors. This project focused on analyzing the response times to incident locations but factors such as weather, traffic volume, railway traffic, road conditions and construction projects were not accounted for during the network analysis.

Other factors that were not accounted for and could influence the data results are emergency call volume and incident severity. These factors could be used in a future study of emergency response time data allowing for an even more in-depth analysis.

Sources of error in this project may be linked to the design of the street network using emergency travel speed limits instead of actual posted speed limits. Another source of error that might have affected the data results may be linked to incidents missing in the data obtained from the fire department.

Conclusion

The analysis methods used in this project provided results indicating significant response time improvements for overall department performance, station response performance, and detailed service area performance using GIS.

The analysis of the data at these levels identified new service areas based on response times, areas of concern in service areas, the performance levels for station response times, the advantages of using GIS in the response process and the areas where response improvements can

be made.

GIS analysis provides an advantage to understanding response time data and is capable of analyzing the data to determine performance measures. The Commission on Fire Accreditation International (2005) suggests "Once a GIS database has been created, deployment analysis can be reviewed and updated at any time with little effort. GIS allows deployment analysis to become a process rather than a periodic event."

The fire service now has a powerful platform in GIS to better optimize resources, improve service delivery, reduce losses, and improve fire fighter safety. This can be deployed in small steps or through a departmental enterprise approach. How an organization chooses to proceed, having a well-thought-out strategy and a long-term goal will enable it to scale and grow as needed (ESRI White Paper, 2012).

Acknowledgments

This project involved obtaining a lot of data and I would like to thank Tom Hoffmann and the Winona County Planning Department for allowing me to obtain and use the county GIS datasets.

I would also like to thank the Winona Fire Department for providing the emergency incident response data and for answering my questions on emergency response.

This project was conducted using methods determined through the research, but I would like to acknowledge the use of Christopher Cantrell's graduate project "Comparative Analysis of Response Times between Actual Emergency Responses and Geographic Information Systems Developed Emergency Responses for Midland County, Michigan" as a formatting and organizational guide.

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Appendix A. Detailed Service Area Comparative Analysis Statistics.

	Central Station			West Station			Both Stations			All Calls		
	GIS	Actual	CR	GIS	Actual	CR	GIS	Actual	CR	GIS	Actual	CR
Total # of Incidents	803	803	0	597	597	0	209	209	0	1609	1609	0
Total Calls in Service Area	733	719	14	570	569	1	203	202	1	1554	1542	12
Average Response Time	2:29	3:10	0:41	2:44	3:37	0:53	2:32	3:30	0:58	2:29	3:25	0:56
90th Percentile	3:50	5:00	1:10	4:10	6:00	1:50	3:54	6:00	2:06	3:52	6:00	2:08
< 1 Minute	0	0	0	0	4	4	0	4	4	0	7	7
1-2 Minute	231	41	190	152	26	126	56	7	49	493	75	418
2-3 Minute	345	198	147	230	146	84	95	45	50	742	396	346
3-4 Minute	92	389	297	111	238	127	36	101	65	189	747	558
> 4 Minute	65	91	26	77	155	78	16	45	29	130	316	186
4-8 Minute	65	86	21	77	148	71	16	42	26	130	300	170
> 8 Minute	0	5	5	0	7	7	0	3	3	0	16	16
% of Calls 4 Minute or Less	91.13	87.34	3.79	86.49	72.759	13.731	92.57	77.72	14.85	91.63	79.44	12.19
% of Calls 8 Minute or Less	100	99.3	0.7	100	98.76	1.24	100	98.514	1.486	100	98.89	1.11
% of Calls in SA	91.282	89.539	1.743	95.477	95.309	0.168	97.129	96.65	0.479	96.581	95.835	0.746
Total # of calls within 4 Minutes	668	628	40	493	414	79	187	157	30	1424	1225	199
Total # of calls over 4 Minutes	65	91	26	77	155	78	16	45	29	130	316	186
% of calls over 4 Minutes	8.867	12.656	3.789	13.508	27.24	13.732	7.881	22.277	14.396	8.365	20.492	12.127