REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
25-05-2019	MASTER'S CAPSTONE PROJECT	

4. TITLE AND SUBTITLE

A GIS SYSTEMS ENGINEERING APPROACH TO OPTIMIZE EMS RESPONSE TIMES IN TOMPKINS COUNTY, NEW YORK

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Civilian Institutions Office (Code 522)
Naval Postgraduate School
1 University Circle, Herrmann Hall Rm HE046
Monterey, CA 93943-5033

10. SPONSOR/MONITOR'S ACRONYM(S)

NPS CIVINS

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Tompkins Emergency Medical Services (EMS) system is unlike many other systems. It is an intricate system involving many subsystems, people, locations, and motivations. The goal of optimization or streamlining is an impossible task without the full understanding of system components including political personalities, geographical barriers, fiscal differences, and legal ramifications. Realizing this, a full "systems approach" is the ideal method to address the county's EMS system deficiencies. The report explains the application of each system tool. Seen early on, the abstract application of some tools is necessary to increase utility. Ultimately, the full system process increased understanding of the complete EMS network resulting in feasible and practical solutions to implement.

15. SUBJECT TERMS

Optimization, EMS, ambulance service optimization, GIS tools

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPONE NUMBER (*Include area code*)
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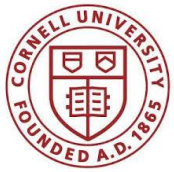

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Introduction

The Tompkins Emergency Medical Services (EMS) system is unlike many other systems. It is an intricate system involving many subsystems, people, locations, and motivations. The goal of optimization or streamlining is an impossible task without the full understanding of system components including political personalities, geographical barriers, fiscal differences, and legal ramifications. Realizing this, a full "systems approach" is the ideal method to address the county's EMS system deficiencies. The sections below explain the application of each system tool. Seen early on, the abstract application of some tools is necessary to increase utility. Ultimately, the full system process increased understanding of the complete EMS network resulting in feasible and practical solutions to implement.

I. Problem Analysis

The current method of providing emergency response is known as the "two-tier" system. The first tier is volunteer rescue squads. These are operated by fire departments and are currently the primary and most desired method of providing first response. Most fire departments have a form of volunteer rescue squad capability. The second tier is the ambulance companies. There are four ambulance companies in Tompkins County, Groton Ambulance, Dryden Ambulance, Trumansburg Ambulance, and Bangs Ambulance. Each tier operates independently of the other even though they share the responsibility of first response. Achieving rescue squad first response is generally preferable. Rescue squad first response is the most desired manner of first response because usually there is a local rescue squad vehicle closer to the emergency call, and since the responders are volunteers, cost significantly less than paid ambulance response. The final component of the two-tier system, although not a tier itself, is the Department of Emergency Response (DER). The DER does not directly supervise or control either the ambulance companies or fire departments. It does however maintain an indirect responsibility for their performance and that of general county EMS functions. The DER is also directly responsible for the 911 dispatch center which activates resources according to availability and location.

II. Requirements

The complexities of the county EMS system, including numerous relationships, and a high number of stakeholders, make a Systems Engineering approach ideal for this problem. To fully define the problem and requirements of EMS in the county, four high level goals were developed through stakeholder interaction: *1. Make the system address acute demand failures, 2. Engage, develop, and recruit volunteers, 3. Optimize county EMS resources, 4. Create a shared vision for all EMS providers in the county* (McCarthy, 2018). System performance according to these goals was measured using response time averages. These goals were developed in a previous semester. Various groups of Cornell students are helping to tackle these goals, however this report focuses on goals 1 and 3.

Developing the functional requirements from the above stated goals is an iterative process where requirements and system characteristics are continuously refined. If requirements are not approved by stakeholders, then a potentially unusable solution could be developed.

Use case behavioral diagrams were used to glean originating requirements. These requirements are strictly functional in nature and defined the aspects of a quality system without defining what the system should look like. This tool proved to be extremely useful in the development of benchmarks and standards within the system. It is understood that the EMS system should be required to meet a time standard for response, but at first, these values, and how to achieve them, were not fully understood. Placeholders were created to represent a benchmark value which the system would need to meet. After further engagement with the stakeholder, and research into national standards, a response time average of 14 minutes was agreed upon.

Further requirements can be viewed in appendix A.

III. Solution Definition

Response times are still the main metric utilized to determine overall system performance, as the proper flow and completion of system functions are required to achieve desired results. The complete response process includes acknowledgement of the 911 (alarm answering time), determining the responsible asset by the dispatcher, and notifying that asset (alarm processing time), first responder preparation time from the receipt of call (turnout time), travel time, and movement of personnel and medical supplies from emergency vehicle to the patient's side (intervention time).[1] Response times are valuable to consider because multiple systems and relationships are tested by a single response. Additionally, through travel times, total response time also captures the importance of geographical distance from call origin to first responder originating location (McCarthy)

The value in analyzing response times is not in the time itself, but rather in their deviation from standards established by decision making authorities. Tompkins County does not have EMS response time standards and nationwide benchmarks are also limited. The National Fire Protection Agency (NFPA) 1720 Manual sets guidelines for volunteer organizations yet does not indicate standards for EMS provision. It does however list response time standards for fire response. Because these values are determined through population density, they fit appropriately to our problem and will be applied to EMS provision for this study.

[1] Since the county 911 dispatch center receives all emergency calls directly and answers them immediately, alarm handling time, alarm transfer time, and alarm answering time are not applicable. The average processing time for a 911 call is 73 seconds from when the call was answered.

Figure 1: National Fire Protection Agency 1720 Response Time Standards (Volunteer Fire- Applied to EMS) (NFPA 1720, 2004)			
Demand Zone	*Demographics Population/ mi^2*	*Response Time (Minutes)*	*Applicable Departments*
Urban	>1000	9	Ithaca*
Suburban	500-1000	10	Cayuga Heights
Rural	<500	14	All others
Remote	Travel dist. > 8 mi.	None	
** Response time standard for career department is 7.17 minutes (NFPA 1710)*			

According to population density, most fire departments and volunteer rescue squads in the county are responsible for rural and suburban regions. By using 1720 fire response standards, an EMS response time of 10-14 minutes in these areas is acceptable. This point is critical for expectation management and future decisions towards solution implementation. For many EMS experts, a response time of 14 minutes is appalling, especially for severe calls. But for others who understand the difficulties of providing first response, especially in rural areas, 14 minutes is reasonable. Before performance can be categorized as acceptable or unacceptable, a consensus must be reached on response time standards for the county as a whole and also for individual regions in the county.

IV. Structural Alternatives

The way forward for Tompkins County EMS is still unknown, but multiple approaches are likely, including efforts to increase volunteer EMTs, hiring new paid EMTs, the use of "fly cars", and the stationing of ambulances at various nodes at particular locations in the county. A volunteer recruiting and hiring process improvement was proposed by Stephen McCarthy and TF EMS, and is being worked on by a separate group of Cornell students. (McCarthy)(TCDER)

The different solutions vary greatly in cost. A patient in need who obtains ALS care in the fastest manner possible greatly increases their odds for survival and recovery. That is why response time is the supreme metric in this systems analysis, but that does not necessarily mean more ambulances are needed. Fly cars, which could provide effective and expert first response by an EMT with an Automatic Defibrillator (AED) and ALS (Advanced Life Saving) bag, cost about $40,000 initially for a vehicle and medical supplies, plus $68,000 per year for EMT salary and maintenance. A new ambulance, fully outfitted costs on average $220,000 dollars, plus at least double the 68k for EMT salary, and more for as many crew needed (McCarthy). Fly cars are a relatively quick and relatively inexpensive potential solution.

A natural idea to reach an acceptable level of first response is to "pool" resources within the county. Under this process, rescue squads and ambulances intended for use in specific districts would be available to share with nearby districts in need. This process is formally known as mutual aid. For it to be effective, one or more departments must have the capability to respond to more calls than their anticipated and actual requirement. Even with special mutual aid districts which attempt to define the support relationships, the current system does not provide a guarantee on response times for those districts receiving support. Furthermore, mutual aid causes strain on the supporting fire department in monetary expense and resource consumption. Because of mutual aid, some departments who assist others have been unable to

meet their own demand because their own EMS resources are occupied in helping others (Butler, 2017).

A significant portion of Tompkins County already depends on resource pooling, for example the towns of Caroline and Enfield, which extend to the far southeast and southwest of the county's boundaries, depend on both Dryden Ambulance(Caroline) and Bangs Ambulance Co. for their emergency transport and response services. Strategically placing first response vehicles, whether ambulances or fly cars, would ensure optimal response. This placement of vehicles has been the significant focus of the research, and will further be known as "ambulance nodes". The cost of ambulance nodes is difficult to quantify. The cheapest solution is to use existing fire houses or parking lots at strategic locations. This assumes that the existing ambulances in the county, Bangs, Groton, Dryden, and Trumansburg have excess capacity to assign ambulances or fly cars to these extra nodes. Currently, it seems that a combination of resource pooling and repositioning to provide optimal mutual aid and fly-cars, with to-be-agreed-upon compensation to increase available resources by the aided area, is the most attractive option.

V. Analysis and Optimization

Repositioning current ambulance nodes to provide mutual aid at the town level is the fastest approach for reducing county wide response times, due to the lack of legal restrictions. Also, the existing ambulance districts, such as Groton, Dryden and Ulysses (Trumansburg), may remain intact. To establish new Emergency Service districts in the rest of the county, each town must follow an approval process outlined in New York Town Law Article 12 and 12A (Town Article 12, 2016). The process, from introducing a motion by town boards to the holding of public hearings and financial planning may take up to five years. At this time, each town that decides to move forward may begin to grow funds for capital expenses needed to increase paid first responders. EMS services must be provided by a certified agency, and the ambulance companies are the logical candidates for increasing capacity. There are no legal restrictions on extending service areas or resources of regional ambulance companies, such as Groton, Dryden and Trumansburg, but since Bangs Ambulance maintains the certificate of need for the county, the natural means to achieving full paid first response is through them (EMS operating certificate, 2006). The cost of implementation of various solutions were explored in depth (McCarthy), so here the focus is the location optimization of the ambulance nodes.

The first iteration of optimization was with the goal of population-based redistricting with constraints. This is very similar to the practice of gerrymandering. Utilizing QGIS, the Tompkins County population was plotted in its respective census block. QGIS is a free, open-source software with robust data import capabilities. It is easily available at https://qgis.org. The population was represented using a dot, or centroid, labeled with the population in that particular block. The area of gerrymandering and political districting has made great advances in evenly and fairly distributing populations, and their research was the basis for this analysis. Using the shortest split-line algorithm Tompkins County was divided into nearly equal population districts by hand on the QGIS program. (Smith and Ryan) The shortest split-line algorithm is as follows:

- Start with the boundary outline of the state (here Tompkins County).
- Let N=A+B where N is the number of districts to create, and A and B are two whole numbers, either equal (if N is even) or differing by exactly one (if N is odd). For example, if N is 10, each of A and B would be 5. If N is 7, A would be 4 and B would be 3.
- Among all possible straight lines that split the state into two parts with the population ratio A:B, choose the *shortest*. If there are two or more such shortest lines, choose the one that is most north-south in direction; if there is still more than one possibility, choose the westernmost.
- We now have two hemi-states, each to contain a specified number (namely A and B) of districts. Handle them recursively via the same splitting procedure.
- Any human residence that is split in two or more parts by the resulting lines is considered to be a part of the most north-eastern of the resulting districts; if this doesn't decide it, then of the most northern.

During the next analysis, East and West lines were experimented with, as well as NW/SE and NE/SW lines along the major roadways in the county. Further analysis was completed using the software Maptitude.

The next step explored in reducing response times explored the possibility of solving a classic optimization problem. The aim in selecting locations for ambulances is to locate them as close as possible to the demand sites in order to shorten the response time, when demands can be served by any available resource. One of these models is the set covering model, where the question to be answered is: When there are a given number of people who require the service, how many resources should be located? So that everyone who is to be served is within a given distance from the nearest resource. As it is, there are already a fixed number of ambulances in Tompkins County, and it does not seem very probable that more resources are going to be acquired. Therefore, a maximum covering model, where the objective is to maximize the coverage provided by the resources, given that the resources are limited to a certain number. For the construction of an EMS model, we need to know the number of ambulances to be located, the

demands of the zones (nodes) and the distances between them. This information was gleaned through open source research.

Simulation is typically used when experimentation with the real system is too expensive, too dangerous, or not possible. (Banks, J., Carson, J., Nelson B) The EMS systems are highly complex systems that give rise to numerous challenges and cannot be solved with real-life testing. Therefore, simulation offers a natural framework within which to address these challenges and help us to gain knowledge about improvement of the system. In (Haghani, A., Yang, S.) the authors used a simulation model to the management of emergency vehicle fleet. They emphasized the integration and exchange of information across public safety and transportation agencies, and coordinated the activities of three public safety services, namely fire protection agencies, police and paramedic services. In (Li, G., Zhou, Y., Liu, M.), the authors established an optimization model based on the simulation of evacuation route that can simulate the evacuation traffic flow and proposed a heuristic algorithm for the optimization of the model. Simulation was also used in where several policies for districting/dispatching where proposed and provided as inputs to a simulation model that compares the performances of different policies.(Mayorga, M., Bandara, D., McLay, L.A) In this paper we are concerned with relocation strategies to manage the emergency vehicles based on population served, as well as considering historical need. For this purpose, a drive time simulation model from existing ambulance locations, as well as potential locations, is used to study and compare the performances and the impact of the relocation strategies under various scenarios based on the response time to emergencies and the coverage rates of the zones. This model takes into account the road network, including traffic conditions, distances, road type, and speed limits.

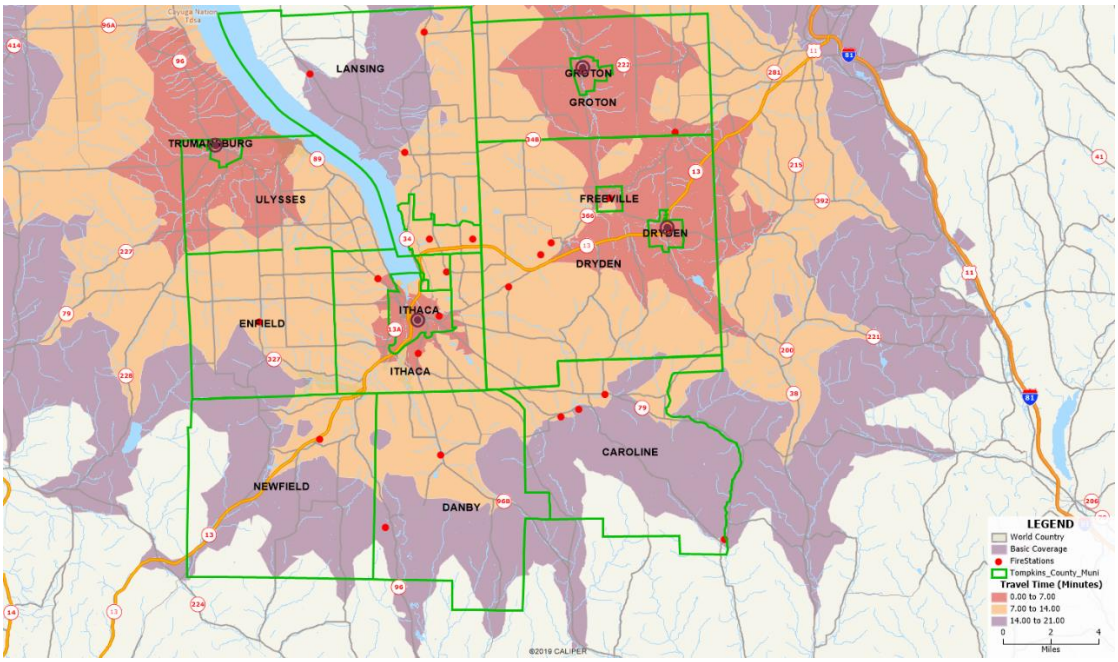

Figure 2: Current Tompkins County Coverage

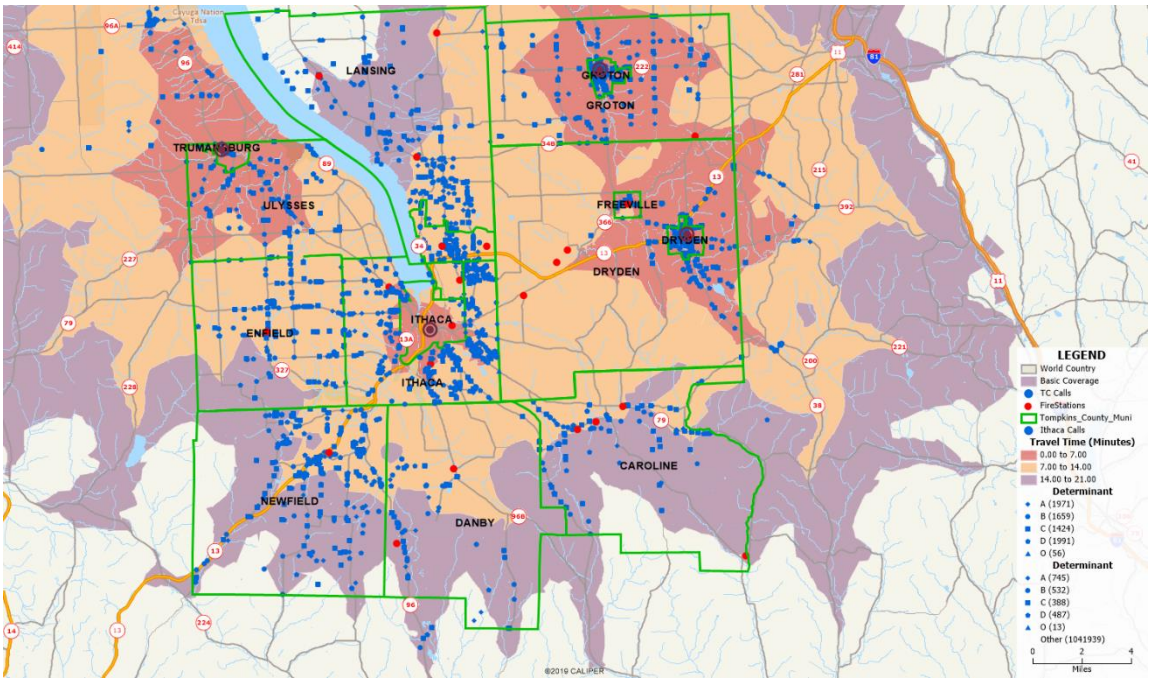

Figure 3: Current Tompkins County Coverage with 2015-2016 911 Call Data

These optimization methods were explored with the addition of some heuristic-based constraints. The number of emergency vehicles in the county is set, as well as most of the locations. For displaying response time results, the software Maptitude was used. Maptitude is a robust Geographic Information System (GIS) tool that includes population data, town/city/county/state boundaries, urban data, the ability to map, or "geo-code" addresses into points on the map, and most importantly a calculable road network with accurate speed limits and traffic data. Many other simulation tools were explored, but Maptitude was chosen for its ease of use and comprehensive image displaying ability. The specific algorithm and instructions used can be found in Appendix B. Maptitude is available from www.caliper.com, and costs a reasonable $695, although a free student license was used for this project.

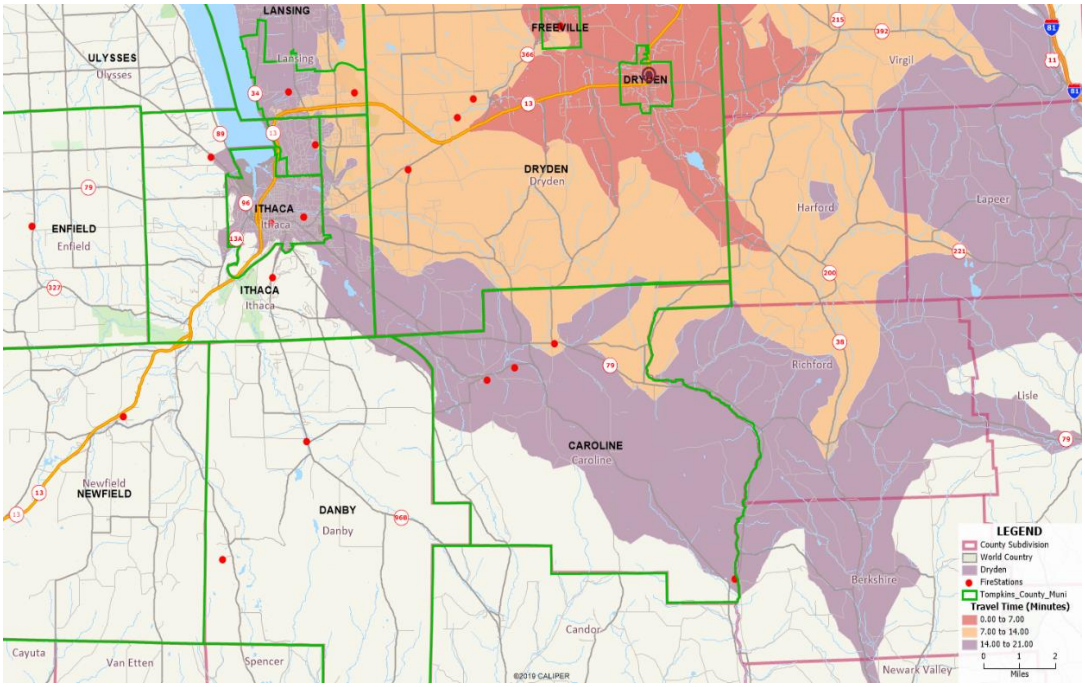

Figure 4: Response time from Dryden to Caroline.

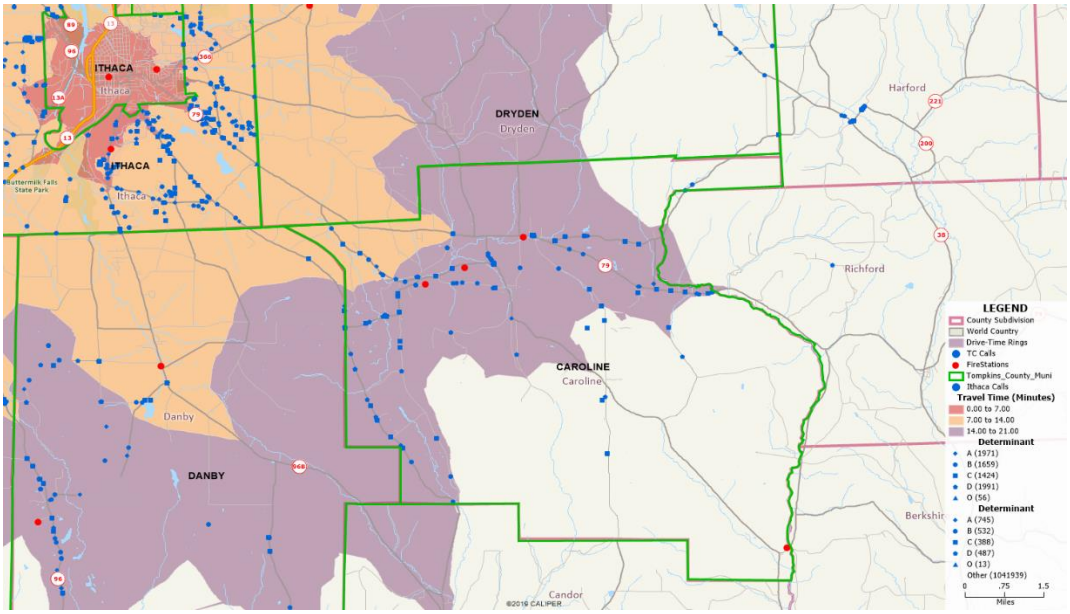

Figure 5: Response Time from Bangs Ambulance to Caroline w/ 2015-2016 911 Call Data

When using response rates and response times as metrics to determine capacity limits, Bangs, Cayuga Heights rescue, and Dryden Ambulance are the closest to having excess capacity as most of their response times are under ten minutes. Dryden Ambulance currently provides support to Caroline as well as parts of Cortland County, but because its area of responsibility is so large (Dryden town), it is not currently a reliable source of mutual for any other districts. Other significant potential resource pooling opportunities, Cayuga Heights Rescue(volunteer) and Bangs. Even though Cayuga Heights may have excess capacity, it is not able to support districts in need of the most assistance because of distance and travel time. Cayuga Heights could however provide marginally adequate aid to some areas of Lansing, at least those closest to the Ithaca and Lansing town boundary. Although, from figure 7, it is clear that a fly-car or ambulance solution at the Ridge St. Fire Station is the optimal solution for lowest response times in the northern section of Tompkins County.

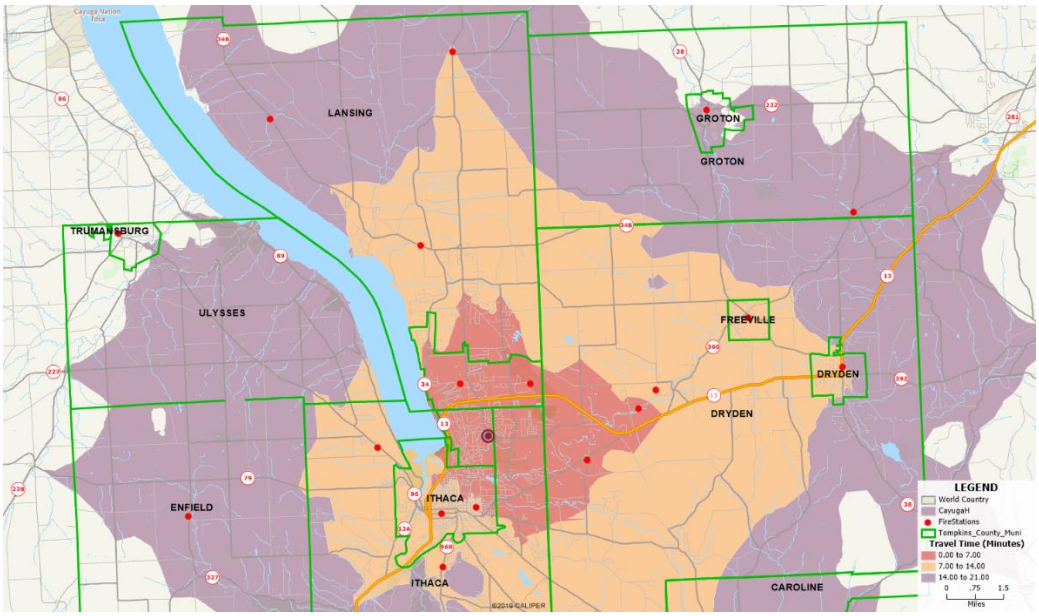

Figure 6: Response Times from Cayuga Heights

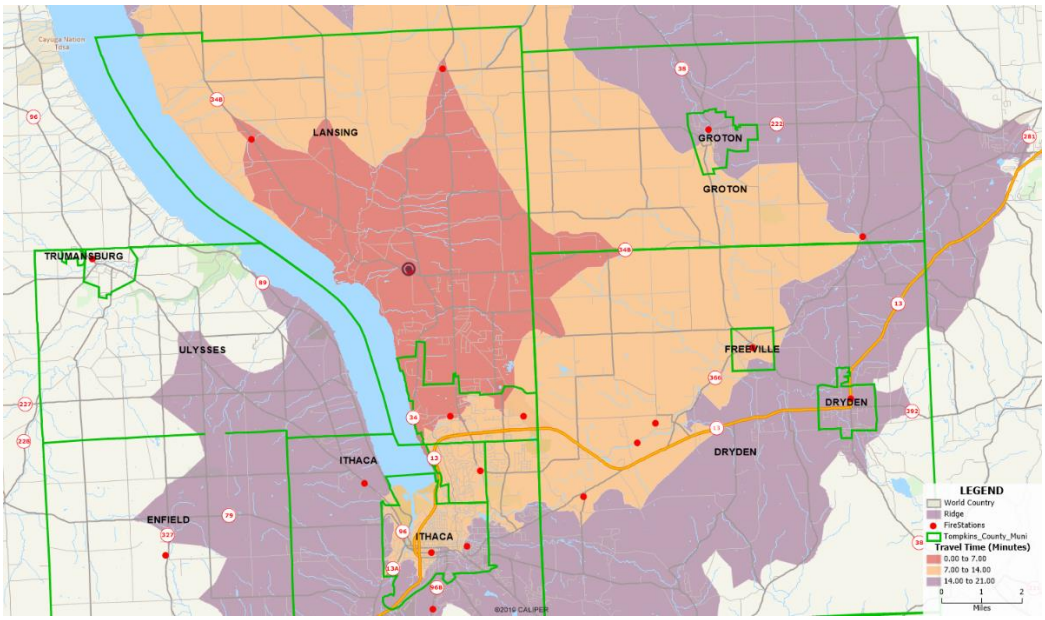

Figure 7: Response Time from Ridge St. Station

The second significant resource pooling opportunity would be utilizing Bangs Ambulance or fly-cars in the south east of Tompkins County. Positioning one emergency unit on the eastern edge of Ithaca, East Hill Plaza for instance, would enable rapid response times for

many areas in the towns of Caroline and Dryden while also enabling rapid response within many areas of Ithaca town. A unit at East Hill could respond to calls in Slaterville, a region with one of the poorest response time averages, within ten minutes.

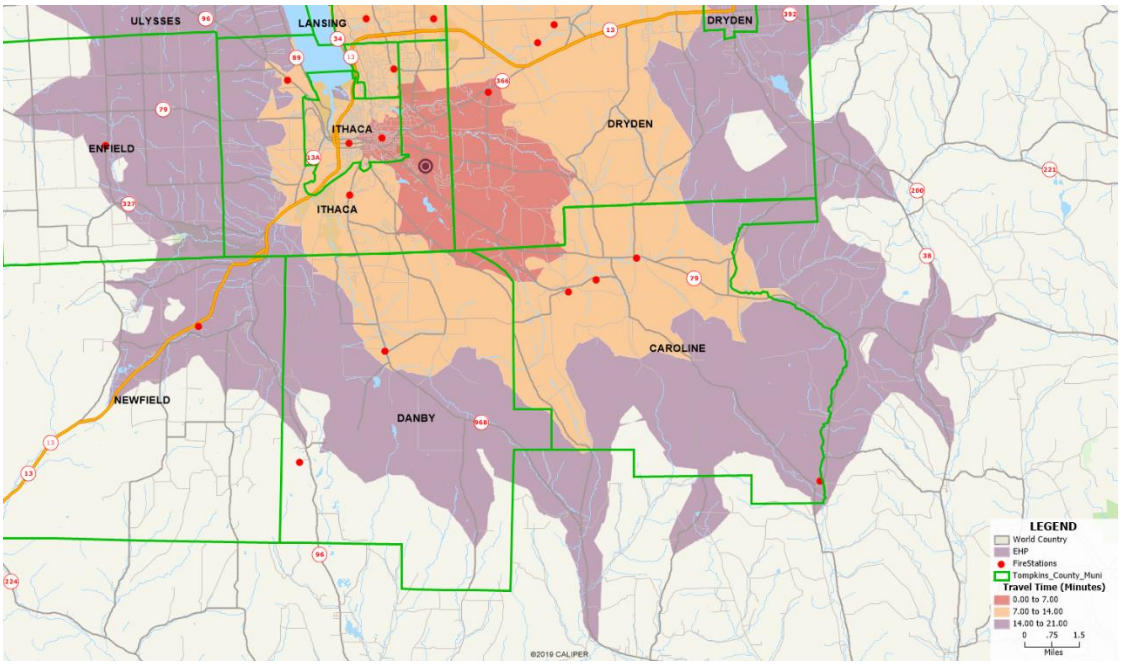

Figure 8: East Hill Plaza Response Times

Another trouble spot is the south and southwest portion of the county. Newfield, Enfield, and especially Danby have relatively poor ambulance coverage. The majority of Enfield could be covered adequately by Trumansburg Ambulance, but Trumansburg has a mutual aid agreement with Hector and Covert, so it is assumed that the shown coverage below in figure 9 is not always available. Placing an ambulance at Cayuga Medical Center, if there is not one there already, would alleviate the mutual aid stress upon Trumansburg.

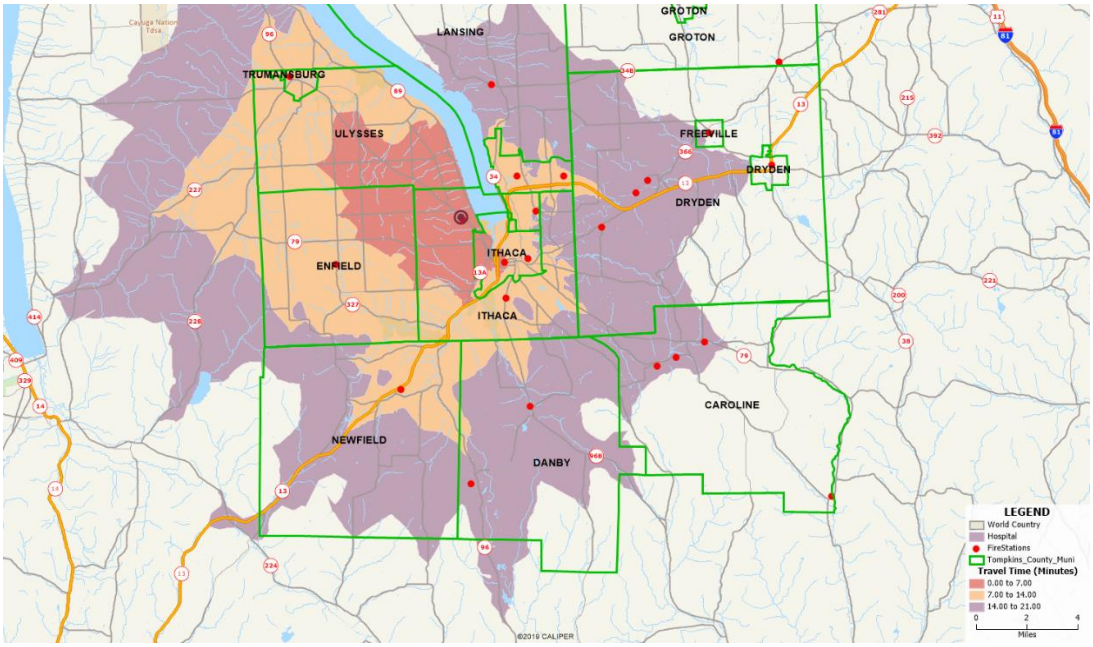

Figure 9: Response Times from Cayuga Medical Center

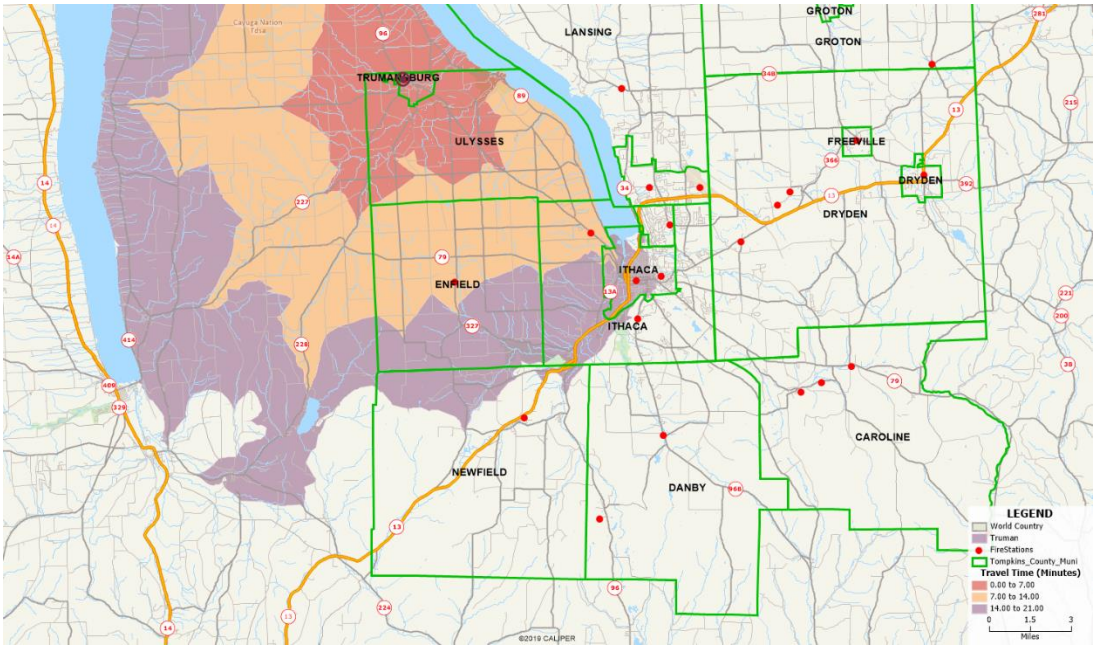

Figure 10: Trumansburg Ambulance Response Times

Shown below are some possible solutions. An ambulance at the Cayuga Medical Center or Ithaca Fire Department Station 4 would provide terrific coverage to Enfield, and a significant

portion of Newfield. Also, an emergency vehicle stationed in the vicinity of the Home Depot on Rt. 13 would adequately cover Newfield and parts of Danby. For this specific region of Tompkins County, a blended solution is optimal. A fly-car at the West Danby Fire Station, combined with an ambulance in the vicinity of Walmart provides excellent EMS coverage to the western and southern regions of Tompkins County. Also, stationing a unit in the vicinity of the intersection of Danby and King Rd. on South Hill adequately covers Danby and South Ithaca, which will be crucial in coming years as new housing developments in the area become occupied.

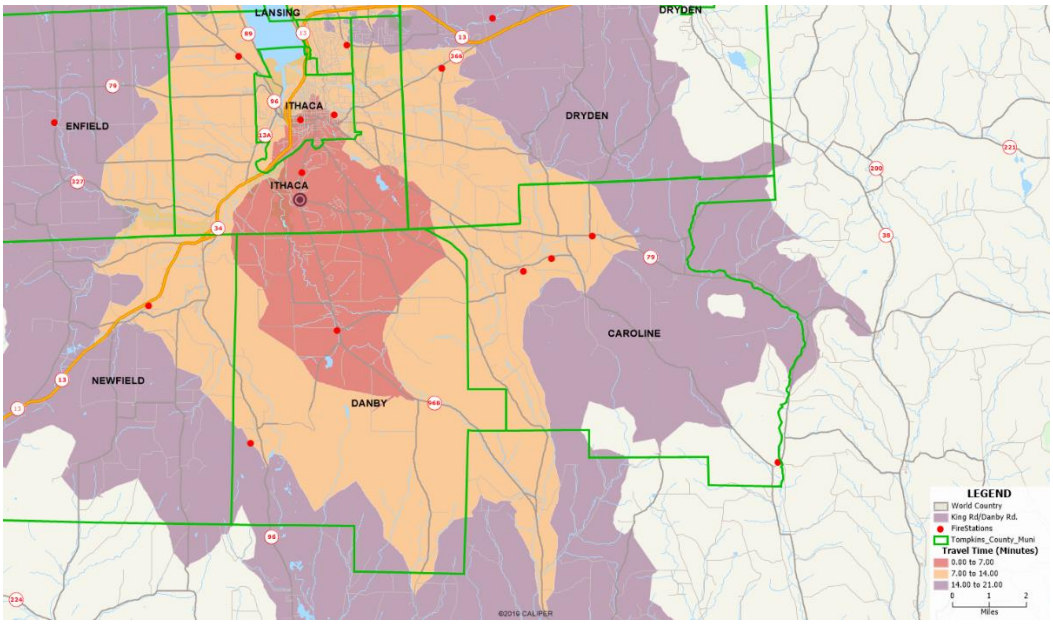

Figure 11: Response Times from King Rd.

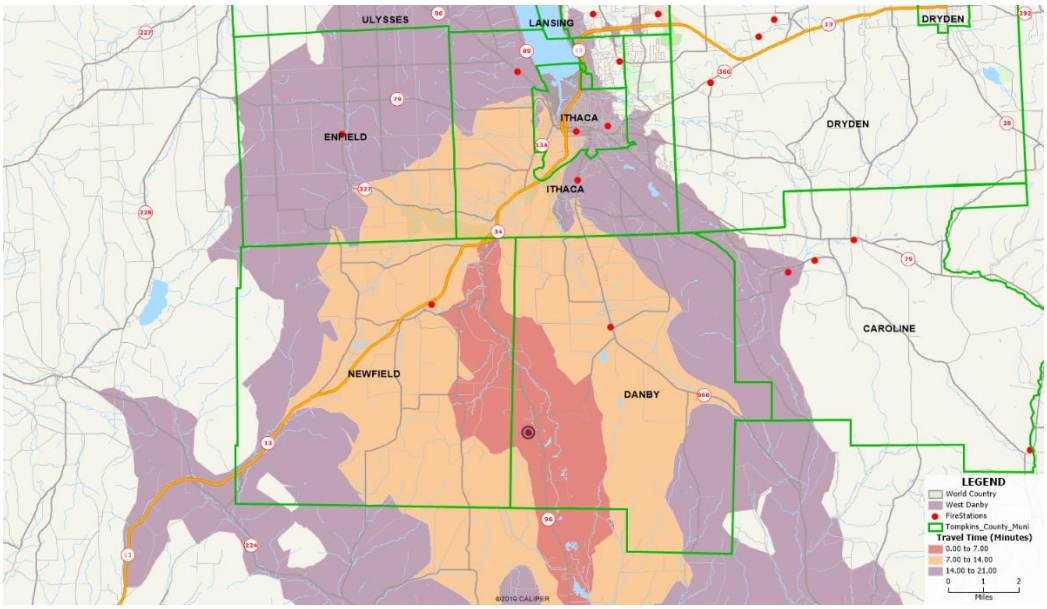

Figure 12: Response Times from West Danby

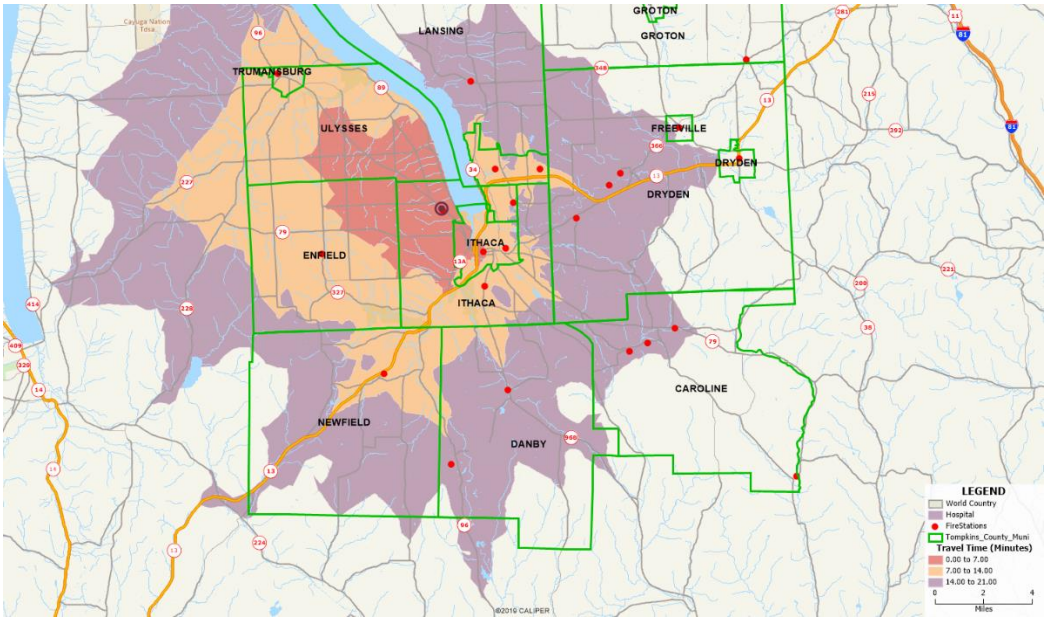

Figure 13: Response times from IFD Station 4/Cayuga Medical Center

A clearly robust feature of Maptitude is the ability to display population data, as well as import 911 emergency call data, sorted by call determinant(severity/type of call), shown in a few examples above. This is very important for this particular use of the software because area

coverage is not of utmost importance, but population and expected call areas are paramount. Although the 911 call data is from 2016, it is a reasonable assumption that areas and times of high call density will continue to be similar. Examples of possible causes of high call density include senior living housing, Collegetown (Ithaca) on a Friday night, or a major roadway (Rt. 13) during inclement weather. Most figures displayed in this report do not have the population and call data overlaid for the purpose of ease of reading, however, all maps generated with the above-mentioned data can be viewed in Appendix C. The final response times of all implemented stations can be viewed below in figure 14 and 15(plus fly cars at Brooktondale, Danby and Main St), with population served data in tables 1 and 2.

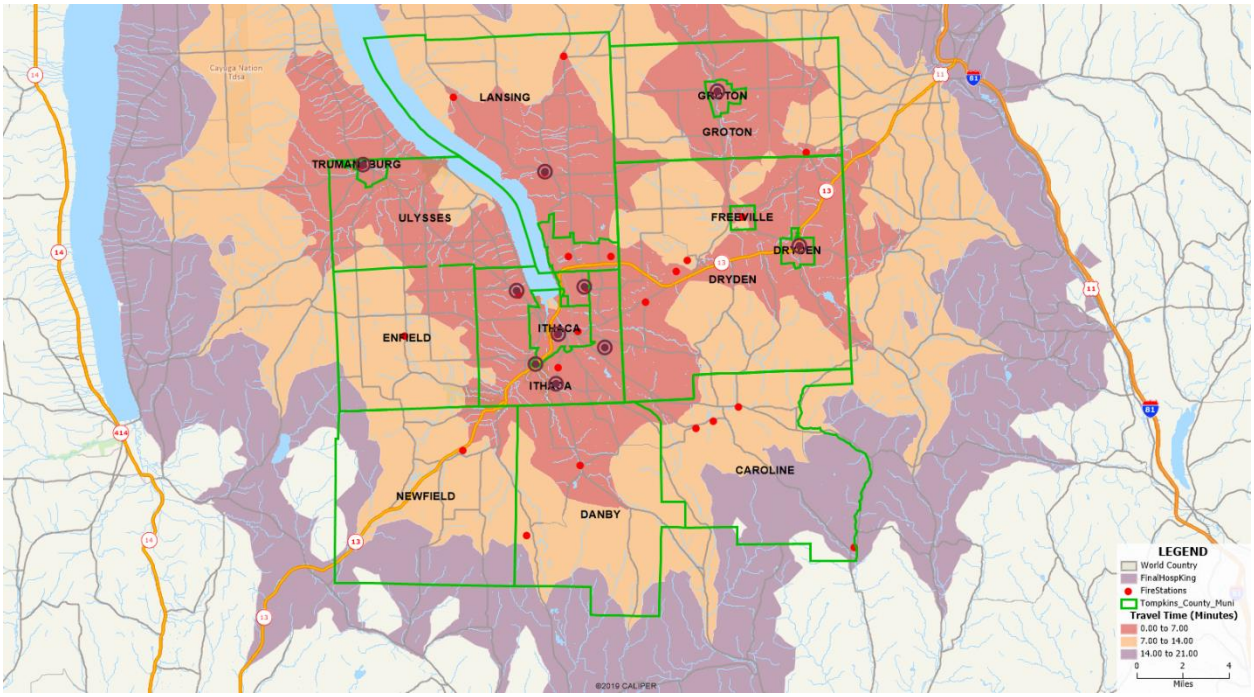

Figure 14: Response Times from All Recommended Ambulance Locations

Table 1: Population Served from Figure 14 Simulation

	0-7 minutes	7-14 minutes
Bangs	17,171	45,829
Trumansburg	4,171	11,348
Dryden	6,379	39,533
Groton	4,485	16,945
Cayuga Heights	22,577	42,392
Ridge Rd.	7,535	38,064
King Rd.	18,572	39,582
Home Depot	13,197	53,223
East Hill Plaza	20,323	39,854
Hospital	8,499	44,280
Total	81,307	46,132

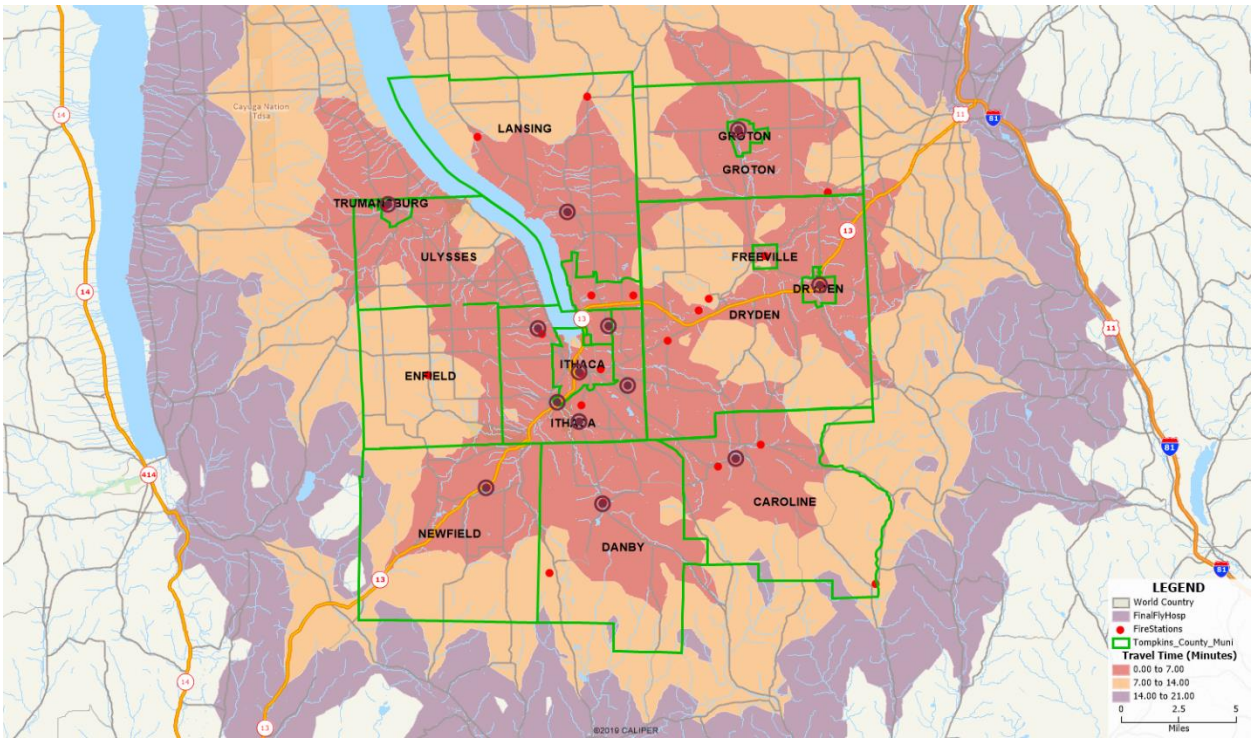

Figure 15: Response Times from All Recommended Ambulance Locations + Fly Cars

Table 2: Population Served from Figure 15 Simulation

	0-7 minutes	7-14 minutes
Bangs	17,171	45,829
Trumansburg	4,171	11,348
Dryden	6,379	39,533
Groton	4,485	16,945
Cayuga Heights	22,577	42,392
Ridge Rd.	7,535	38,064
King Rd.	18,572	39,582
Home Depot	13,197	53,223
East Hill Plaza	20,323	39,854
Hospital	8,499	44,280
Brooktondale	3,742	25,207
Danby	6,531	33,239
Newfield-Main St.	4,143	24,700
Total	87,333	47,430

VI. Planning, Implementation and Testing.

Planning the full implementation of the above recommended solutions for Tompkins County could take some time. Various town and county government officials will need to weigh recommendations vs. their respective budgets and put the issue to a vote or referendum. With cooperation between Bangs, the holder of Tompkins County's Certificate of Need (McCarthy), and the county government, the beginning of incremental implementation could happen within 6-8 months.

There are various methods for implementing recommended solutions. A combination of fly-cars and ambulances are needed to achieve the desired coverage throughout Tompkins County. The implementation process will greatly modify the Tompkins County EMS system. Taking an incremental approach of stationing primarily fly-cars and perhaps an underutilized ambulance at the recommended locations would be most cost effective initially. Continuous data collection, as well as real-world lessons learned from the EMTs and dispatchers will give an initial data point for the effectiveness of the solution. Later, the verification process will analyze the data gained during initial implementation, once statistically significant, and the various stakeholders from the towns of Tompkins County can discuss whether the solution is improving EMS system performance to the degree that it is worth the cost to their respective tax paying citizens. If the results are satisfactory, paid ambulance resources could be added, commensurate with the tax burden the county leadership is willing to bear, until desired coverage is achieved.

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