Optimization of EMS Facilities in Anne Arundel County, MD

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Executive Summary

Incorporating emergency medical services (EMS) are a vital part of any jurisdiction's planning. They are a cornerstone of public safety and an indispensable resource. With evolving challenges to public safety, it is crucial that jurisdictions deploy their EMS resources as efficiently as possible to serve the most people over the widest area possible.

This report examines the capacity of EMS resources in Anne Arundel County, Maryland, using real emergency call data to determine coverage of incidents. Using state and county road network data, the team assesses EMS resource coverage using both distance and response time standards for Basic Life Support and Advanced Life support services.

The report proposes a methodology for modeling EMS vehicle speed and response times in the absence of real world data and applies several iterations of modeling to predict EMS response times and coverage areas.

The research team found that the current configuration of fire stations in the county appear to cast a wide net of coverage within both arbitrary distance buffers and four-minute and eight-minute response time standards. However, some areas of the county may not have adequate coverage, though it is possible that those areas are sufficiently covered by resources deployed under mutual aid agreements. Lack of coverage is not a result of insufficient data. The report proposes future areas of study for developing more accurate models of EMS vehicle speed and coverage areas.

Introduction

Adequate and efficient use of emergency services resources is a crucial component of any jurisdiction's planning process. Emergency personnel serve several functions to keep communities safe and save lives daily. However, with finite resources and continually evolving challenges to public safety, emergency services organization cannot afford to waste time or money. It is imperative that Emergency Medical Services (EMS) resources are maximized to assist residents across the widest possible area.

Research Goals

The research team will expand on research performed during the Fall 2016 semester by University of Maryland students, which examined recent time and location data of EMS calls and determined hotspots for activity. By further analyzing the data, the research team seeks to assess demand for emergency services in Anne Arundel County on current EMS capacity. Additionally, the team will make recommendations for changes in policy and location of resources to better meet demand.

Background Information

Anne Arundel County is located in central Maryland and is home to its capital, Annapolis. In 2016, the population was 537,656 dispersed over 588 square miles (415 square miles of land), giving it a population density of 1,296 residents per square mile (U.S. Census Bureau, 2016). According to county data, the county has 39 fire stations that are pretty well dispersed, although some gaps exist in the western and southern parts of the county.[1]

The primary focus of this study was the 48,677 requests for emergency services recorded between January and June 2016 (the most recent available data). Additionally, data from 2015 (71,319 calls)

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[1] The research team performed its analyses under the impression that there were 39 fire stations. We were informed shortly before the project deadline that one location is the county's Emergency Medical Services Division headquarters which does not respond to calls. Due to time limitations, we were unable to re-run our analyses excluding that location. We were also informed that seven of the locations do not belong to the county. Under Dr. Liu's guidance we kept our analysis reasoning that though the models reflect EMS activity by other departments, they are still within the county and therefore relevant.

and 2014 (69,120 calls) was examined, but less extensively. All call data was provided by Anne Arundel County. Road network data from Anne Arundel County and the Maryland Department of Transportation were used for network analyses.

The county's Emergency Medical Services Division seeks to provide EMS service under two standards: four minutes (Basic Life Support) and eight minutes (Advanced Life Support). Basic life support is use for "patients who do not require extra support or cardiac monitoring," and advanced life support is for "patients who need a higher level of care during transport above those services provided by a BLS ambulance, but still do not require an R.N." (The Johns Hopkins University).

Methodology

The research team sought to use network data to determine the coverage of reported incidents by EMS resources under varying conditions. To determine coverage, we took two approaches: distance and time.

Distance-based Analysis

The first method was a distance-based road network analysis. Using a shapefile of roads in Anne Arundel County from the county website, we built a network dataset in ArcGIS. For this network, we set distance as our only cost parameter using shape length data of the roads segments. We imported the shapefile of fire stations from Anne Arundel County's website and point data of emergency services incidents from Anne Arundel County. We then performed two Network Analyst Functions—Service Area and Closest Facility—to generate routes and coverage areas. The Service Area analysis showed buffers along the road network of ¼ mile, ½ mile, 1 mile, 2 miles, and 3 miles of fire stations. For the Closest Facility analysis, we generated routes for one, two, and three facilities within the aforementioned distances.

Time-based Analysis

The second method was a time-based road network analysis. Using a shapefile of the roads in Anne Arundel County from the Maryland Department of Transportation, we built a network dataset, and derived our own time cost parameters. In the absence of pre-calculated time cost data, we derived our own using a modified distance divided by speed equation. We calculated time costs (T) for each road segment by dividing the length of the edges ($D_{TF}/_{FT}$) in miles by their speed limit multiplied by five different factors (M) to simulate varying traffic and vehicle travel speeds. We then multiplied the quotient by 60 to get time cost values in minutes.

$$T = \left(\frac{D_{TF/FT}}{S_{RC} * M}\right) * 60$$

Speed limits were provided for less than five percent of road segments in the network, so we assigned speed limits to all of them based on road class. The research team used U.S. Federal Highway Administration speed limit ranges, outlined in Table 1, for road classes to assign speed limits for our network. For each class, we assigned minimum, maximum, and average speed limit values (S_{RC}) and ran each through our equation to determine time costs. We used the multipliers (M) of .75, .9, 1, 1.1, and 1.25 to represent travel speed at various percentages of the speed limit. Our rationale was without real world data, it is difficult to discern how fast EMS vehicles travel. Understanding that under Maryland law, EMS drivers may "exceed any maximum speed limit, but only so long as the driver does not endanger life or property" (Emergency vehicles, Maryland Code. § 21-106), we performed several iterations of analysis to create "fence posts" for modeling vehicle speed.

Table 1 – Federal Highway Administration Speed Limit Guidelines[2]	
Road Class	**Assigned Speed Limit**
Local	20-45 mph
Minor Collector	30-55 mph
Major Collector	35-55 mph
Minor Arterial	50-65 mph
Principal Arterial - Interstate	55-65 mph

[2] (Federal Highway Administration, 2017)

Using the time cost data generated by our methodology, we then ran Service Area analysis for four minutes and eight minutes per the Anne Arundel County Fire Department's guidelines. We then used the output of the analyses described above to calculate the percentage of the road network and incidents covered by each iteration of analysis and assess the coverage of EMS resources.

Results

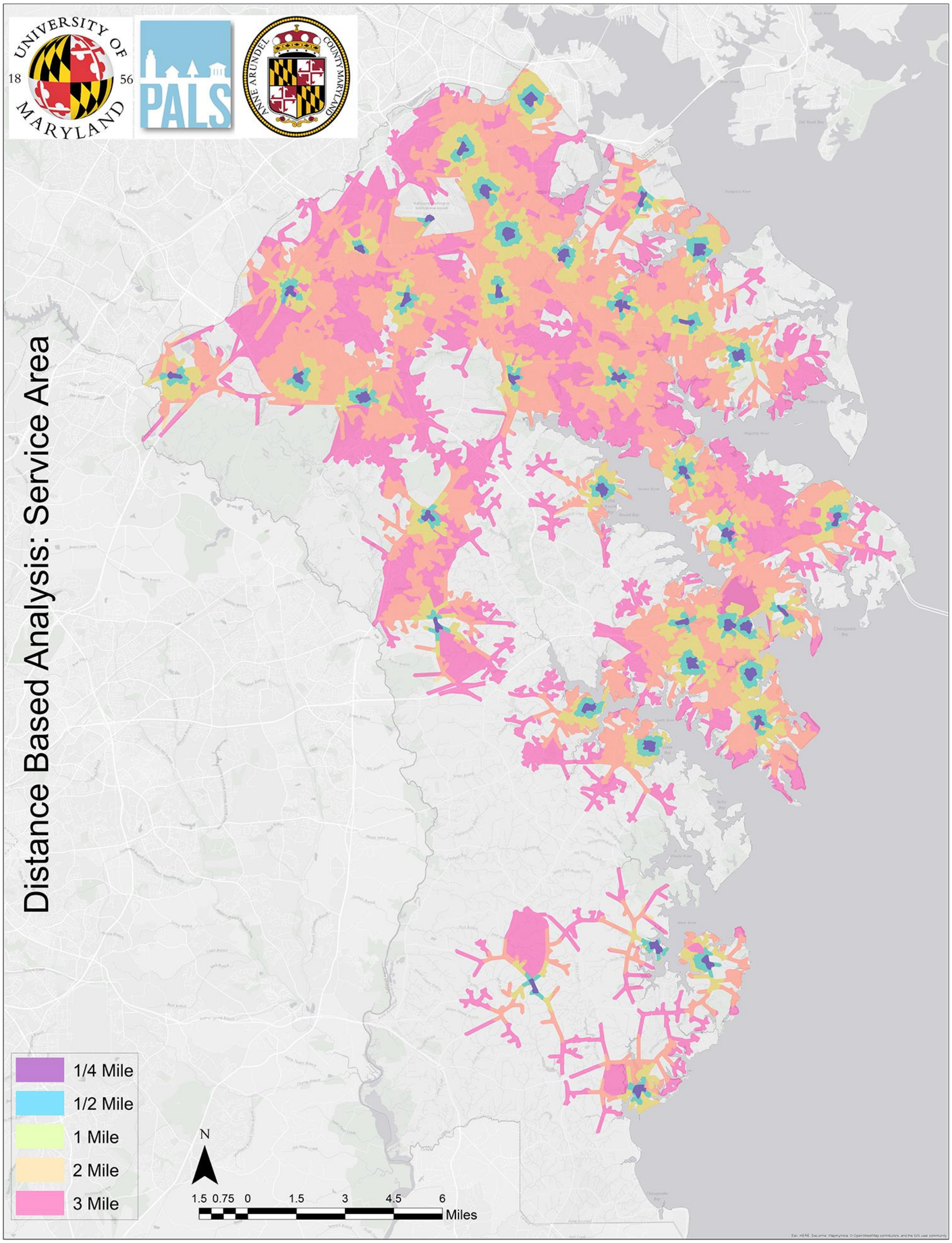
Distance-based Results

The Service Area analysis showed excellent coverage of incidents across the county overall, as shown in Map 1. Looking at each buffer, we saw increasing coverage with each step up in buffer distance with just five percent of incidents covered within ¼ mile of fire stations and up to 89 percent within three miles. Full results are available in Table 2.

Table 2 – Emergency Incident Coverage by Distance from Fire Stations		
Distance-Based Service Area		
	Covered	Percentage
1/4 Mile	2,557	5%
1/2 Mile	5,938	12%
1 Mile	16,325	34%
2 Miles	35,740	73%
3 Miles	43,392	89%
Total Incidents (2016) = 48,677		

The Closest Facility analysis provided more detailed information regarding coverage, showing the number of calls covered by at least one to three facilities. Incident coverage at three miles is 92 percent as shown in Table 3. That number drops slightly at two facilities (62 percent) and three facilities (35 percent), which is to be expected with the dispersal of fire stations throughout the county, presumably to provide even coverage.

Map 1 – Fire Station Service Area Coverage with Distance Buffers Along Road Network



The percent of incidents covered looks largely the same at one facility, however, there are some slight discrepancies in the number of incidents covered compared to the Service Area analysis. The Closest Facility analysis showed slightly higher numbers of covered incidents and higher percentages at two and three miles. One possible explanation for this is differences in how incidents are counted. For Service Area, the research team used the “Select by location” tool to tally incidents inside each buffer layer. The Closest Facility tool includes a search distance of 300 meters to find incidents within the selected parameters. It is possible that there are incidents just outside the Service Area buffers that are counted in the Closest Facility analysis because they are still within the search distance of the tool but outside of the buffer. The research team was not able to confirm this as the reason.

Map 2 – Closest Facility Analysis with Routes to Incidents by Responding Station Rank

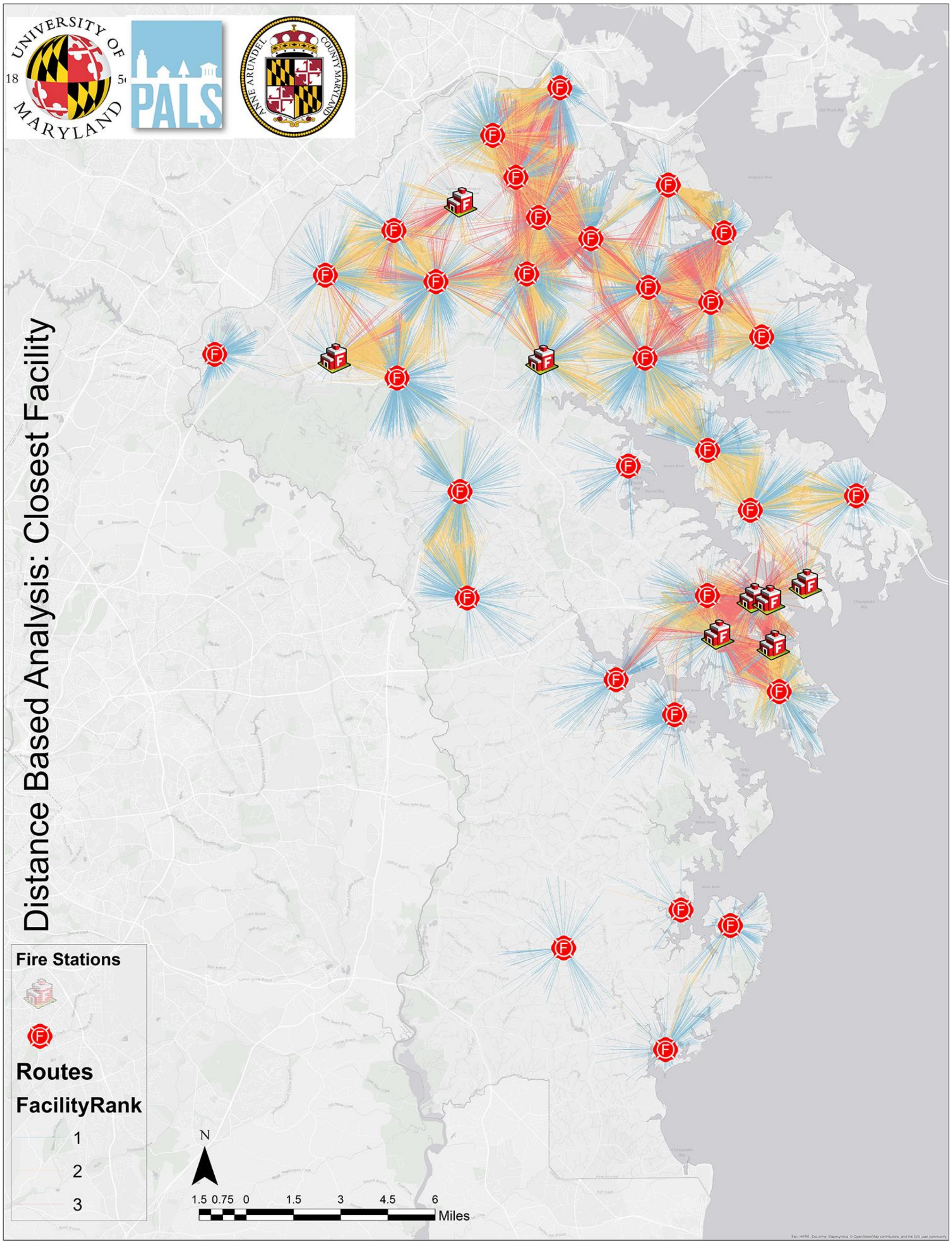


Table 3 – Coverage of Incidents Based on Closest Facility Analysis						
Distance-Based - Closest Facility						
	1 Facility		2 Facilities		3 Facilities	
Distance	Covered	Percentage	Covered	Percentage	Covered	Percentage
1/4 Mile	2,271	5%	0	0%	0	0%
1/2 Mile	5,852	12%	1	0%	0	0%
1 Mile	16,473	34%	375	1%	0	0%
2 Miles	36,635	75%	11,827	24%	3,508	7%
3 Miles	44,571	92%	30,131	62%	17,206	35%
Total Incidents (2016) = 48,677						

Additional results for 2014 and 2015 data are provided in Table 4. However, time and resource constraints precluded running more in-depth analysis.

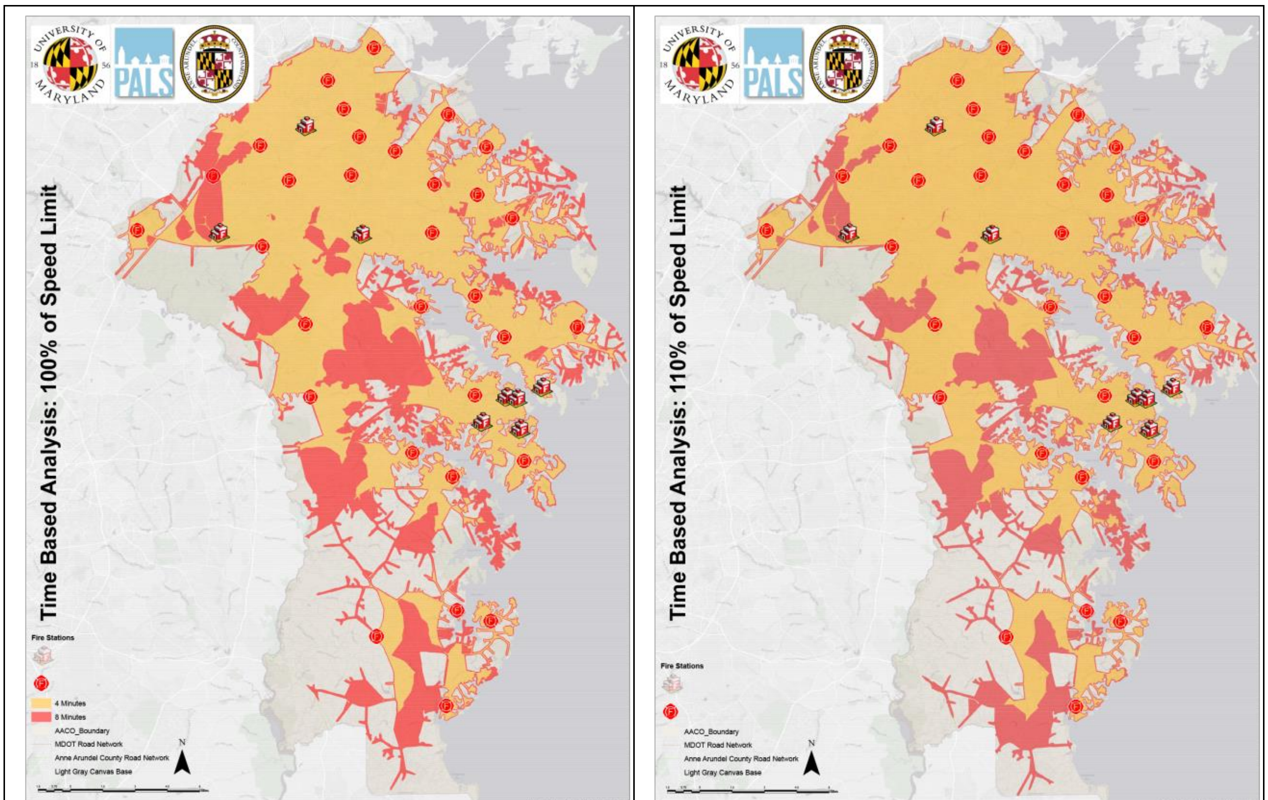
Table 4 – Service Area Coverage for Incidents in 2014 and 2015				
Distance-Based Service Area				
	2014		2015	
	Covered	Percentage	Covered	Percentage
1/4 Mile	3,342	5%	3,530	5%
1/2 Mile	8,137	11%	8,444	12%
1 Mile	23,117	32%	23,863	33%
2 Miles	50,705	71%	52,313	73%
3 Miles	61,858	87%	63,520	89%
Total Incidents	69,120		71,319	

Time-based Results

The time-based service area analysis showed considerably more coverage across the county than the distance-based analyses. Some central areas of the county are far better covered than the distance-based analyses show.

Maps 3 and 4 compare Service Areas based on the assigned average speed limits at 100 percent and 110 percent of the speed limit. The maps look very similar in coverage, however, there are a few areas of expanded coverage in the four-minute area in the western, central, and southern areas of the county. It is difficult to discern whether the areas with a complete lack of coverage are due to shortcomings in the network data used for analysis or a lack of resources in the county or other jurisdictions. However, mutual aid agreements with neighboring counties may cover these areas in either case (Anne Arundel County Office of Emergency Management, 2010).

Map 3 and Map 4 – Time-based Service Area Analysis at 100% and 110% of Average Speed Limit



Looking more closely at the incident coverage in Table 5, we found the range of coverage for the four-minute response time to be 86 percent to 91 percent of incidents; for eight minutes, it was 91 percent to 94 percent. Each successive increase in the percent of speed limit only yielded marginal increases in the percentages of covered incidents. The difference between the lowest multiplier to the highest in the four-minute analysis resulted in a five percent increase in coverage

(2,390 more incidents); for the eight-minute analysis, it was an increase of three percent (1,202 more incidents).

Table 5 – Time-based Service Area Incident Coverage

Time-Based Service Area				
	4 Minutes		8 Minutes	
% of Speed Limit	Covered	Percentage	Covered	Percentage
75	41,847	86%	44,452	91%
90	42,560	87%	45,071	93%
100	42,910	88%	45,606	94%
110	43,104	89%	45,646	94%
125	44,237	91%	45,654	94%
Total Incidents = 48,677				

The Closest Facility analyses for assigned average speed limits show more fine-grain differences in network coverage across different parameters. Incidents covered by at least one facility range from 78 percent to 98 percent of all incidents (two facilities: 40 percent to 94 percent; three facilities: 17 percent to 91 percent). This supports coverage seen in the time-based Service Area and distance-based Service Area and Closest Facility analyses. Again, there is a decrease in coverage as the number of facilities serving each incident increases, but that can be interpreted as a well-dispersed network of fire stations. Examining single facility service, there are considerable increases in coverage when moving from four-minute to eight-minute response times, but the gap closes as travel speed increases. The biggest jumps are seen in the three facility analyses in which the change in time standard results in a 53 percent increase in covered incidents.

Table 6 – Time-based Closest Facility Analysis of 4-minute and 8-minute Response Times						
Time-Based Closest Facility						
75% of Speed Limit						
	1 Facility		**2 Facilities**		**3 Facilities**	
4 Minutes	37,954	78%	19,378	40%	8,179	17%
8 Minutes	46,359	95%	40,316	83%	33,839	70%
90% of Speed Limit						
	1 Facility		**2 Facilities**		**3 Facilities**	
4 Minutes	41,209	85%	26,919	55%	15,526	32%
8 Minutes	46,917	96%	43,654	90%	38,562	79%
100% of Speed Limit						
	1 Facility		**2 Facilities**		**3 Facilities**	
4 Minutes	42,571	87%	30,945	64%	19,706	40%
8 Minutes	47,467	98%	44,520	91%	40,637	83%
110% of Speed Limit						
	1 Facility		**2 Facilities**		**3 Facilities**	
4 Minutes	43,704	90%	34,039	70%	23,952	49%
8 Minutes	47,582	98%	45,102	93%	42,416	87%
125% of Speed Limit						
	1 Facility		**2 Facilities**		**3 Facilities**	
4 Minutes	45,005	92%	36,909	76%	29,018	60%
8 Minutes	47,660	98%	45,947	94%	44,317	91%
Total Incidents = 48,677						

Limitations

In pursuing this project, the research team made several decisions about what data to use and how to use it. We carefully considered the pros and cons of our options and used a combination of literature review and common sense to make reasonable decisions in developing a model for simulating vehicle speeds.

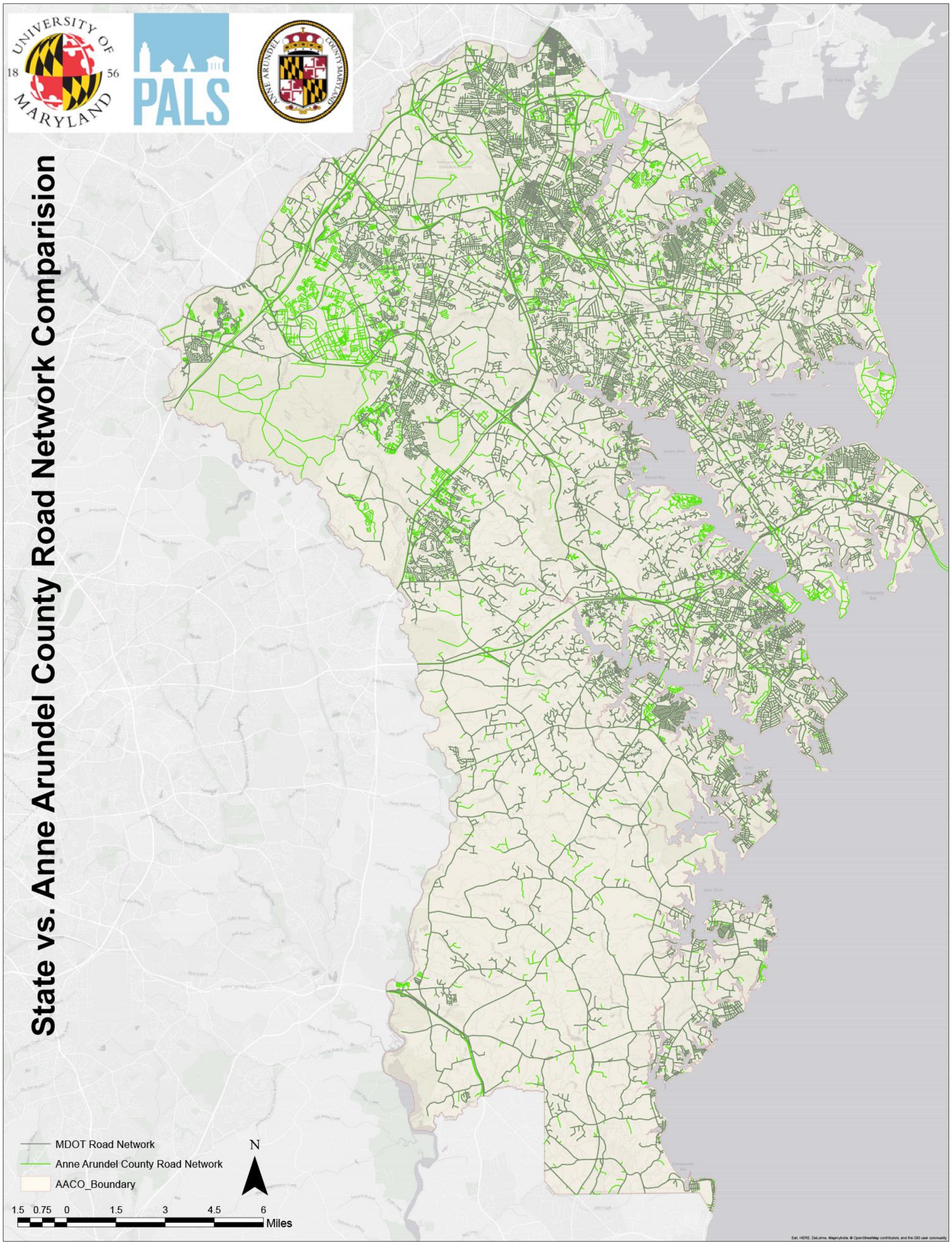
Finding Reliable Data

The biggest challenge was finding complete, reliable data. The road network from Anne Arundel County covered the most distance and appeared to have the most complete road data. This made it well-suited for distance-based network analysis. However, this network did not contain speed limit or road class information, which we needed to construct a network with time cost parameters.

The road network provided by the state of Maryland had less complete network data but had complete road class information, which we used to assign speed limits and derive time costs. The drawback was that certain areas where streets exist were not covered by this network, so it is likely the calculated incident coverage is artificially low because incidents occurred at addresses that were not reachable on the state network.

We consulted with another student group that attempted to perform a spatial join between the Anne Arundel County and the Maryland state road networks to create a complete network with road class information. Unfortunately, the differences between the networks were too great, and fewer than 15 percent of road segments had the appropriate data after the join.

Map 5 – Comparison of Anne Arundel County and Maryland Department of Transportation Road Networks



Network connectivity emerged as another issue. After constructing a network dataset using the Maryland's road network and running preliminary Service Area and Closest Facility analyses, we discovered that the results didn't represent the network's actual connectivity. Only very small portions of the incidents were covered and it appeared that most roads were not connected to each other. We revised the parameters for connectivity for the network dataset from "Endpoint" to "Any vertex," which allowed the network to connect roads that intersected on our map regardless of whether they actually are connected. The results from subsequent analyses appeared to show results that were much more consistent with actual road connectivity. However, this type of connectivity parameter is problematic in places where there are overpasses that do not have off/on-ramps to the roads they cross. There were no obvious examples of this issue based on spot checks of the map, but there were far too many intersections to be checked manually given the project's time constraints.

Also related to the road network is the lack of hazards, obstacles, and traffic data that might impact vehicle speed. Our networks assume that all roads are completely functional and there are no impedance factors that might slow or even stop emergency vehicles, which could result in the need for them to be re-routed.

Modeling Travel Speed and Calculating Time Costs

Regarding the derivation of time costs, it is difficult to know whether our methodology captures real world vehicle speed. We recognize that some of our calculations will be extreme and unlikely to represent real world conditions. For example, 75 percent of 25 mph is just under 19 mph. A fire truck or ambulance almost certainly can be operated at least at the full speed limit and would be unlikely to travel slower, particularly if there is no traffic or other hazards. At the other extreme, 125 percent of 70 mph is nearly 88 mph. We believe it is safe to assume that even with no traffic, a large emergency vehicle is unlikely to go nearly 20 mph over the speed limit. Our expectation is that emergency vehicles travel close to or slightly above the speed limit when possible, but there are several factors consider:

- EMS vehicles have lights and sirens that, in theory, signal other drivers to clear the road. However, common sense and personal experience tell us that roads do not instantly or completely clear the moment the lights and sirens turn on, so EMS vehicles will not have a clear path immediately and as they travel along the road, and varying conditions may prevent roads from clearing completely.

- Even with relatively clear roads, it still might not be advisable for EMS vehicles to travel at or above the speed limit. In denser, urban areas, the frequency of intersections and turns may have a greater impact on speed as EMS vehicle drivers are advised to slow down when approaching intersections (Patrick, 2012). This is likely to keep vehicle speeds under the speed limit and affect the average travel speed between destinations. Our model does not account for this in a scientific way, however, our 75 percent and 90 percent multipliers may capture this phenomenon.

- Because we did not have complete speed limits for the road network, we assigned them based on guidelines from the U.S. Federal Highway Administration. It is reasonable to expect that those guidelines capture the range of speed limits, but we do not know the accuracy of the assigned speed limits. This creates several problems when trying to perform the analysis.

    - *Artificially low calculations:* When using the minimum speed limit values, it is likely that routes through less dense road networks with higher speed limits will be too short because the speed limits are too low and model a vehicle speed slower than reality.

    - *Artificially high calculations:* Conversely, when using maximum speed limits, routes through more dense road networks with lower speed limits may be too long because they model a vehicle speed too high.

    - *The problem of speed limits:* Using average speed limits may not represent reality for similar reasons described above. The average of the range of speed limits for a local road is 32.5 mph, meaning in areas where the actual speed limit is 20 mph, the base speed limit in our calculations is nearly 13 mph above the actual speed limit; for areas in which the actual speed limit is 45 mph, our calculations use a speed limit that is 13 mph too low. Depending on the combination of road segments with inaccurate speed limits, our calculations could be severely off, particularly along longer routes, which compounds the errors and routes with a mix of roads.

- The multipliers were arbitrary numbers to simulate a range of impedance factors. Again, common sense tells us that the extremes of 75 percent of a 25-mph road and 125 percent of 70-mph road are likely to produce vehicle speeds that don't reflect what we would expect EMS vehicle drivers to drive in the interests of urgency and safety. Assuming that those extremes mark the low and high ends of actual vehicle speeds, some combination of the parameters for calculating vehicle speed should produce realistic results. However, without data such as actual speed limits and/or EMS vehicle travel speed, it is difficult to discern which model best reflects reality.

One final thing to note is that the analyses did not consider the resource capacity of each fire station nor did it examine data regarding time of day and severity of calls. These data points are crucial in understanding real demand (and strain) on EMS resources and exposing potential weaknesses in the EMS network.

Further Research

We saw a lot of potential for future research areas. We expect that there is a resource that has all of the correct speed limits for the road network. Using this information to re-run the analysis would improve the accuracy of calculations. It would also be useful to survey EMS vehicle speed on actual calls to get a better sense of their speed as a function of the speed limit and other impedance factors. In theory, a sufficient sample of EMS vehicle speeds over all types of road classes can provide valuable information for assessing the proper multipliers to use in these calculations. The aforementioned data could be used to develop a cleaner methodology for assessing coverage area and could be continually updated with data on an annual or semi-annual basis to ensure EMS resources are meeting the county's standards.

Conclusions

Based on our analyses, there appears to be good placement of fire stations throughout the county, which ensures that the lion's share of calls can be reached within the county's time standards. The dispersal of facilities allows for a considerable redundancy of coverage, which may mitigate potential issues of lack of resources at any single fire department. However, the northern half of the county has better coverage than the southern part, which is likely a function in the difference in population density.

There are areas of the county that appear to be inadequately served, however, at least two of those areas (west and southwest) are close to the border of the county and would likely be covered by resources from neighboring Prince George's County in the event that Anne Arundel County's resources were unable to respond within a reasonable amount of time.

Team Roles

Technical and Mapping Lead: David Lipscomb. Lipscomb managed data preparation and organization and performed ArcGIS mapping and analysis functions.

Data Analysis and Policy Lead: Terrence Harrington. Harrington performed detailed analysis of outputs and advised on policy recommendations.

It should be noted that with just a two-person team, most responsibilities will be shared to some degree.

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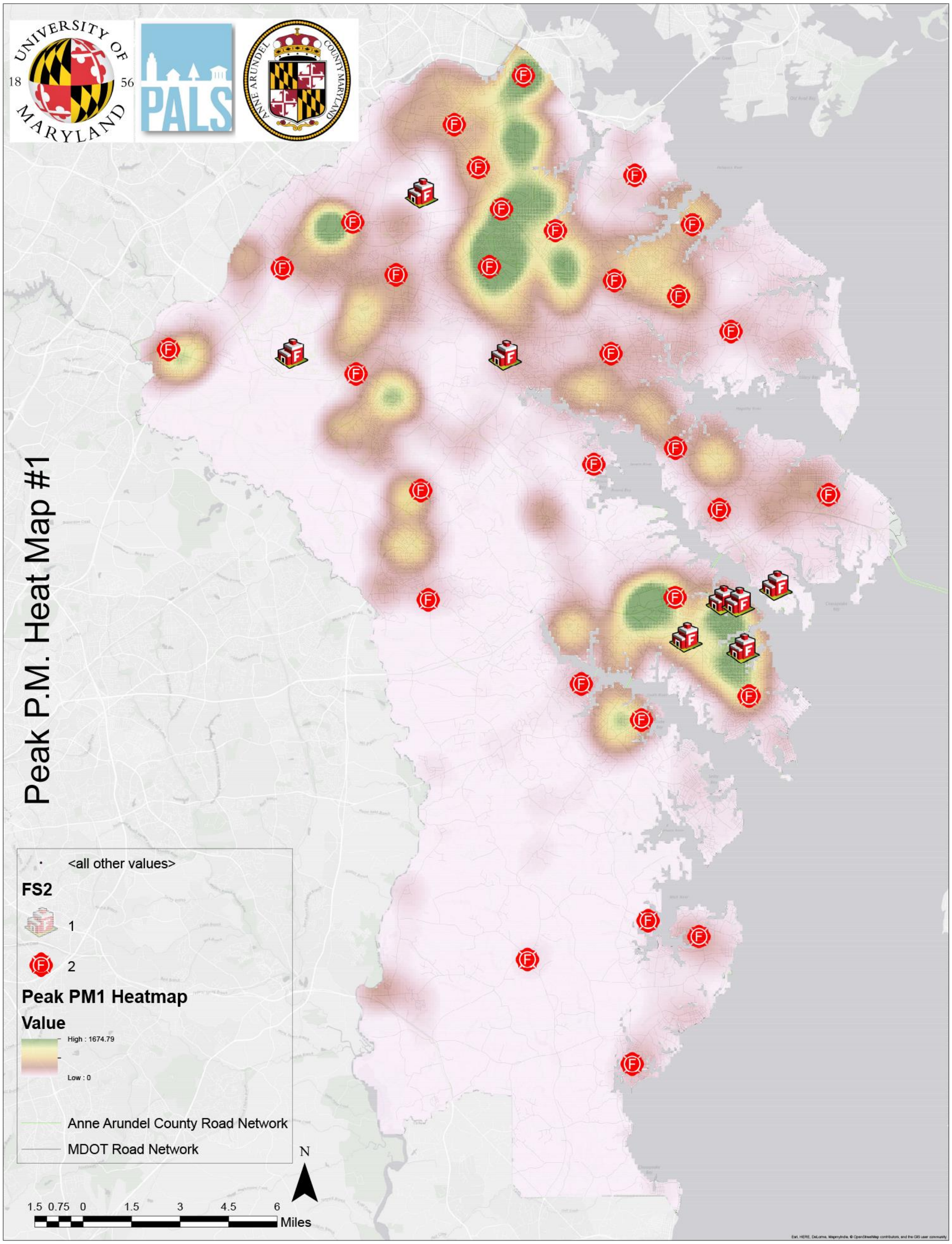
Appendix

Map 6 – Heat Map of Peak of PM1 Calls



Map 7 – Heat Map of Peak of PM2 Calls