An Exploratory Spatial Analysis of Fire Service and EMS Accessibility in Northeastern Illinois Communities

by

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To my parents, Chris and Michelle Dixon

Table of Contents

List of Figures

List of Tables

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List of Abbreviations

2SFCA	two-step floating catchment area
AED	Automated External Defibrillator
CFD	Carpentersville Fire Department
E2SFCA	enhanced two-step floating catchment area
EDFPD	East Dundee Fire Protection District
EMS	Emergency Medical Services
GPS	Global Positioning System
MC2SFCA	multi-criterion two-step floating catchment area
NFPA	National Fire Protection Association
RDFPD	Rutland Dundee Fire Protection District
ST-E2SFCA	spatio-temporal enhanced two-step floating catchment area
WDFD	West Dundee Fire Department

Abstract

Emergencies occur every day, and it is critical that emergency services respond to those emergencies to limit or prevent damage, injury, or loss of life. In order to provide effective service, it is critical that Fire and Emergency Medical Services (EMS) Departments understand where and how often emergencies occur so resources can be adequately distributed. In northeastern Illinois, QuadCom 911 dispatches emergency services for four fire departments and has been collecting emergency data for years. This study examines the spatial accessibility of QuadCom 911's partner fire departments by using the two-step floating catchment area (2SFCA) method and to propose a standard range of acceptable accessibility values for suburban, regional emergency services. The method is used in three scenarios to explore how accessibility changes for QuadCom 911 if either of two fire stations were to close due to consolidation. Overall, the results show access to emergency services is affected by closing a fire station, but the effects are significantly higher if West Dundee Fire Department Station 2 (WDFD #2) is closed. Furthermore, the methodology proves that creating a standard range of acceptable accessibility values is possible, but this project did not have a large enough sample size for formal proposal of such a standard.

Chapter 1 Introduction

Emergencies happen every day: houses catch fire, car accidents occur, people suffer heart attacks, strokes, and broken bones. When an emergency occurs, a 911 dispatch center analyzes the type and location of the emergency and then dispatches an appropriate allocation of emergency vehicles and personnel from the nearest and most effective locations. Getting the required staff and equipment to an emergency quickly is of the utmost important. Every second services are delayed increases the risk and the severity of the consequences. It is not hyperbole to say that lives are at stake.

People rely on fire services and emergency medical services (EMS) to assist them when they require it, and it is the responsibility of a dispatch center to organize and direct a response to an emergency. QuadCom 911, a regional dispatch center in northeastern Illinois, is responsible for dispatching four fire departments serving the communities of Carpentersville, East Dundee, Gilberts, Sleepy Hollow, and West Dundee, and portions of South Barrington, Barrington Hills, and unincorporated areas of Kane and Cook Counties, in addition to dispatching a total of seven police departments. Overall, QuadCom 911 serves an 82 square mile area with a population nearing 69,000 people. The center handles an average of 350 calls a day and dispatches about 45,000 calls for service each year. This thesis uses the emergency response data gathered daily by QuadCom 911 to examine the spatial accessibility of the fire and emergency medical services dispatched by the organization and to propose accessibility standards for emergency response.

1.1. Study Area

QuadCom 911 dispatches for four fire departments in northern Kane and Cook counties in Illinois (Figure 1). Two of the communities, Carpentersville and West Dundee, maintain and operate their own fire departments. The others are served by the two other organizations. Gilberts and Sleepy Hollow are served by a joint fire protection district, Rutland Dundee Fire Protection District, and the fire protection district, East Dundee Fire Protection

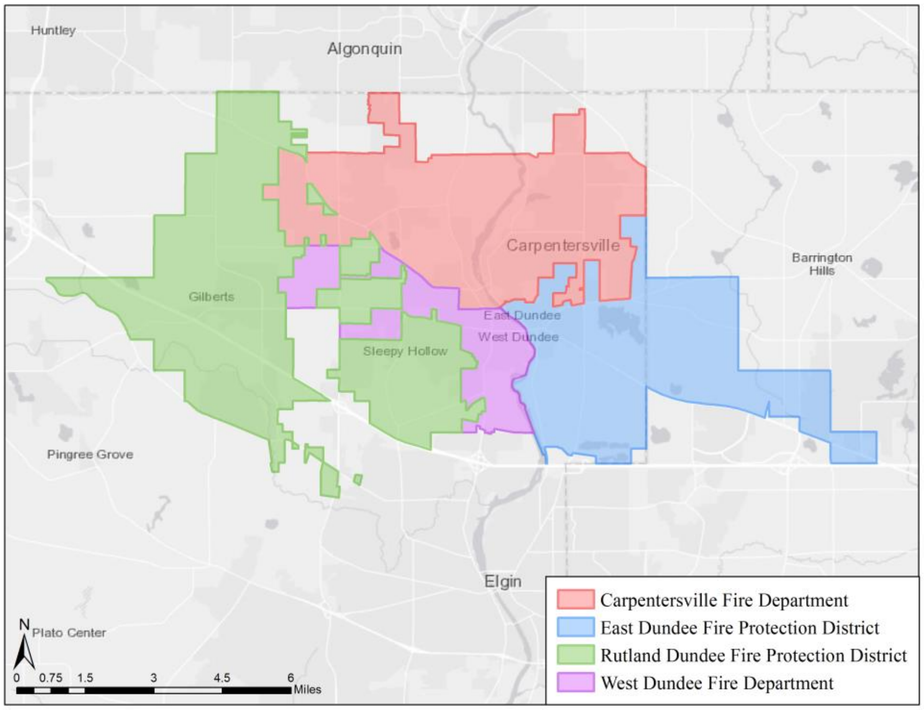


Figure 1. QuadCom 911 Fire Departments and Service Areas. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

District, serves the residents of East Dundee and portions of Barrington Hills, South Barrington, and areas of unincorporated Kane and Cook counties.

The Village of Carpentersville (Figure 2) covers a total area of 8.097 square miles and has an estimated population of 37,691 people according to the 2010 census. Carpentersville operates its own fire department, Carpentersville Fire Department (CFD), which is also provides EMS services for the community. CFD operates three fire stations, Carpentersville Fire Department Station 1 (CFD #1), Carpentersville Fire Department Station 2 (CFD #2), and Carpentersville Fire Department Station 3 (CFD #3).

The Village of West Dundee (Figure 3) has an estimated population of 7,331 people and covers an area of 3.811 square miles. West Dundee has its own fire department, the West

Dundee Fire Department (WDFD), which provides fire and EMS services through two fire stations: West Dundee Fire Department Station #1 (WDFD #1) and West Dundee Fire Department Station #2 (WDFD #2).

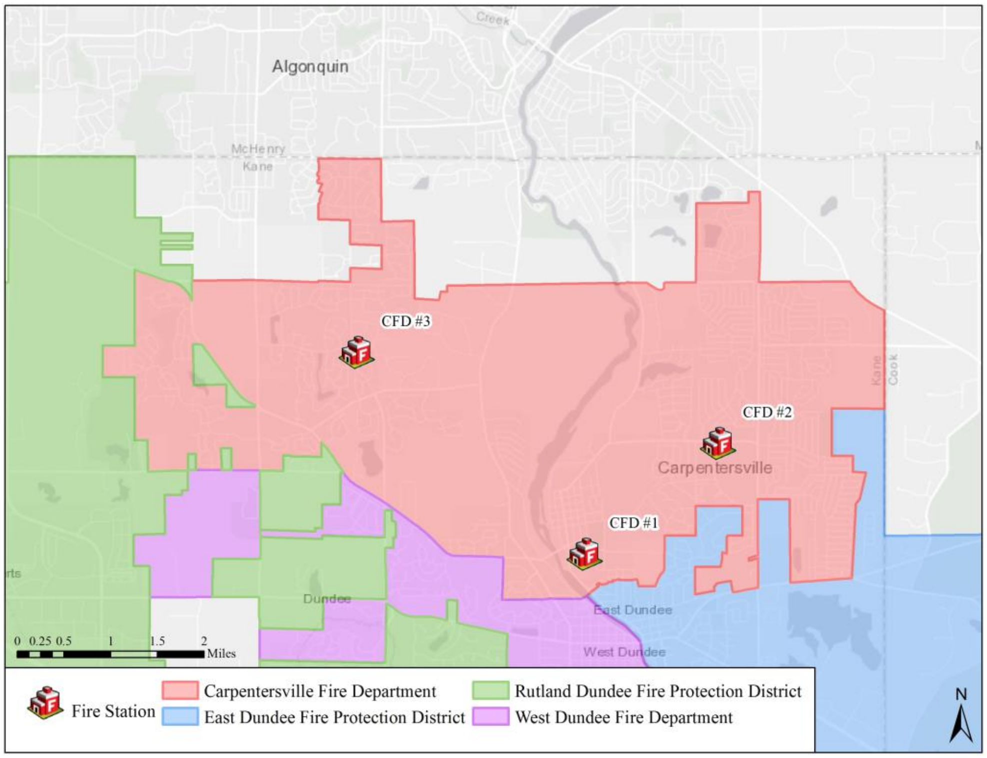


Figure 2. Carpentersville Fire Department. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Rutland Dundee Fire Protection District (RDFPD) serves the villages of Gilberts and Sleepy Hollow, in addition to areas of unincorporated Rutland Township and Dundee Township (Figure 4). Their service area covers an area of about 28 square miles and an estimate population of about 14,600 people. RDFPD operates two fire stations which provide fire and EMS services. The stations are Rutland Dundee Fire Protection District Station 1 (RDFPD #1) and Rutland Dundee Fire Protection District Station 2 (RDFPD #2).

The fourth fire department dispatched by QuadCom 911 is the East Dundee Fire Protection District (EDFPD) (Figure 5). EDFPD serves the communities of East Dundee and parts of South Barrington, Barrington Hills, and areas of unincorporated Cook and Kane counties. Its service area covers an area of about 10.5 square miles and serves about 7,500 residents. EDFPD provides both fire and EMS services, deployed out of one station.

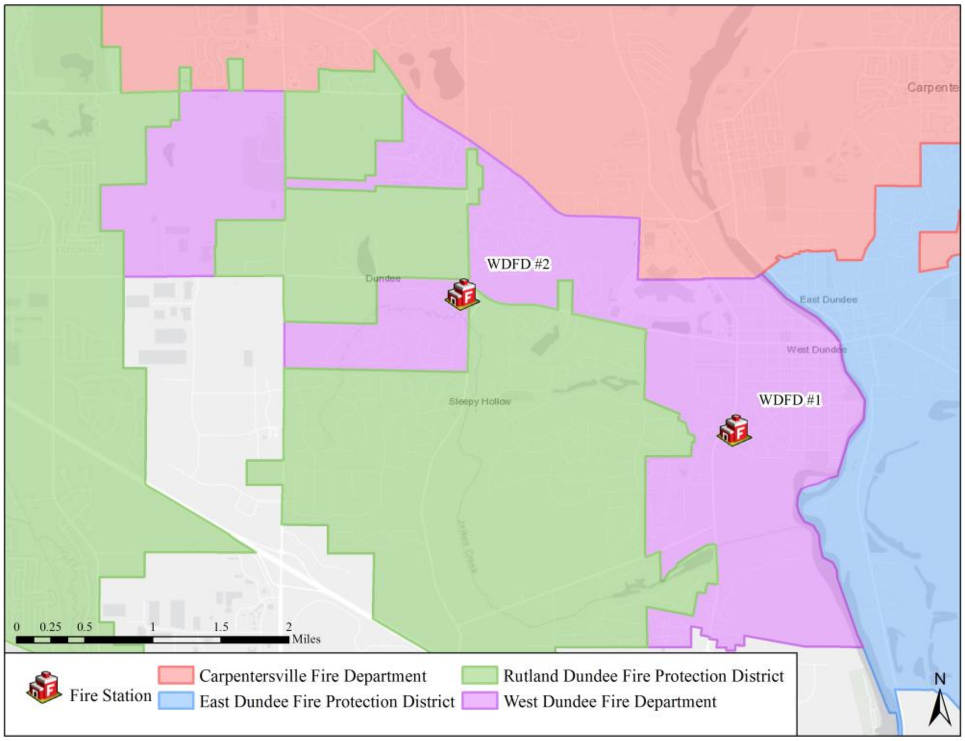


Figure 3. West Dundee Fire Department. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

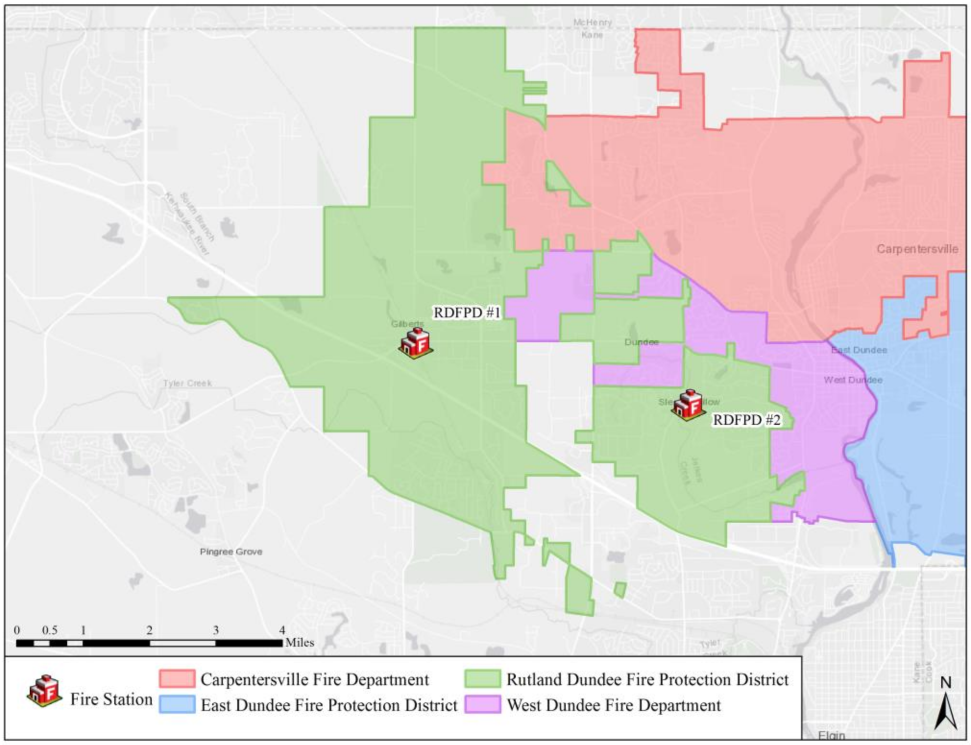


Figure 4. Rutland Dundee Fire Protection District. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

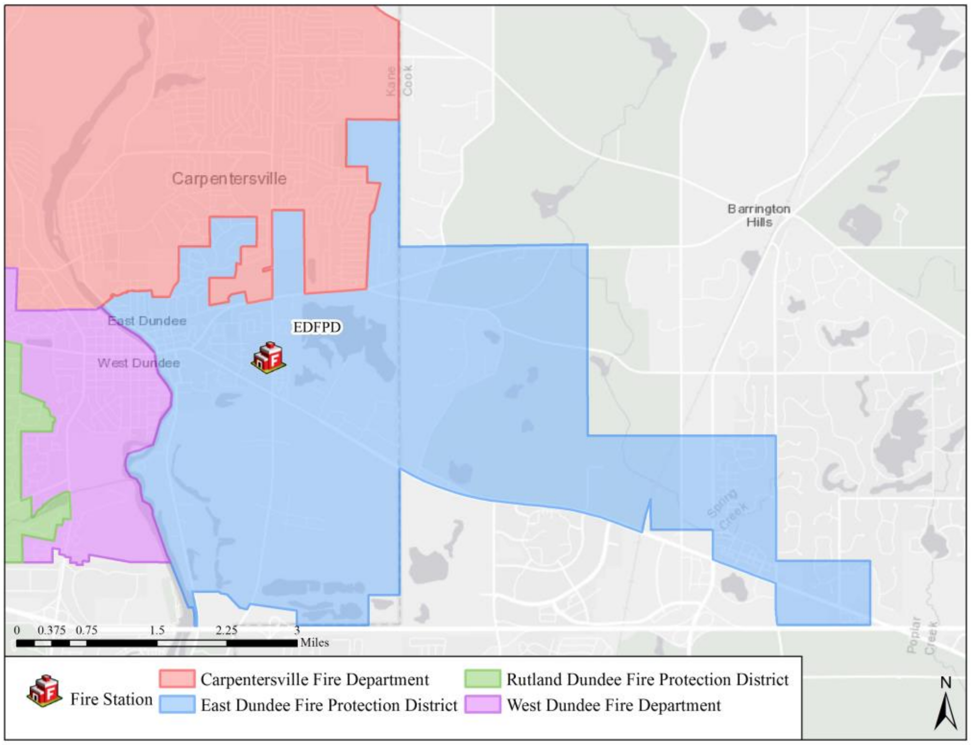


Figure 5. East Dundee Fire Protection District. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

1.2. QuadCom 911 Operations

Traditionally, each of the four fire departments operated independently from each other, but were all jointly dispatched by QuadCom 911. Each fire department was responsible for emergencies within its respective town's municipal boundary or defined service area and on occasion would respond to emergencies in neighboring communities if its emergency crews were unavailable. This resulted in a system in which four departments operated eight fire stations within a relatively small area. An emergency could occur close to one station but be responded to by another due to administrative boundaries. For example, an emergency would occur in Carpentersville near the border with West Dundee and closest to a West Dundee station but a Carpentersville station farther away would respond instead.

Emergencies are often time sensitive and the shortest possible response time is critical to provide the necessary medical assistance. The four fire departments realized that such problems could be avoided if they combined forces. In early 2018, QuadCom 911 and its partner fire departments changed their operational model. Under the new regime, emergency services are dispatched based entirely on proximity, meaning that under standard operating procedures, the closest, available fire station sends emergency vehicles to an emergency, regardless of the incident's jurisdiction. Stations already dispatched are considered unavailable and not considered in a dispatch decision when multiple calls occur simultaneously.

This change has already had an effect. Average response times are down overall, some fire stations have seen decreases in call volume, and others have seen increases in their call volume. While this model has been successful so far, the departments are eager to have a better understanding of where emergencies are occurring and how those emergencies are affecting departmental workloads and costs as the departments are still independent. They are not sharing costs, so departments experiencing increased workloads are accruing additional costs. At the same time, preliminary discussions are occurring in regards to the possibility of the four departments consolidating in order to better manage emergencies, allocate resources, manage costs. In fact, WDFD and RDFPD announced in late 2018 they were entering preliminary discussions relating to a potential merger of the two departments.

As stated above, QuadCom 911 dispatches vehicles to about 45,000 calls for service every year for fires, emergencies, and police calls. For fires and emergencies alone QuadCom received over 6,000 calls for service. No matter what context the call is, either fire or medical in nature, both a fire engine and an ambulance are dispatched to a call. This ensures each emergency has medical personnel to treat any injuries and enough overall personnel to adequately mitigate emergency situations. If an emergency requires more support, additional units can be dispatched from other QuadCom 911 stations or units from other communities can be brought in to assist.

Each one of these calls, no matter the severity, generates a plethora of data including the response times, the vehicles dispatched, which crew members responded, the location of the incident, injury reports, information on patients and victims, contact information, dates and times, and call types just to name a few. Every aspect of the call for service and the response are tracked and recorded. Over the years the amount of data QuadCom 911 maintains continues to grow. In fact, QuadCom has records going back at least 20 years, in both physical and digital formats, for much of the data mentioned above.

For the most part this data has gone largely unexamined. Only simple examinations have been used, such as call type counts, average response times, and simple point or heat maps. No advanced metrics or scientific methodologies have been implemented and no studies have gone beyond the relatively superficial aspects of the data. But with QuadCom 911 and their partner fire departments desire to better understand where emergencies are occurring and how they are affecting call volumes and in turn departmental costs and with the amount of data available, an opportunity to implement a scientific methodology to answer some of their questions has arisen.

This project aims to produce results applicable on multiple fronts with significant benefits for QuadCom 911, specifically as discussions between WDFD and RDFPD progress. They could be used to examine the departments current call volume and theoretically help them establish their annual budgets, organize resources, and assign appropriate staff. Additionally, the results would be incredibly helpful as the departments discuss the possible consolidation and reallocation of their resources. The results could be used to inform the decisions on where to put which trucks, where to assign staff, and help QuadCom 911 identify areas that would need more or less coverage based on historical patterns. In any case, the results enable the departments to make better, more informed decisions based on scientific analysis instead of solely based on perception or intuition. Furthermore, the methods developed in this project could be applied by other organizations around the world to help make similar decisions.

1.3. Research Objectives

In order to provide fast and reliable service, not only must the dispatchers themselves be consistent and effective, but the emergency resources, fire engines, ambulances, and personnel must be in locations where response time to all emergencies is as short as possible. In essence, services must be accessible to the people that rely on them. The aim of this study is to complete an analysis of the spatial accessibility of the fire stations to assist QuadCom 911 and their partnering fire departments' decision making and to contribute to the overall study of fire and EMS accessibility. In order to achieve this objective, this thesis intends *to analyze how accessibility is impacted if two fire departments were to merge and consolidate and to propose a standard range of acceptable accessibility values for suburban, regional emergency services.*

Along with the real-world benefits this analysis has for QuadCom 911 and the communities it serves, the results also benefit the spatial science of emergency response. Over the last few decades there has been an increasing amount of work in emergency response and emergency calls for service. Many scholars studying EMS response have been inspired studies of hospital and primary healthcare accessibility (Lee 2014; Neeki et al. 2016; Freyssenge et al. 2018). Others have focused on looking for spatial patterns of specific injury types or on identifying indicators of future incidents in order to predict future emergencies or to mitigate those factors (Warden, Daya, and LeGrady 2007; Cramer, Brown, and Hu 2011; Hibdon and Groff 2014; Hansen, Loker, and Warden 2016).

This project explores and develop a comparative spatial analysis for fire and EMS calls for service. The literature studying fire and EMS accessibility is just starting to expand. There are a number of important studies, but many rely on straightforward and basic methods. However, more and more studies are beginning to utilize more advanced analytical methods. These studies have begun to establish a number of sound and effective analytical methods. Having sound, defensible methods is critical for any spatial analysis study. This thesis establishes a sound, defensible methodology and provide a robust and beneficial addition to the study of fire and EMS accessibility.

Chapter 2 Related Work

This chapter reviews the literature necessary to frame the importance of research into fire and EMS service accessibility and for the successful implementation of the methodology. To that end, the chapter covers four main categories of related work: Fire and EMS services, emergency accessibility, the two-step floating catchment area method, and data mining. Overall, the literature guides the process used in this thesis and points to future areas of EMS and fire research.

2.1. Fire and Emergency Medical Services

In the United States, a fire department is defined as “a public organization that provides fire prevention, fire suppression and associated emergency and non-emergency services to a jurisdiction such as a county, municipality, or organized fire district”(Everts and Stein 2019, 15) and according to the U.S. Fire Department Profile 2017 (Everts and Stein 2019) there are an estimated 29,819 fire departments in the United States. Of these departments, 65% are completely staffed by volunteers, 26% are staffed by a combination of volunteer and career firefighters, and 9% are staffed completely by career firefighters. The type of staffing at each department seems to be directly tied to how large a community’s population is. As population increases, the likelihood a station is manned completely by career firefighters also increases.

According to the study (Everts and Stein 2019), 69% of the US population is protected by departments that are mostly or completely staffed by career firefighters while 31% of the population is served by departments consisting of mostly or entirely volunteer firefighters. These departments operate about 51,000 fire stations across the country resulting in about 0.15 stations per 1000 people. Communities with higher populations tend to have more fire stations than communities with smaller populations, but the ratio of stations per 1000 people declines as populations increase.

Emergency Medical Services are closely related to fire departments. EMS is considered the crossroads of public health, public safety, and patient care and is defined as "the practice of medicine involving the evaluation and management of patients with acute traumatic and medical conditions in an environment outside the hospital (prehospital)." (Federal Interagency Committee on Emergency Medical Services 2012, ix) In the healthcare world, EMS is unique as it requires resources and care to be delivered to the patient within an appropriate amount of time instead of the patient going to the service. It is essential that EMS identifies patients and patients' needs quickly and deliver those patients to an appropriate location for more specialized care (Federal Interagency Committee on Emergency Medical Services 2012).

Modern EMS really began after the publication of *Accidental Death and Disability: The Neglected Disease of Modern Society* in 1966. It detailed the deficiencies in trauma management outside of hospitals and is considered a rallying cry to improving emergency care (Goodloe and Biddinger 2012). Between 1966 and 1981, EMS programs across the United States were funded and supported by federal grants and support. There was a national call to improve service and the idea of a national EMS program started to look like a possibility. Legislation urged local agencies to merge and support one another and by 1981, most of the concerns raised in 1966 were solved and agencies began working to improve services (Bass 2015).

Then the Omnibus Budget Reconciliation Act was passed in 1981. This act reorganized federal departments and federal support for EMS became limited. By 1983, federal financial support for EMS ceased and EMS agencies became the responsibilities of reginal agencies. At this point, the federal government's role was strictly to provide technical assistance and coordination. Since 1983, the federal government's role has increased, and there is some funding to help support EMS agencies, but for the most part EMS falls under the prevue of state and local governments or other regional agencies (Bass 2015).

Today, there are an estimated total of 21,283 credentialled EMS Agencies in the United States. EMS agencies are organized in a number of different organizational types: hospital based, private non-hospital based, tribal, emergency medical dispatch, other agency, or governmental, both fire and non-fire based. Overall, over 60% of EMS agencies are governmental organizations (Federal Interagency Committee on Emergency Medical Services 2012). Municipal or government established EMS organizations are usually organized either as part of an existing department, such as a fire department, or as a third public safety agency, distinct from a fire or police department (Goodloe and Biddinger 2012).

Of the estimated 29,819 fire departments in the US, roughly 18,260 of them provide some level of EMS service, leaving roughly 11,559 departments not providing EMS service to residents (Evarts and Stein 2019). EMS service is broken down into three main categories: first responder, basic life support, and advanced life support. Each level of care requires different requirements based on which agency is responsible for EMS licensing in an area. In order for a department to provide a service, they must have someone staffed who meets the required training (NFPA 1710, 2016). In the US, about 13,631 fire departments provide basic life support service and 4,629 provide advanced life support services (Evarts and Stein 2019).

Fire service and EMS service are most related in terms of how they deliver their services: both a required to travel to their respective emergency instead of having their "customer" or "patient" come to them for service. And in both cases the timeliness of that response is critical and a slow response could result in extreme costs, both financially and in lives (NFPA 1710, 2016).

The National Fire Protection Agency publishes suggested standards for emergency response times: the amount of time it takes from when the call comes in until the first unit arrives on the scene. It is recommended a fire response leaves the station within 80 seconds of receiving a call for service and then arrive at the scene within an additional 240 seconds. Overall, they should arrive at an emergency within 5 minutes and 20 seconds. EMS service has similar suggestions. An EMS response should leave the station within 60 seconds of receiving a call for service and arrive with either first responder or basic life support service within an additional 240 seconds. If a department provides advanced life support service, the advanced service has 480 seconds to arrive at the incident as long as basic or first responder service arrived within the first 240 seconds (NFPA 1710, 2016). Thus, a first responder or basic life support must arrive at a patient in under 5 minutes from then the call comes in and advanced support must arrive within 9 minutes.

These recommendations are just that: suggested standards. There are no state or federal response time standards for either fire or EMS services. And even though many agencies have adopted these standards, the actual response times are highly varied. For EMS, the national average response time is just below eight minutes. In a more detailed breakdown, urban areas have an average of seven-minute response times and suburban areas have an average just under eight minutes. Rural areas on the other hand see response time balloon to an average of 14 minutes. In fact, nearly one in ten rural calls for service require nearly 30 minutes of response time, and research suggests longer response times result in worse outcomes for trauma patients (Mell et al. 2017).

2.2. Emergency Accessibility

For both fire and EMS service, accessibility is critical in responding to emergencies. Vehicles and crews need to arrive at emergencies as quickly as possible in order to manage incidents. If that accessibility is hampered in any way the quality of service can be impacted and result in loss of more property and life. So for fire departments and EMS, studying how accessible their services are for the populations which depend on them are critical for their operation. This is especially important as EMS personnel underestimate their travel time from incident to a hospital by a median of nine minutes (Neeki et al. 2016).

There are two types of accessibility. The first, potential or perceived accessibility, is a prediction and reflect the possible utilization of a service by a patient. It assumes the patient will use the nearest service location and does not account for actual usage of a service (Guagliardo 2004). The second type of accessibility is revealed accessibility. Revealed accessibility examines actual usage patterns and calculates accessibility with actual use cases. In general, these types of studies are less common in the healthcare field as data on actual uses of healthcare services can be difficult to obtain (Lu and Davidson 2017).

For studies of EMS accessibility, accessibility is typically measured in a variety of ways. Some studies use a ration ratio of supply and demand in a service area (Lin et al. 2016). Others have used a number of factors to predict the total mileage an ambulance covers in a year (Patterson, Probst, and Moore 2006). In general, there are four categories of spatial accessibility measures: provider to population ratios, distance to the nearest provider, average distance to a group of providers, and gravitational models of provider influence (Freyssenge et al. 2018).

Spatial accessibility essentially has two dimensions: the accessibility dimension and the availability dimension. The accessibility dimension is the distance or time between a service location and a patient while the availability dimension involves the number of service locations a patient can choose from. Studies which rely on distance or time as a measure of accessibility focus exclusively on the accessibility dimension. On the other hand, studies which use a gravity model or a provider to population ratio as a measure of accessibility include both dimensions in their analysis. Overall, all studies of accessibility share one feature: they all account for distance in some fashion, either with a value like Euclidean Distance or a measure like travel-time. Furthermore, research of EMS accessibility tends to cover many of the different components of an EMS system including ambulance depot locations, hospital locations, and levels of service (Lu and Davidson 2017).

For example, Brodsky and Hakkert examined how accessibility impacted potentially fatal incidents in rural Texas. They used response time to define areas with accessible EMS services. Using a log linear analysis, they determined EMS accessibility across rural Texas was not uniform and in fact was highly variable even within areas with access. Furthermore, they demonstrated that areas with higher accessibility experienced fewer accidents with fatal outcomes (Brodsky and Hakkert 1983).

Researchers are not just concerned with how long it takes a vehicle to travel to the scene of an emergency. Morrison et al. examined how a patient's location in a building, the patient access, affected response times and in turn the severity of the final outcomes of an emergency. Through an observational analysis they demonstrated that patients residing above the third floor of a high-rise experience longer response times because they are less accessible to emergency crews. In fact, response time saw an increase of over 30% when a patient was above the third floor (Morrison et al. 2005).

In a study of how accessible stroke care centers are for stroke victims, Freyssenge and his colleagues used a simple measure of travel time along a network to measure access. They tested the potential accessibility of the study area using a number of different scenarios, each defined by travel times adjusted by different speed limit requirements. They demonstrated that even within a small metropolitan area the accessibility of emergency services could be highly varied (Freyssenge et al. 2018).

As GIS technologies developed the spatial analysis of EMS accessibility also developed and became more complex. McArthur, Gregersen, and Hagen used a measure which measured accessibility from a population center to all hospitals in the study area as part of a study examining the costs of an EMS system. Their method utilized travel-time along a network as a measure of distance between a population-weighted centroid instead of Euclidean Distance, a weighted function, and an impedance function as a way to model real-world factors which impact travel-time, such as traffic (McArthur, Gregersen, and Hagen 2014).

Accessibility studies have become significantly more important for rural EMS systems where response times are higher. It is critical for these rural departments to understand the different factors that could impact the timely provision of care. To that end, He et al. utilized a series of regression models to statistically analyze the different factors contributing to response time. They successfully identified factors that contribute to increased response times and were able to show that if these factors are mitigated, response times can be reduced and optimized (He et al. 2018).

2.3. Two-Step Floating Catchment Area Method

One of the most popular methods used to study spatial accessibility of healthcare services is the two-step floating catchment area method (2SFCA). This method produces a provider to population ratio which accounts for both the accessibility and availability dimensions of spatial accessibility. The method was first implemented by Luo and Wang in 2003 in a study of access to primary care physicians. Since then, the method has been upgraded, improved, and optimized in a number of different ways and versions of it have been used in studies of primary care access, hospital access, and, of course, EMS access.

The precursor to the 2SFCA was first implemented in 2003 by Luo and Wang. The method, called the Floating Catchment Area method, utilized buffer and overlay functions to assign census tracts a physician to population ratio within a euclidean circle based on the census tract's centroid. Based on these ratios, Luo was able to identify census tracts that had a shortage of healthcare services. The only main issue with this method was it assumed an equal access to services across euclidean distance and did not account for other factors, such as travel time (Luo and Wang 2003). Luo again used this same method in 2004 in another study of access to healthcare facilities (Luo 2004).

Luo and Wang also ran into an issue with edge effects, which they accounted for using a buffer along the edge of their study area (Luo and Wang 2003). The issue was that healthcare services do not just cease beyond the study area and it is more than likely that people living along the edge can and do utilize services beyond the study area. The buffer is used to identify the areas with suspect results. This solution is used regularly to account for edge effects in floating catchment area studies.

In 2005, Wang and Luo revised the floating catchment model, now called the two-step floating catchment area model. This time they used travel time along a network to calculate the catchment distance around the census tract centroid and from the healthcare service locations themselves. In the first step, a catchment is drawn around a healthcare service location and a provider to population ratio was calculated based on the number providers at the location and the population which resided within the catchment, generalized on the census tract centroids. The second step placed a catchment around each centroid and summed the ratio of each of the service locations within the catchment (Wang and Luo 2005).

This method helped eliminate the issue of unequal access as the model now accounted for the idea that not every resident could access every healthcare service location within a census tract catchment zone. Furthermore, the methodology considered interactions across catchment borders. It made the model permeable and more fluid as people along the edges of catchment areas may go across the border for service (Wang and Luo 2005). The methodology used here can be easily implemented with fire stations by replacing the healthcare locations with the stations. The method would need a few more minor tweaks, particularly with the maximum drive time setting, but otherwise it would be fairly straight forward.

2.3.1. Variant Two-Step Floating Catchment Area Methods

The 2SFCA method has continued to be improved upon and augmented. In 2009, Luo and Qi weighted the process to add a distance decay to the equation (Luo and Qi 2009). They broke up the catchments into time zones and applied a decay weight to each zone. They called this method the enhanced two-step floating catchment area method (E2SFCA). DeWulf et al. (2013) also published additions to the base formula to add further weights which restricted the size of the catchments. Overall, the formula is fairly flexible, which has been discussed as both a strength and weakness (McGrail 2012). McGrail (2012) argues the method does not allow for enough geographic variation as different geographies should have different restrictions on catchment size. For a largescale study area, this could be a major issue. However, at the local level of this thesis and with the understanding that maximum drive time is a set standard by QuadCom 911, this should not be an issue.

Other improvements have also been implemented in different studies. Dai and Wang (2011) used a kernel density function to weight the catchments like a gravity model. Dai (2011) also utilized a Gaussian function to calculate weights. Luo and Whippo (2012) adjusted the catchment sizes based on population density while Kim and his colleagues (2018) did the same thing but used hospital levels instead of population density. In 2014, Luo integrated the Huff Model into the 2SFCA which attempted to expand the sensitivity of the supply and demand model embedded in the 2SFCA. Wan et al. (2012) tackled this same issue by adding a third step which accounted for demand changes due to hospitals being near to each other, thus creating the Three Step Floating Catchment Area Method (3SFCA).

Delamater (2013) proposed a 2SFCA method which calculated a pairwise ratio which added a weight to represent populations preferences in hospital selection. Other researchers focused on how transportation networks and methods of transportation affected accessibility and how those factors could be accounted for in the 2SFCA. Langford et al. (2016) and Mao and Nekorchuk (2013) both modified the 2SFCA by calculating different transportation methods separately as they argued different modes of transportation should have different travel-time thresholds. Chen and Zhou (2016) on the other hand believed congestions played a critical role in accessibility and used GPS trajectories to calculate drive-time thresholds and broke up the day into different blocks to track how accessibility changed over both space and time.

2.3.2. EMS Applications of the 2SFCA Method

The basic 2SFCA method and its different variations have become widely popular in studies of healthcare service, specifically in relation to primary care and hospital care services.

But the methodology and its variations have also been adopted in more recent studies of EMS service. The standard 2SFCA method utilizing drive-time based catchments was used by Tansley and his colleagues in a study of rural EMS response in Ghana (Tansley et al. 2016). The study demonstrated that significant improvements in accessibility were made between 2004 and 2014. But the results also showed that accessibility varied greatly from population district to population n district.

Variant 2SFCA methods have also been implemented in EMS accessibility studies. For example, EunSu Lee (2014) proposed a new method to study EMS potential accessibility and compared the method to a gravity-based 2SFCA. The method uses a travel friction coefficient and a decay function to optimize the methodology. In practice, this model reduces the amount of space that can be traveled in an allotted timeframe.

EunSu Lee utilized a variant of the 2SFCA to validate a new methodology, but the 2SFCA has been used to analyze EMS accessibility in its own right. In 2016, Bo-Cheng Lin and his colleagues used a variation called the multi-criterion two-step floating catchment area (MC2SFCA) method. Their study examined access to AEDs, Automated External Defibrillators, for cardiac arrest patients. The AEDs were located within buildings and in ambulances which could be deployed to an incident (Lin et al. 2016)

Like the standard 2SFCA, this method considers the interaction between supply and demand, but uses a composite indicator for demand instead of a single factor, such as emergency incident. In this case, the composite indicator was calculated using spatial regression analysis to identify and understand the relationship between an incident and possible risk factors. The regression model produced a value for potential risk for an area and this value was used as the demand factor for the MC2SFCA (Lin et al. 2016).

Another variant of the 2SFCA for use with EMS was proposed by Xi et al. (2019). They proposed a method which they called the spatio-temporal enhanced two-step floating catchment area method (ST-E2SFCA) to analyze spatio-temporal accessibility. The method is time sensitive like the E2SFCA but considers potential demand dynamic and measures this demand by estimating dynamic population distributions using GPS points collected from mobile phones. Xi et al. argue EMS accessibility requires dynamic population demand across time and space to be accounted for as people are constantly moving across a landscape and demand could change depending on the time of day. The ST-E2SFCA method accounts for this dynamism whereas most variants of the 2SFCA consider population, and thus demand, static (Xi et al. 2019).

2.4. Summary of Related Work

The literature related to fire service, EMS, healthcare service, and accessibility all assisted in providing the foundation for this thesis. First, the literature on Fire and EMS services demonstrate that both are closely related in the United States and in a majority of cases work together. This justifies the inclusion of both fire calls for service and EMS calls for service in this study. The literature on accessibility show that, no matter how accessibility is defined, it is a critical component of emergency response and an appropriate measure of how effective a set of emergency services are. In addition, the literature on the 2SFCA method and its variants demonstrate the method is widely accepted as an effective method to analyze accessibility and why applying the method to EMS services is not only possible but also acceptable. Finally, the literature on data mining discusses that the process used to develop this thesis and methodology is an acceptable research process, especially in our modern world of Big Data. Overall, the literature reviewed in this chapter guides the methods used in the thesis and is used to demonstrate some of the areas to expand or refine the study in the future.

Chapter 3 Methods

This study aims to assess how accessible the QuadCom 911 fire stations are in eight- and seven-station configurations and analyze the differences. The analysis utilizes the 2SFCA method to calculate accessibility for population areas in and near the QuadCom 911 service area. Two types of accessibility values are calculated. The first, perceived accessibility, is a service provider to population ratio which measures the potential accessibility an area has. As a ratio moves closer to zero, a population in an area has less access to a service. The second value, the revealed accessibility, is a service provider to actual users ratio which measures how accessible a service is under actual use conditions. In this case, a call for service has a specific location and represents a use of a service and can be used to calculate a revealed accessibility as a ratio of service providers to calls for service. Using these accessibility measurements for each configuration, areas with low levels of access to emergency services are identified. These results are analyzed to determine how a potential merger and consolidation of emergency services within the QuadCom service area would affect access to those services. Finally, the values derived for accessibility in this analysis are used to propose an acceptable range of accessibility measurements for suburban, regional EMS.

3.1. Overview of Methodology

The following methodology (Figure 6) is the process by which accessibility is calculated for the QuadCom 911 service area. The unit of analysis is census block groups and they are generalized by their population-weighted centroids for use in the 2SFCA method tests. The study area includes all blocks groups to which responders from the eight fire stations were dispatched – this includes the official QuadCom 911 service area as well as some neighboring census blocks. Drive-time based catchment areas are calculated for each fire station. Catchment

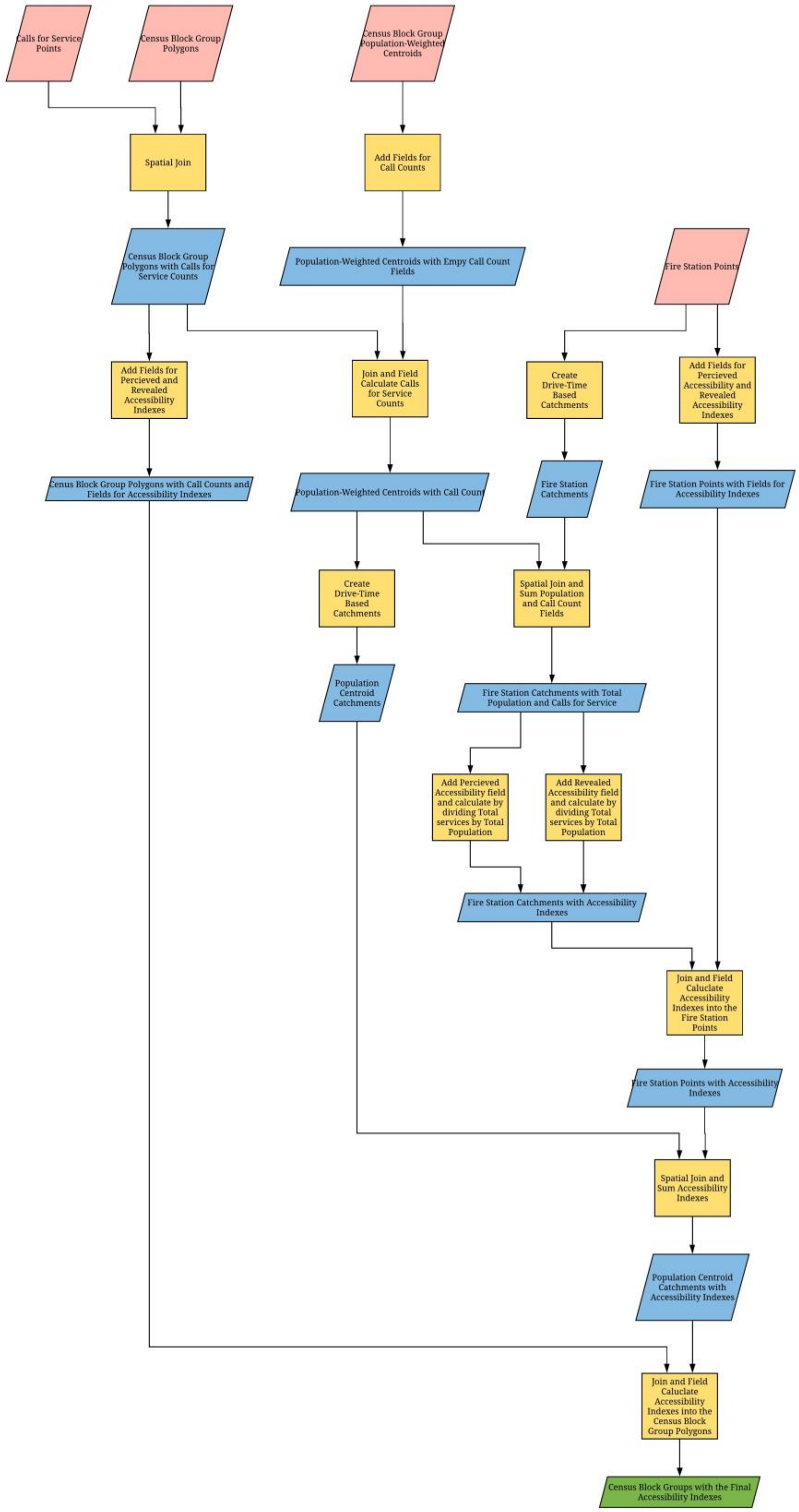


Figure 6. General methodology outline

areas for the accessibility measurements are calculated using three drive-time intervals: six minutes, eight minutes, and ten minutes. For this project, a perceived accessibility index and a revealed accessibility index is calculated for calls in 2014, 2015, 2016, 2017, and 2018 for each Fire Station. The perceived accessibility index for each fire station is calculated by dividing the total number of available services at a station by the sum of the populations of the population-weighted centroids that are within the drive-time catchments for that station. The revealed accessibility index on the other hand is the total number of available services at a station divided by the sum of the calls for service in a specific year of each census block group population-weighted centroid that falls within the station's drive-time catchments.

The analysis then moves to the census blocks. Drive-time based catchment areas are calculated for each census block, centered on the population-weighted centroids at three drive-time intervals: six minutes, eight minutes, and ten minutes. Perceived and revealed accessibility indexes are calculated for each block group by selecting all the fire stations within each centroid's catchment and summing their accessibility indexes. Specifically, if there are three fire stations within a catchment, that block group's perceived accessibility index is the sum of those three fire stations' perceived accessibility indexes. For that same catchment, the revealed accessibility index for a specific year would be the sum of that years revealed accessibility value from all three fire stations.

This process is used in three scenarios: an eight-station configuration which represents the current conditions of 911 services in the study area, and two seven-station configurations which represent possible realignments due to the pending merger of two local fire departments. The accessibility indexes calculated in all three scenarios are then compared by establishing standard Natural Jenks breaks for each of the drive-time intervals using the revealed accessibility indexes calculated under the eight-station configuration. With these standard breaks, the accessibility values can be examined to see how they change over time, how accessibility values are affected by different drive-time standards, and if and how access to 911 services would be affected if two fire departments were to merge and close a fire station.

3.2. Data

Data for this project is provided by two main sources: The United States Census via Census.gov and QuadCom 911 through a data sharing agreement. The first Census dataset is a polygon shapefile of 2018 block groups for the state of Illinois. The shapefile has a coordinate system of GCS North American NAD83 and includes attributes for identifying each block group and geographic information including its geographic coordinates and its water and land areas. The second Census dataset is a .txt document with the population-weighted centroids for Illinois block groups. It contains identifying information which allows the centroids to be related to their associated block group as well as the total population for each block group.

QuadCom 911 provided four datasets: two reference and two primary datasets. The first reference dataset is a regional street network line feature class. It is formatted in the NAD 1983 State Plane Illinois East FIPS 1201 projected coordinate system and contains attribute information identifying each street and the address ranges for each segment. The second reference layer is a polygon feature class representing the jurisdictions of each of the fire stations dispatched by QuadCom 911. It is formatted in the NAD 1983 State Plane Illinois East FIPS 1201 projected coordinate system. It also has attributes including the station name and the station ID number.

The first of the two primary QuadCom 911 datasets is a point feature class representing the eight QuadCom 911 fire stations. Its projected coordinate system is NAD 1983 State Plane

Illinois East FIPS 1201. The attributes for this feature class include fields for identification and location. The second of the primary QuadCom 911 datasets is a .csv file with calls for service. For each call for service, it contains the call ID number, call type, call description, date, address, longitude, latitude, and travel time. The longitude and latitude data are in the WGS 1984 geographic coordinate system. All datasets used in this project were imported into ArcMap and, if not already in the correct projected coordinate system, were projected into NAD 1983 State Plane Illinois East FIPS 1201.

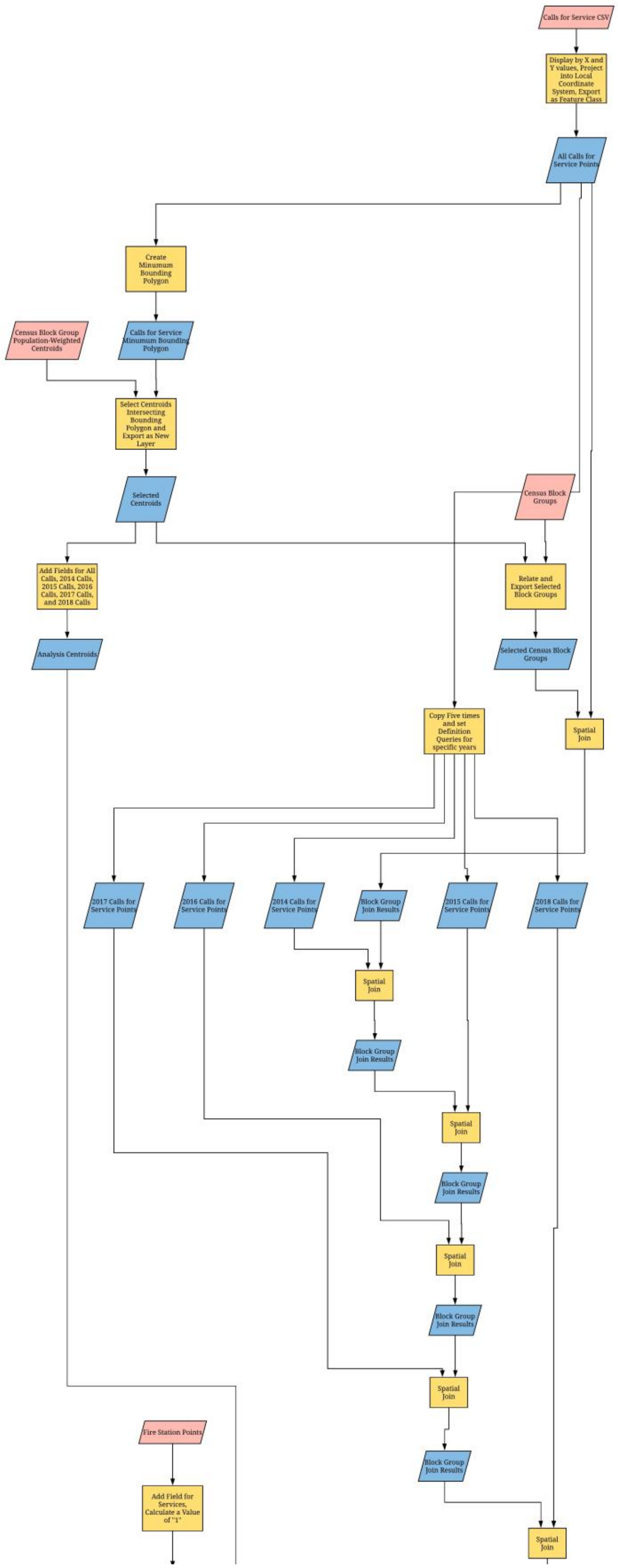
3.3. Analysis Process

This section presents in detail the process used by this study to calculate the accessibility values over time for census block groups at three drive-time intervals in three station configuration scenarios.

3.3.1. Eight-Station Configuration

To begin, the Calls for Service Data was cleaned, added the table to ArcMap, and displayed the data by X and Y values. The calls for service were projected and displayed into the local coordinate system NAD 1983 State Plane Illinois East FIPS 1201 and exported the XY data to a feature class for All Calls for Service. Next, annual layers for service calls were created by copying the All Calls for Service layer and pasting in 5 copies, naming them Calls 2014, Calls 2015, Calls 2016, Calls 2017, and Calls 2018, and setting the definition queries so only calls in 2014, 2015, 2016, 2017, and 2018 are displayed respectively.

Next, the Fire Stations data were added to ArcMap. A field was added to the Fire Stations layer named “Services” and field calculated a value of 1 for each. Each station can only provide 1 ambulance and fire engine, so the number of service providers each station represents is 1. This value was required later to calculate the accessibility indexes. Then, a Minimum


Calls for Service CSV
Display by X and Y values, Project into Local Coordinate System, Export as Feature Class
All Calls for Service Points
Create Minumum Bounding Polygon
Census Block Group Population-Weighted Centroids
Calls for Service Minumum Bounding Polygon
Select Centroids Intersecting Bounding Polygon and Export as New Layer
Selected Centroids
Census Block Groups
Add Fields for All Calls, 2014 Calls, 2015 Calls, 2016 Calls, 2017 Calls, and 2018 Calls
Relate and Export Selected Block Groups
Analysis Centroids
Selected Census Block Groups
Copy Five times and set Definition Queries for specific years
Spatial Join
2017 Calls for Service Points
2016 Calls for Service Points
2014 Calls for Service Points
Block Group Join Results
2015 Calls for Service Points
2018 Calls for Service Points
Spatial Join
Block Group Join Results
Spatial Join
Block Group Join Results
Spatial Join
Block Group Join Results
Spatial Join
Fire Station Points
Block Group Join Results
Add Field for Services, Calculate a Value of "1"
Spatial Join

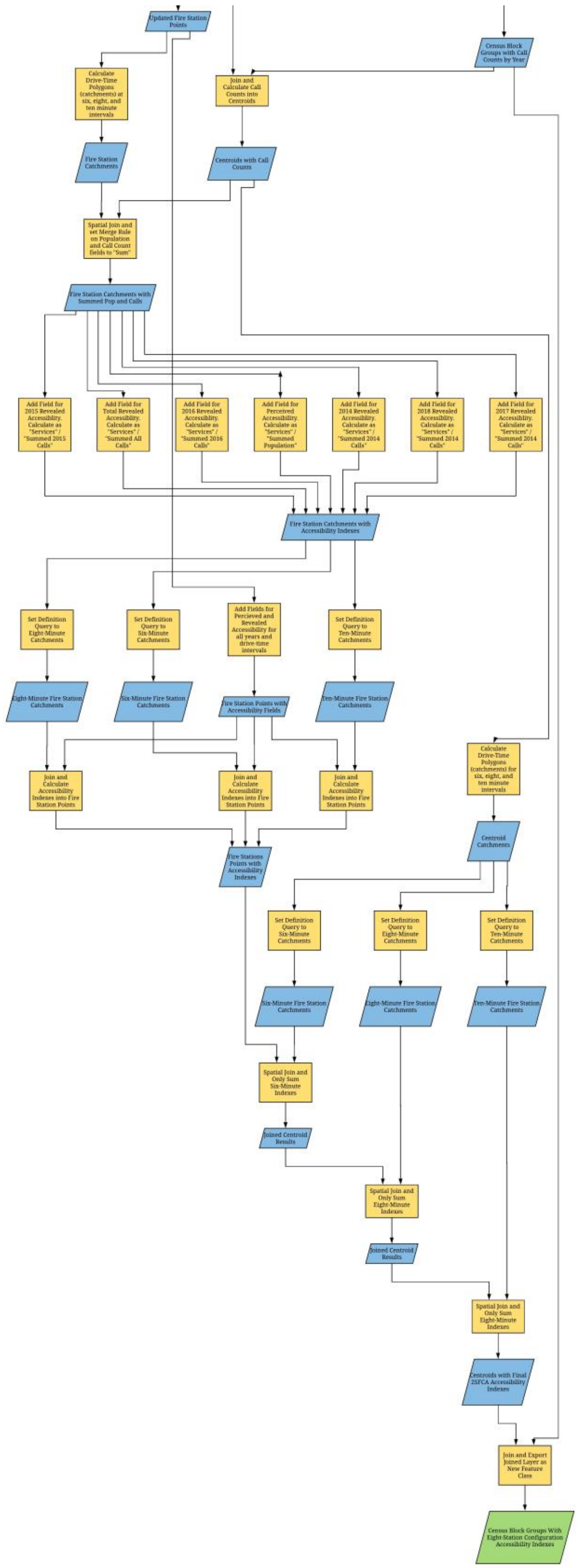


Figure 7. Eight-station configuration methodology outline

Bounding Polygon was created based on the All Calls for Service layer. The default shape of the polygon is a rectangle. This minimum bounding polygon defined the study area for this project. Then the Census Block Group polygons and the Census Block Group Population Weighted Centroids from Census.gov were added. All the centroids which intersected the Minimum Bounding Polygon were selected and exported these as a new layer. The original centroid layer was then discarded.

Then the new centroids layer was related, not joined, to the Census Block Groups and exported the selected, related census block groups as a new Census Block Group layer. This was the study area. Then the original Census Block Group layer was removed. Next, the new Census Block Groups layer was spatially joined to the All Calls for Service layer using “Completely Contains” as the spatial relationship and this join was repeated five times between the new Joined Census Block Groups layer and the Calls 2014, 2015, 2016, 2017, and 2018 layers. The final Joined Census Block Groups layer contained call counts for All Calls for Service and each of the five years.

Next, the Joined Census Block Groups layer was joined to the population-weighted centroids and the call counts for All Calls for Service, Calls 2014, Calls 2015, Calls 2016, Calls 2017, and Calls 2018 were field calculated into the centroids attribute table. Using Network Analyst and ArcGIS Pro, drive-time polygons (catchments) were calculated at six, eight, and ten-minute intervals for each centroid and each fire station. Then the Fire Station Catchments were spatially joined with the Population-Weighted centroids with the spatial relationship set as “Completely Contains”. The centroid table included a population field and the six call count fields created earlier. For each of these fields, the merge rule was set to “Sum”. The resulting fields in the Joined Fire Station Catchments layer contained the Summed Population, Summed

All Calls for Service, Summed Calls 2014, Summed Calls 2015, Summed Calls 2016, Summed Calls 2017, and Summed Calls 2018.

With the new, joined catchment layer, fields were added for perceived accessibility, total revealed accessibility, and revealed accessibility for each year 2014 to 2018. Each new field was field calculated to create accessibility values. Some areas had no calls, which resulted in an error because you cannot divide by 0. For those areas with 0 calls, the accessibility values were field calculated to 0 first, then the rest were selected and calculated as follows:

1. Perceived accessibility: “Services” / “Summed Population”
2. Total revealed accessibility: “Services” / “Summed All Calls”
3. 2014 revealed accessibility: “Services” / “Summed Calls 2014”
4. 2015 revealed accessibility: “Services” / “Summed Calls 2015”
5. 2016 revealed accessibility: “Services” / “Summed Calls 2016”
6. 2017 revealed accessibility: “Services” / “Summed Calls 2017”
7. 2018 revealed accessibility: “Services” / “Summed Calls 2018”

In the Fire Stations point layer, fields were added for perceived accessibility, total revealed accessibility, and a field for revealed accessibility in 2014, 2015, 2016, 2017, and 2018 at six, eight, and ten-minute intervals. The created fields were:

- 6-min Perceived Accessibility
- 6-min Total Revealed Accessibility
- 6-min 2014 Revealed Accessibility
- 6-min 2015 Revealed Accessibility
- 6-min 2016 Revealed Accessibility
- 6-min 2017 Revealed Accessibility
- 6-min 2018 Revealed Accessibility
- 8-min Perceived Accessibility
- 8-min Total Revealed Accessibility
- 8-min 2014 Revealed Accessibility
- 8-min 2015 Revealed Accessibility
- 8-min 2016 Revealed Accessibility
- 8-min 2017 Revealed Accessibility
- 8-min 2018 Revealed Accessibility
- 10-min Perceived Accessibility
- 10-min Total Revealed Accessibility
- 10-min 2014 Revealed Accessibility

- 10-min 2015 Revealed Accessibility
- 10-min 2016 Revealed Accessibility
- 10-min 2017 Revealed Accessibility
- 10-min 2018 Revealed Accessibility

The Definition Query was set on the Fire Station Catchments layer to only show the layers with a value of six in the "ToBreak" field, which represented the drive-time intervals, meaning that only the six-minute drive-time catchments would be included in the analysis. Without any definition queries, the Fire Station Catchments layer contains 24 catchments: Each of the eight stations has a catchment at six, eight, and ten-minute intervals, totaling 24. As previously calculated, the Fire Station Catchments layer table had seven fields with accessibility values. The accessibility index values for each of the catchments needed to be field calculated into the Fire Stations point layer, which only had eight features and because ArcGIS does not allow for a one-to-many join. So, the six, eight, and ten-minute interval catchments needed to be field calculated separately. The definition query assigned in this step ensured the proper values were calculated into the proper fields in the Fire Stations point layer.

Next, the Fire Stations point layer was joined with the Fire Station catchment accessibility layer (the Definition Query was set on the catchment accessibility layer so only the six-minute catchments are used as described above). Then the accessibility values were field calculated from the catchments into the six-minute fields added to the fire station layer and the last few steps were repeated, but with the eight and ten-minute intervals. The fire station layer then contained accessibility values for each station at six, eight, and ten-minute intervals.

Then the Centroid drive-time polygons (catchments) were definition queried to only display the six-minute catchments. The spatial join was used to join the catchments with the fire stations point layer with all the accessibility values and set "Completely Contains" as the relationship. First, only the six-minute accessibility values were joined and the "Sum" merge rule was used for each and then repeated this step for the eight and ten-minute catchments using the eight and ten-minute accessibility values respectively. The summed accessibility values in this layer were our Accessibility index and the final result of the two-step floating catchment area process.

Finally, the Census Block Groups were joined with the Centroids and the Centroid catchments (including the accessibility values) and the joined Census Block Group layer were exported so unnecessary fields were turned off. This layer only contained Population, Total Calls, Calls 2014, Calls 2015, Calls 2016, Calls 2017, and Calls 2018, and Accessibility Index values (both perceived and revealed) for totals and each year at each drive-time interval. This layer was utilized to visualize and examine the results.

3.3.2. Seven-Station Configuration

The next stage of this project was to calculate the accessibility indexes for the two different seven-station configurations. Using the original fire station catchments layer, the three catchments for West Dundee Fire Station #2 were removed then spatially joined with the population-weighted centroids with spatial relationship set as “Completely Contains”. For the Population field, and all 6 calls fields, the merge rule was set to “Sum”.

With the new, joined catchment layer, fields were added for perceived accessibility, total revealed accessibility, and fields for revealed accessibility in 2014, 2015, 2016, 2017, and 2018. Each new field was field calculated to create accessibility value (Some areas may have no calls, which resulted in an error because you cannot divide by 0. For those areas with 0 calls, the accessibility values were field calculated to 0 first, then the rest calculated as below):

1. Perceived accessibility: “Services” / “Summed Population”
2. Total revealed accessibility: “Services” / “Summed All Calls”
3. 2014 revealed accessibility: “Services” / “Summed Calls 2014”
4. 2015 revealed accessibility: “Services” / “Summed Calls 2015”

5. 2016 revealed accessibility: “Services” / “Summed Calls 2016”
6. 2017 revealed accessibility: “Services” / “Summed Calls 2017”
7. 2018 revealed accessibility: “Services” / “Summed Calls 2018”

In the Fire Stations point layer, fields were added for perceived accessibility, total revealed accessibility, and a field for revealed accessibility in 2014, 2015, 2016, 2017, and 2018 at six, eight, and ten-minute intervals. The created fields were:

- 6-min Perceived Accessibility
- 6-min Total Revealed Accessibility
- 6-min 2014 Revealed Accessibility
- 6-min 2015 Revealed Accessibility
- 6-min 2016 Revealed Accessibility
- 6-min 2017 Revealed Accessibility
- 6-min 2018 Revealed Accessibility
- 8-min Perceived Accessibility
- 8-min Total Revealed Accessibility
- 8-min 2014 Revealed Accessibility
- 8-min 2015 Revealed Accessibility
- 8-min 2016 Revealed Accessibility
- 8-min 2017 Revealed Accessibility
- 8-min 2018 Revealed Accessibility
- 10-min Perceived Accessibility
- 10-min Total Revealed Accessibility
- 10-min 2014 Revealed Accessibility
- 10-min 2015 Revealed Accessibility
- 10-min 2016 Revealed Accessibility
- 10-min 2017 Revealed Accessibility
- 10-min 2018 Revealed Accessibility

Then the Definition Query was set on the Fire Station Catchments layer to only show the layers with a value of 6 in the “ToBreak” field. This let the six-minute drive-time catchments draw. Without any definition queries, the Fire Station Catchments layer contains 24 catchments: Each of the eight stations has a catchment at six, eight, and ten-minute intervals, totaling 24. As with the eight-station configuration, this fire station catchments layer table had seven fields with accessibility values. The accessibility index values for each of the catchments needed to be field calculated into the Fire Stations point layer, which only had 8 features and because ArcGIS does not allow for a one-to-many join, the six, eight, and ten-minute interval catchments needed to be

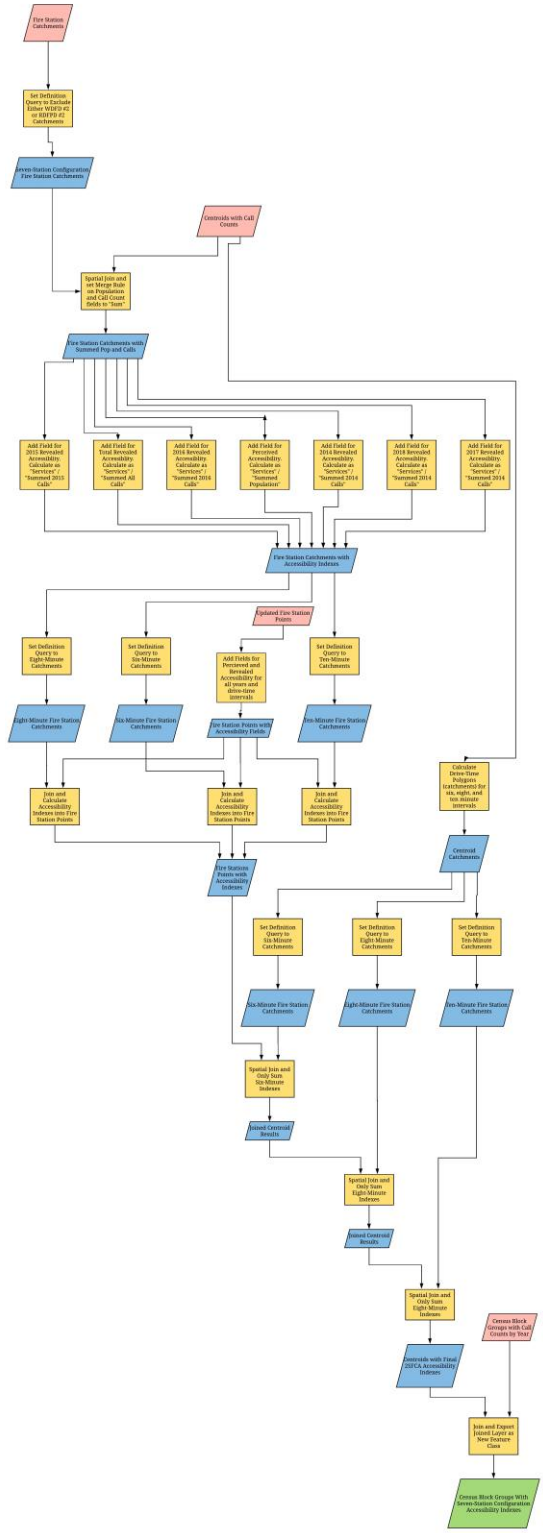


Figure 8. Seven-station configuration methodology outline

field calculated separately. The definition query assigned in this step ensured the proper values were calculated into the proper fields in the Fire Stations point layer.

The Fire Stations point layer was joined with the Fire Station catchment accessibility layer (the catchment accessibility layer should be definition queried to only show six-minute catchments). The accessibility values were field calculated from the catchments into the six-minute fields added to the fire station layer and repeated the previous steps, but with the eight and ten-minute intervals. The fire station layer then contained accessibility values for each station at six, eight, and ten-minute intervals. The Centroid drive-time polygons (catchments) were queried to only show the six-minute catchments. The catchments were spatially joined with the fire stations point layer which contained all the accessibility values with the relationship set as "Completely Contains". First only the six-minute accessibility values were joined using the "Sum" merge rule for each of these and then the join was repeated for the eight and ten-minute catchments using the eight and ten-minute accessibility values respectively. The summed accessibility values in this layer were the Accessibility index and the final result of the two-step floating catchment area process for one of the seven-station configurations.

The Census Block Groups were joined with the Centroids and the Centroid catchments (including the accessibility values) and exported the joined Census Block Group layer so the unnecessary fields were turned off. This exported layer only showed Population, Total Calls, Calls 2014, Calls 2015, Calls 2016, Calls 2017, and Calls 2018, and Accessibility Index values (both perceived and revealed) for totals and each year at three drive-time intervals in a seven-station configuration. This layer was used to visualize and analyze the results. Finally, this whole section was repeated but with Rutland Dundee Fire Protection District Station #2 in Sleepy Hollow removed instead of West Dundee Fire Station #2. With results for both seven-station configurations calculated, the results were then compared and analyzed against the eight-station configuration at all three drive-time intervals.

3.4. Analysis Breaks

The next step of this project was to establish a set of standard breaks for each of the drive-time intervals to aid in the analysis of the accessibility indexes over time and across the station configuration scenarios. To create these breaks, the revealed accessibility values from the eight-station configuration were utilized, because these values represent the current accessibility of the real-world emergency services. In total there were accessibility values calculated for 183 census block groups over five years at three separate drive-time intervals, totaling 2,745 accessibility values. Each drive-time interval accounted for 915 of the accessibility values. The first step to establish standard breaks was to group the accessibility values by drive-time interval.

To do this, all the fields from the final eight-station configuration results, except for the six-minute accessibility results for 2014, were turned off and then exported features as a new feature class, called Six Minute Breaks. Next, the six-minute accessibility results for 2015 in the final eight-station configuration results were turned on and the 2014 results were turned off and the table was appended into the Six Minute Breaks feature class. This step was repeated for the years 2016, 2017, and 2018. With this complete, the Six Minute Breaks feature class now contained 915 rows and contained all the revealed accessibility values for the six-minute drive time. This process was repeated two more times but with the eight and ten-minute drive-time interval results. In the end, three feature classes, Six Minute Breaks, Eight Minute Breaks, and Ten Minute Breaks, were created that each contained 915 features.

The final step was to calculate the breaks for each feature class. Class breaks were created using Natural Jenks and five classes were created. Once the breaks were set, consistent, graduated symbology was set based on those breaks and these feature classes were used as the source when setting up and importing the symbology for all the layers and maps used to analyze the results of the accessibility calculations. These standard breaks are used at all years and configurations so changes in accessibility can be easily differentiated.

Table 1. Six-Minute Interval Class Breaks. This table shows the class breaks for the six-minute interval

Class	Breaks
1	0 – 0.000336
2	0.000337 – 0.001066
3	0.001067 – 0.001722
4	0.001723 – 0.002538
5	0.002539 – 0.003642

Table 2. Eight-Minute Interval Class Breaks. This table shows the class breaks for the eight-minute interval

Class	Breaks
1	0 – 0.000300
2	0.000301 – 0.000922
3	0.000923 – 0.001392
4	0.001393 – 0.001956
5	0.001957 – 0.003464

Table 3. Ten-Minute Interval Class Breaks. This table shows the class breaks for the ten-minute interval

Class	Breaks
1	0
2	0.000001 – 0.000512
3	0.000513 – 0.000950
4	0.000951 – 0.001540
5	0.001541 – 0.002420

Chapter 4 Results

This chapter presents the results of the methodology described in Chapter 3. The first section discusses the procedural results of the methodology, specifically the results of those processes which produced new datasets. The following sections present the final results of the 2SFCA method for all three station configuration scenarios.

4.1. Procedural Results

The first set of procedural results produced by the projects methodology were the Calls for Service points. Overall, there are 31,515 specific Calls for Service between 2014 and 2018. Broken down by year, there were 6,150 calls in 2014, 6,043 in 2015, 6,210 in 2016, 6,346 in 2017, and 6,766 calls in 2018. Of all 31,515 calls, 30,135 of them occurred within the jurisdictional boundaries of the QuadCom 911 dispatched fire departments. Thus, emergency services were dispatched to 1,380 calls outside of their jurisdictional boundaries for an average of 276 calls a year.

Figure 9 shows the distribution of calls within the study area over time and how all 31,515 calls are distributed. The heatmap shows that a majority of the calls occur in the eastern half of the service area and centered near the river that splits the area in two. Like the call counts themselves, the locations of calls remain mostly consistent between 2014 and 2018. Some of the hotspots may increase or decrease in intensity from year to year, but overall, those hotspots are occurring in the same areas year in and year out. Additionally, this call distribution is also consistent with the population distribution in the area.

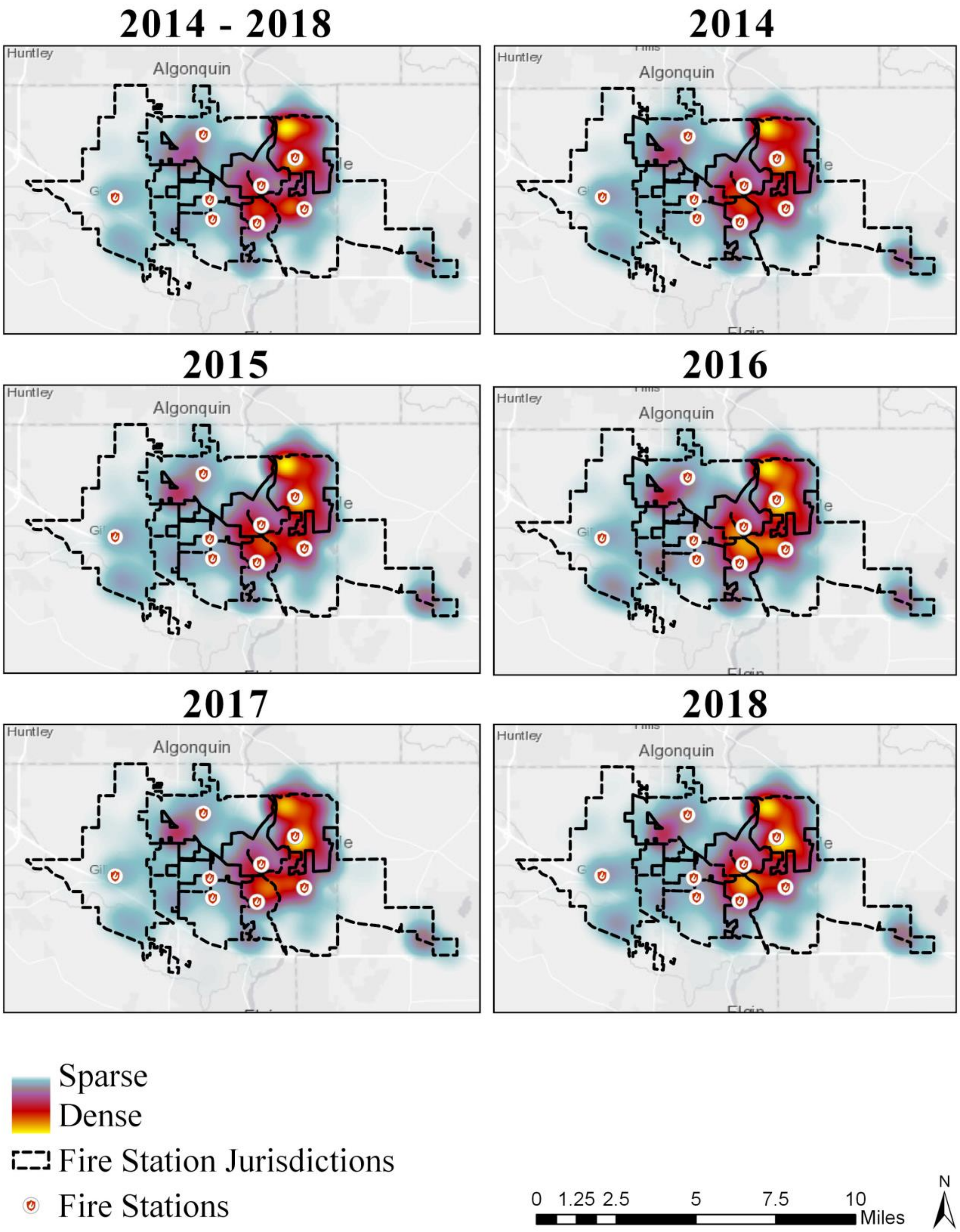


Figure 9. Distribution of calls for service by year. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Using the Calls for Service data, a minimum bounding polygon was created (Figure 10). This boundary, as the name entails, is the smallest, rectangular area, due to the default settings of the minimum boundary polygon tool, which encompasses all the calls for service. As described in the methodology, this polygon is used to spatially define the study area for this project. The minimum bounding polygon covers an area of about 218 square miles.

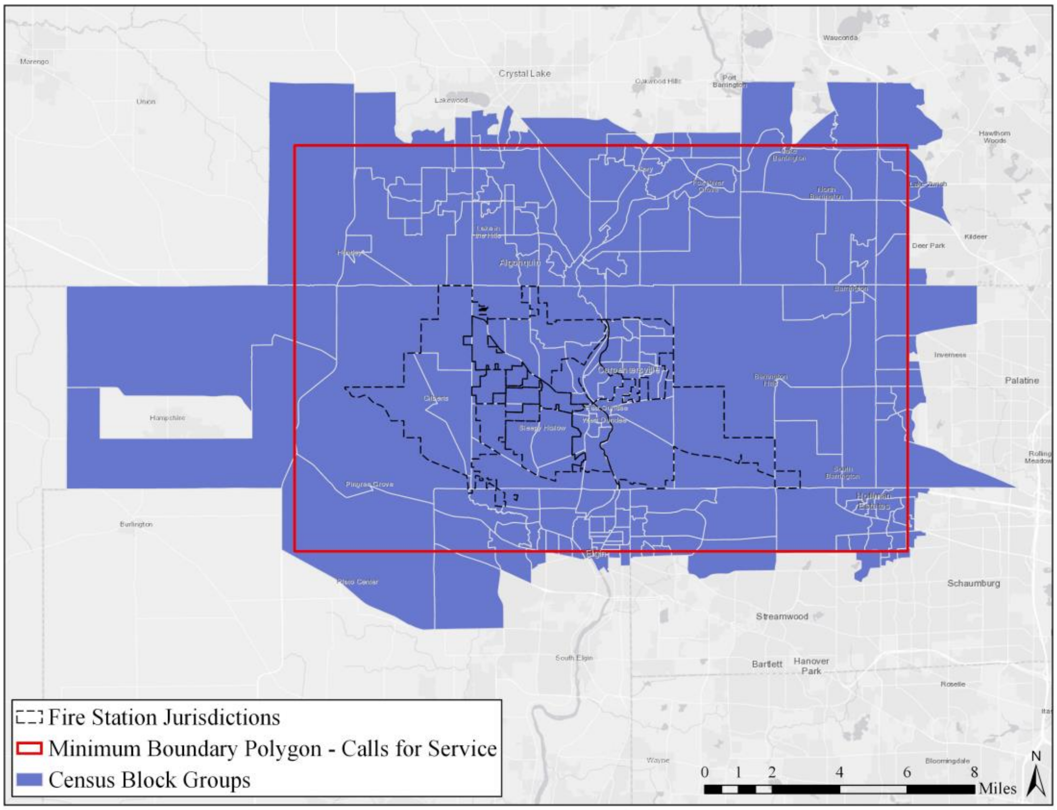


Figure 10. Thesis study area. This map includes the minimum boundary polygon and the census block groups included in the study. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

The study area for this project was defined by selecting the Census Block Groups which have a population-weighted centroid within the minimum bounding polygon. Figure 10 shows the Census Block Groups which are included in the project study area. In total, there are 184 census block groups which have population-weighted centroids within the minimum bounding polygon. These block groups cover an area of about 302 square miles and, according to the 2010 Census, are home to 367,177 people.

The next set of procedural results of the methodology are the drive-time catchments for the eight QuadCom 911 dispatched fire stations. There are 24 total catchments: one for each fire station at six-minute, eight-minute, and ten-minute intervals. Figure 11 shows an example of the eight catchments for the six-minute drive-time interval. Figure 12 shows an example of the catchments for the eight-minute interval and Figure 13 shows an example of the catchments for the ten-minute drive-time interval. The six-minute catchments cover roughly 39 square miles, the eight-minute catchments cover about 74 square miles, and the ten-minute catchments cover an area of about 111 square miles.

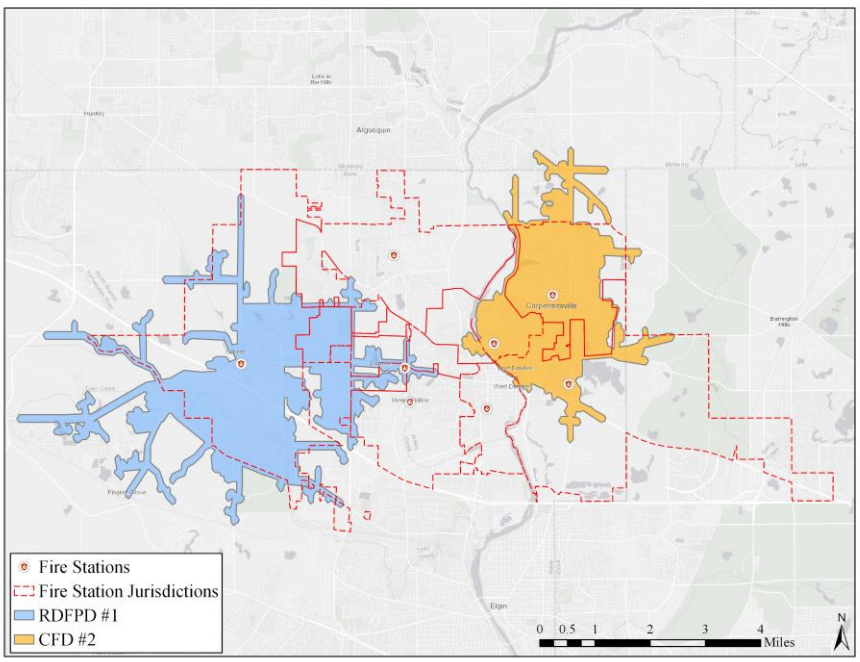


Figure 11. Six-minute fire station catchments. An example of the six-minute drive time fire station catchments used in the analysis. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

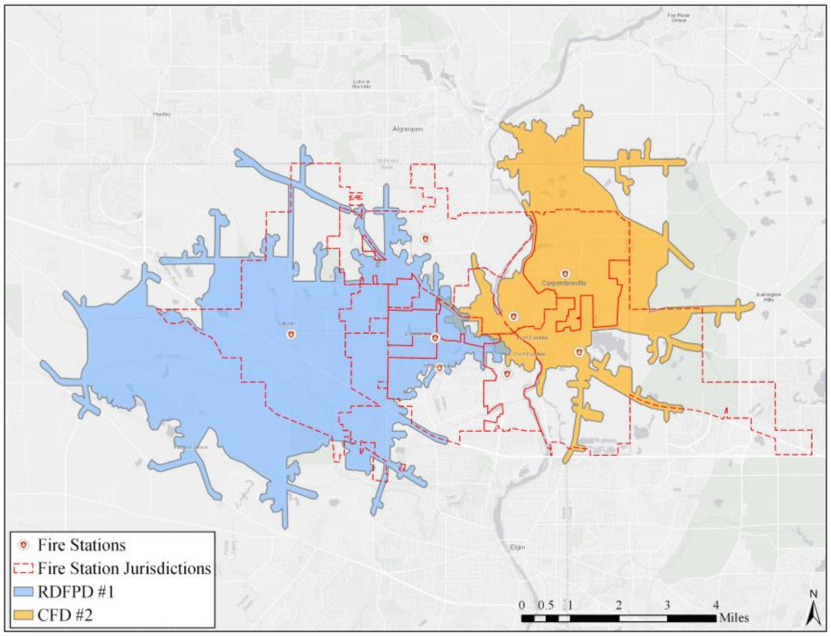


Figure 12. Eight-minute fire station catchments. An example of the eight-minute drive time fire station catchments used in the analysis. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

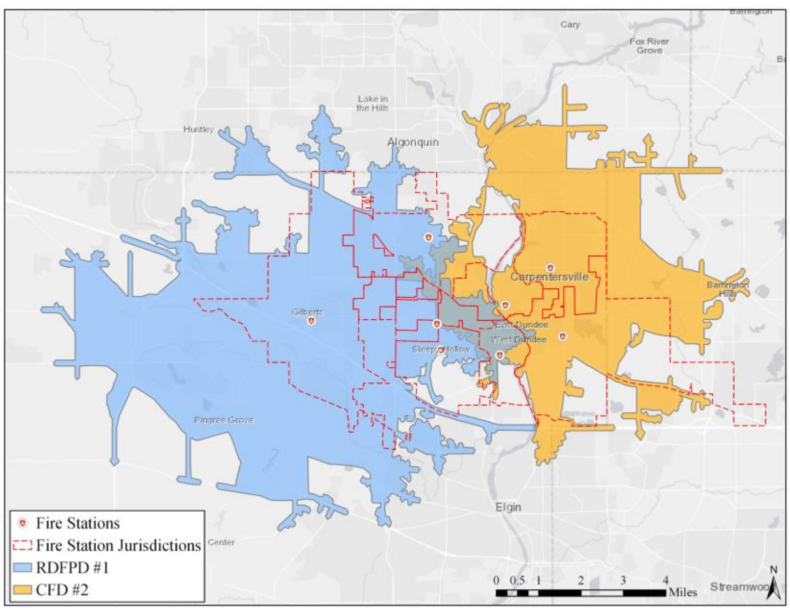


Figure 13. Ten-minute fire station catchments. An example of the ten-minute drive time fire station catchments used in the analysis. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Catchments were also created for each of the population-weighted centroids. Catchments were calculated at six, eight, and ten-minute intervals for each of the 184 census block groups included in this study. In total, there are 552 catchments. Figures 14 to 16 show examples of the drive-time catchments for each centroid at six, eight, and ten-minute drive-time intervals respectively.

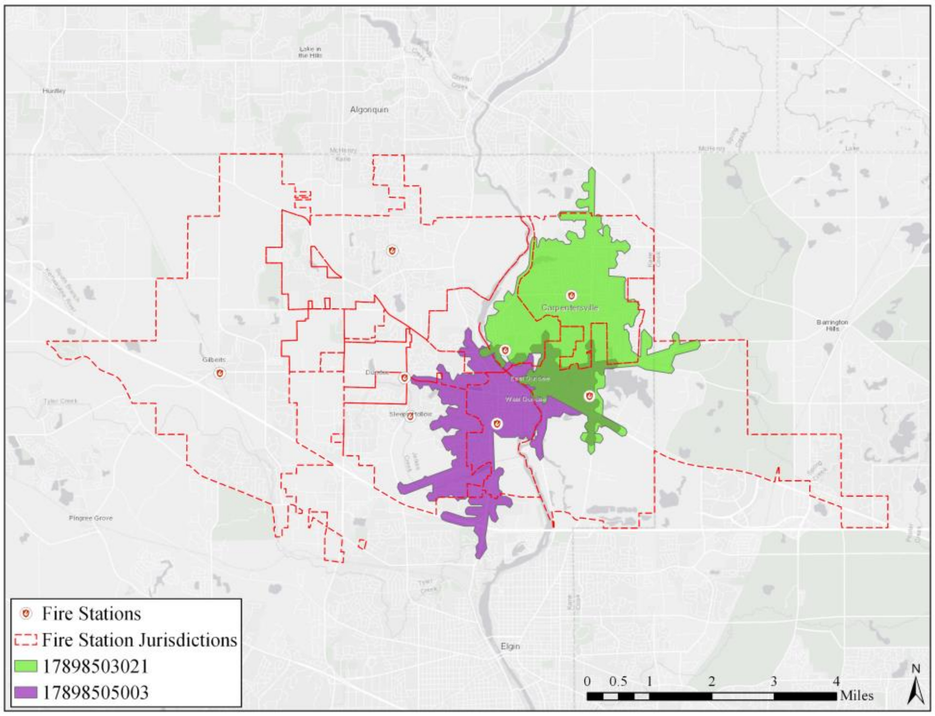


Figure 14. Six-minute census block group catchments. This map shows an example of the six-minute drive time catchments for the census block groups. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

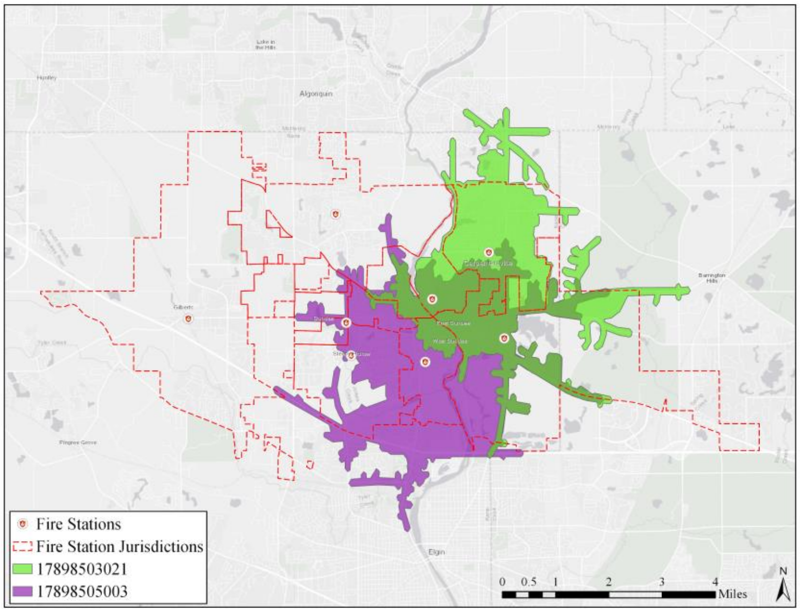


Figure 15. Eight-minute census block group catchments. This map shows an example of the eight-minute drive time catchments for the census block groups. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

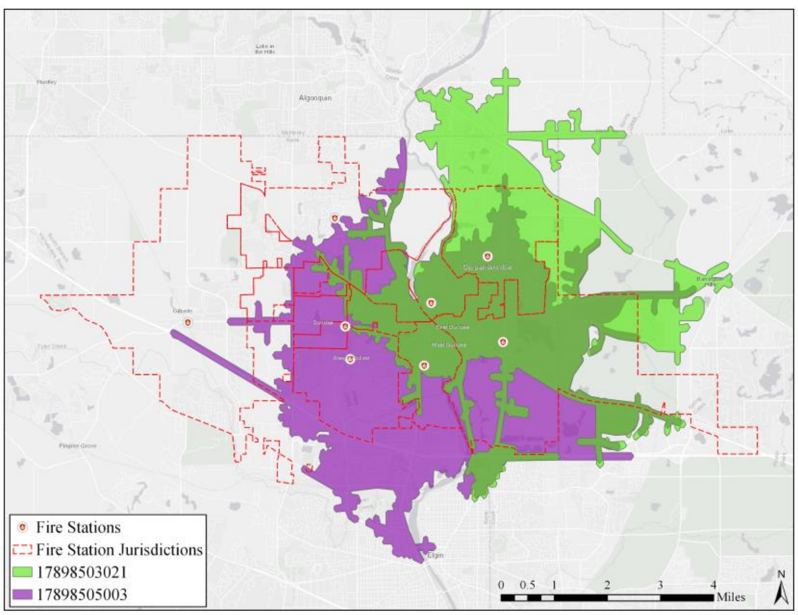


Figure 16. Ten-minute census block group catchments. This map shows an example of the ten-minute drive time catchments for the census block groups. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

4.2. Eight-Station Configuration

The Eight-Station Configuration scenario represents the current, real world environment for emergency services. Accessibility indexes were calculated for each block group using the 2SFCA method at three distinct drive-time intervals: six, eight, and ten-minute intervals. For each of these intervals, perceived accessibility, the ratio of services to populations, and revealed accessibility, the ratio of services to actual uses of the service, for the years 2014 to 2018 were calculated for each block group.

4.2.1. Six-Minute Drive-Time Interval

Figure 17 shows the accessibility index results of the 2SFCA method for the six-minute interval. Of the 184 census block groups included in the study, 41 block groups intersect with the Fire Station Jurisdiction area and only 30 have either perceived or revealed accessibility indexes above zero (Table 4). The other eleven block groups have perceived and revealed accessibility values of zero. In addition, there are two block groups outside of the jurisdictions which have revealed accessibility indexes. This means only the population-weighted centroids of those 32 census block groups are within six minutes of a QuadCom dispatched station. Of those 32, only two of the block groups have perceived accessibility indexes above 0.000336, each at 0.000359 and 0.000363. The other thirty have perceived accessibility indexes between 0.00003 and 0.000267.

In 2014, the revealed accessibility indexes show a much wider range of values. There are three block groups with accessibility above 0.002539, four between 0.001723 and 0.002538, eight between 0.001067 and 0.001722, thirteen between 0.000337 and 0.001066, and four with accessibility at exactly 0.000327. For 2015, there were three block groups with revealed accessibility above 0.002539, which included the highest accessibility index of the entire drive-

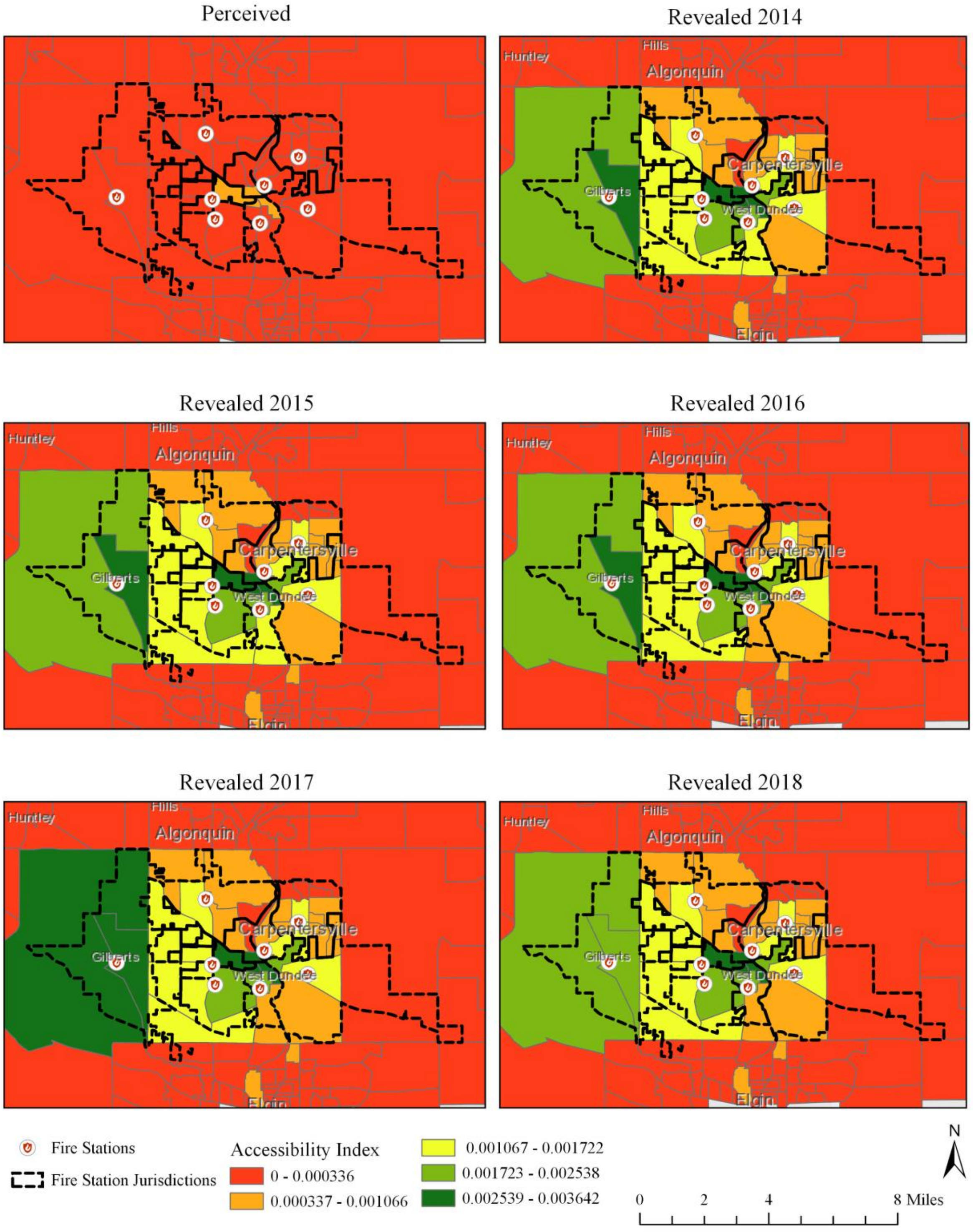


Figure 17. Accessibility for the eight-station configuration, six-minute drive time interval. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

time interval, 0.003642. In regards to the other block groups, four have indexes between 0.001723 and 0.002538, seven between 0.001067 and 0.001722, fourteen between 0.000337 and 0.001066, and four with accessibility values of 0.000336. Again, eleven block groups intersect with the Fire Station Jurisdictions and have accessibility indexes of zero.

2016 had the exact same breakdown as 2015 but the highest revealed accessibility index was 0.003367 and the lowest index above zero was 0.000336. The results are more varied for 2017. Of the 32 block groups with revealed accessibility above zero, four block groups had indexes above 0.002539 with the highest at 0.003518, three were between 0.001723 and 0.002538, seven were between 0.001067 and 0.001722, fourteen between 0.000337 and 0.001066, and four had accessibility indexes of only 0.000309. In 2018, the results were again slightly different. Two of the block groups had revealed accessibility indexes above 0.002539 with the highest index at 0.003232. Five block groups were between 0.001723 and 0.002538, seven between 0.001067 and 0.001722, fourteen between 0.000337 and 0.001066, and four with revealed accessibility of exactly 0.000064.

Table 4. Accessibility indexes, eight station configuration, six-minute interval. This table shows the accessibility indexes for census block groups with indexes above zero. The data is colored based on class: red = 0 to 0.000336, orange = 0.000337 to 0.001066, yellow = 0.001067 to 0.001722, light green = 0.001723 to 0.002538, dark green = 0.001724 to 0.003642

Block Group GEOID	Perceived	2014 Revealed	2015 Revealed	2016 Revealed	2017 Revealed	2018 Revealed
170898501011	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898501012	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898501031	0.000106	0.001368	0.001448	0.001338	0.001411	0.00132
170898501032	0.000363	0.003584	0.003642	0.003367	0.003518	0.003232
170898501051	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898501052	0.000106	0.001368	0.001448	0.001338	0.001411	0.00132
170898501063	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898501064	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898502011	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502012	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502021	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502022	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502023	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898503011	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898503012	0.000144	0.001313	0.001336	0.00131	0.001221	0.001154
170898503013	0.000093	0.000822	0.000849	0.000828	0.000781	0.000739
170898503014	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898503021	0.000144	0.001313	0.001336	0.00131	0.001221	0.001154
170898503022	0.000093	0.000822	0.000849	0.000828	0.000781	0.000739
170898504001	0.000155	0.001425	0.001434	0.001402	0.001328	0.001247
170898504002	0.000267	0.002456	0.002507	0.002413	0.002335	0.002176
170898505001	0.000359	0.003243	0.003241	0.00303	0.003082	0.00281
170898505002	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898505003	0.000124	0.001098	0.001098	0.001066	0.001019	0.000954
170898505004	0.000237	0.002128	0.002171	0.002076	0.002026	0.001883
170898506001	0.000245	0.002257	0.00224	0.002056	0.002171	0.001949
170898506002	0.000172	0.00165	0.001629	0.001472	0.001591	0.00141
170898506003	0.000194	0.001722	0.00168	0.001537	0.001635	0.001466
170898507011	0.00026	0.003074	0.002993	0.002839	0.003305	0.00252
170898507012	0.000209	0.002538	0.002433	0.00232	0.00277	0.002037
170898508001	0.000052	0.000491	0.000487	0.000482	0.00044	0.000414
170898546003	0.000073	0.000607	0.000611	0.000583	0.000579	0.000539

Table 5 shows the average difference in accessibility indexes from year to year as an absolute value. The values in this table are designed to represent how stable accessibility is over time. Accessibility is more stable the closer a value is to zero, as an absolute change of zero would suggest revealed accessibility did not change from one year to the next. At the six-minute interval there was an absolute average difference between 2014 and 2015 of 0.000029, 0.000065 between 2015 and 2016, 0.000089 between 2016 and 2017, and 0.000125 between 2017 and 2018. Overall, the six-minute interval had an average absolute difference of 0.000077.

Table 5. Average accessibility difference from year to year. This table shows the average absolute difference in accessibility from year to year for each drive time interval in each station configuration

	2014-2015	2015-2016	2016-2017	2017-2018	Average
Eight-Station Configuration					
Six-Minute Interval	0.000029	0.000065	0.000089	0.000125	0.000077
Eight-Minute Interval	0.000023	0.000047	0.000035	0.000055	0.000040
Ten-Minute Interval	0.000018	0.000033	0.000020	0.000054	0.000031
Seven-Station Configuration w/ WDFD #2 Removed					
Six-Minute Interval	0.000028	0.000053	0.000087	0.000110	0.000070
Eight-Minute Interval	0.000021	0.000042	0.000034	0.000047	0.000036
Ten-Minute Interval	0.000017	0.000030	0.000020	0.000047	0.000028
Seven-Station Configuration w/ RDFPD #2 Removed					
Six-Minute Interval	0.000031	0.000047	0.000077	0.000104	0.000065
Eight-Minute Interval	0.000021	0.000039	0.000034	0.000049	0.000036
Ten-Minute Interval	0.000015	0.000028	0.000020	0.000045	0.000027

4.2.2. Eight-Minute Drive-Time Interval

Figure 18 shows the results of the eight-station configuration 2SFCA method with the eight-minute drive-time interval. At eight minutes, there are 55 block groups with perceived and revealed accessibility indexes (Table 6). Of those 55 block groups, 36 intersect with the fire station jurisdictions. Additionally, there are five other block groups which intersect the fire station jurisdictions that have perceived and revealed accessibility indexes of zero.

For the eight-minute interval, all 55 block groups had a perceived accessibility index of less than 0.000300. The lowest index was 0.000018 and the highest was 0.000244. In 2014, there were four block groups with indexes above 0.001957 with the highest index at 0.003376, eight block groups between 0.001393 and 0.001956, four between 0.000923 and 0.001392, twenty-four between 0.000301 and 0.000922, and fifteen below 0.000300. In 2015 there were again four block groups with indexes above 0.001957. That year, the highest index was 0.003464, the overall highest index for the eight-minute interval. Additionally, there were eight block groups between 0.001393 and 0.001956, six between 0.000923 and 0.001392, twenty-two between 0.000301 and 0.000922, and fifteen below 0.000300.

In 2016 the distribution of the revealed accessibility indexes matched 2014. There were four block groups above 0.001957, with the highest index at 0.003253, eight block groups between 0.001393 and 0.001956, four between 0.000923 and 0.001392, twenty-four between 0.000301 and 0.000922, and fifteen below 0.000300. 2017 saw four block groups revealed accessibility indexes above 0.001957, six between 0.001393 and 0.001956, six between 0.000923 and 0.001392, twenty-four between 0.000301 and 0.000922, and fifteen below 0.000300. Finally, the distribution in 2018 was exactly the same as in 2017.

The average absolute difference in accessibility (Table 5) for the eight-minute interval was 0.000040. Specifically, there was an absolute average difference of 0.000023 between 2014 and 2015, 0.000047 between 2015 and 2016, 0.000035 between 2016 and 2017, and 0.000055 between 2017 and 2018.

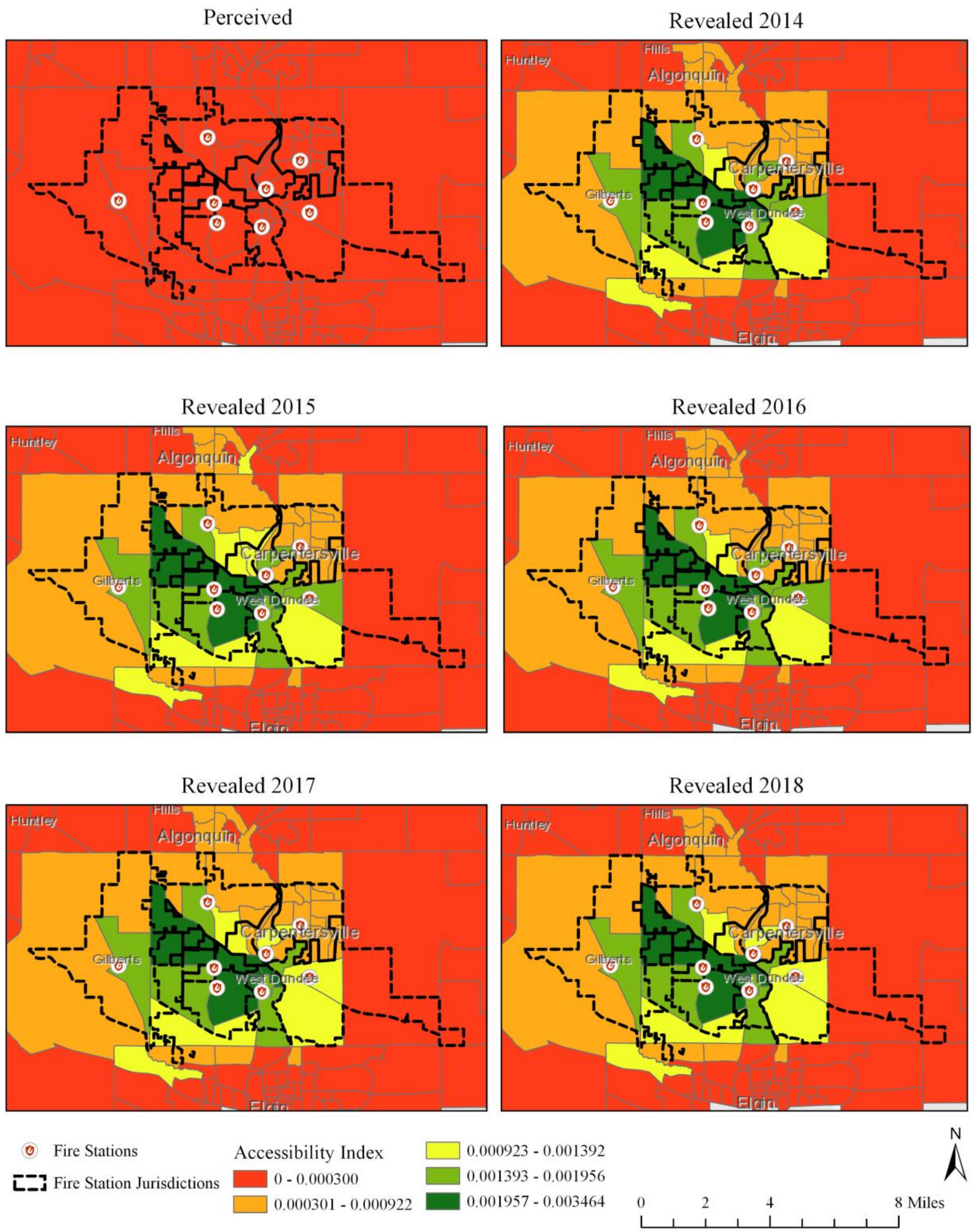


Figure 18. Accessibility for the eight-station configuration, eight-minute drive-time interval. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Table 6. Accessibility indexes, eight station configuration, eight-minute interval. This table shows the accessibility indexes for census block groups with indexes above zero. The data is colored based on class: red = 0 to 0.000300, orange = 0.000301 to 0.000922, yellow = 0.000923 to 0.001392, light green = 0.001393 to 0.001956, dark green = 0.001957 to 0.003464

Block Group GEOID	Perceived	2014 Revealed	2015 Revealed	2016 Revealed	2017 Revealed	2018 Revealed
170318042012	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170318043111	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170318044032	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898501011	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898501012	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898501031	0.000178	0.002501	0.002583	0.002395	0.002522	0.002331
170898501032	0.000244	0.003376	0.003464	0.003253	0.003344	0.003102
170898501051	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
170898501052	0.000134	0.001742	0.001807	0.001683	0.00173	0.001646
170898501061	0.000024	0.000284	0.000293	0.000288	0.000271	0.000256
170898501062	0.000056	0.000916	0.000964	0.000893	0.000922	0.000893
170898501063	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
170898501064	0.000094	0.001271	0.001327	0.001238	0.001275	0.001217
170898502011	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898502012	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898502021	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898502022	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898502023	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503011	0.000047	0.000508	0.000526	0.000513	0.000487	0.000459
170898503012	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503013	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503014	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898503021	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503022	0.000127	0.001455	0.001476	0.001428	0.001392	0.001299
170898504001	0.000127	0.001455	0.001476	0.001428	0.001392	0.001299
170898504002	0.000167	0.001926	0.001956	0.001873	0.001847	0.001727
170898505001	0.0002	0.002617	0.002687	0.002541	0.002553	0.002417
170898505002	0.000089	0.0011	0.001113	0.001083	0.001039	0.000975
170898505003	0.000143	0.001642	0.001664	0.001585	0.001577	0.001472
170898505004	0.000143	0.001642	0.001664	0.001585	0.001577	0.001472
170898506001	0.000176	0.002333	0.002395	0.002252	0.002282	0.002161
170898506002	0.000121	0.001586	0.001619	0.001502	0.001601	0.001438
170898506003	0.000125	0.001351	0.001371	0.001295	0.001307	0.001215
170898507011	0.000121	0.001586	0.001619	0.001502	0.001601	0.001438
170898507012	0.000044	0.000759	0.000776	0.000712	0.000792	0.000685
170898508001	0.000042	0.000591	0.000588	0.00057	0.000551	0.000515
170898508003	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898508004	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898508005	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898508006	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898510001	0.000064	0.000771	0.000776	0.000725	0.000737	0.000687
170898510003	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898511021	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898511023	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898513021	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898519101	0.000064	0.000771	0.000776	0.000725	0.000737	0.000687
170898519102	0.000081	0.001115	0.001139	0.001057	0.001145	0.001009
170898546003	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
171118712061	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118712063	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118713101	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118713103	0.000056	0.000916	0.000964	0.000893	0.000922	0.000893
171118713113	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118714041	0.000024	0.000284	0.000293	0.000288	0.000271	0.000256
171118714042	0.000024	0.000284	0.000293	0.000288	0.000271	0.000256

4.2.3. Ten-Minute Drive-Time Interval

The results for the ten-minute interval are shown in Figure 19 and Table 7. Overall, there are a total of 75 census block groups with perceived and revealed accessibility indexes. Of those 75, 37 intersect with the QuadCom 911 jurisdictions and the other thirty-eight block groups are outside of the jurisdictions. Finally, there are four census block groups which intersect the jurisdictions which have both perceived and revealed accessibility indexes of zero.

The perceived accessibility indexes for the ten-minute interval were all below 0.000512 with the highest index at 0.000155 and the lowest at 0.000012. However, the revealed accessibility indexes between 2014 and 2018 reveal a different pattern. In 2014, 34 census block groups had revealed indexes between 0.000001 and 0.000512, with the lowest at 0.000214, 20 block groups were between 0.000513 and 0.000950, 11 between 0.000951 and 0.001540, and 10 between 0.001541 and 0.002420, with the highest index at 0.002362.

This breakdown also occurred in 2015, 2016, and 2017. However, in 2015 the lowest index was 0.000218 and the highest was 0.002420, the highest overall for the ten-minute interval. In 2016 the low and high indexes were 0.000208 and 0.002305 respectively and in 2017 the low and high indexes were 0.000204 and 0.002313. Only 2018 saw any real variation in the distribution of revealed accessibility values. Thirty-six census block groups had revealed accessibility between 0.000001 and 0.000512, with the lowest at 0.000189, 20 between 0.000513 and 0.000950, 11 between 0.000951 and 0.001540, and eight block groups between 0.001541 and 0.002420, with the highest index at 0.002144.

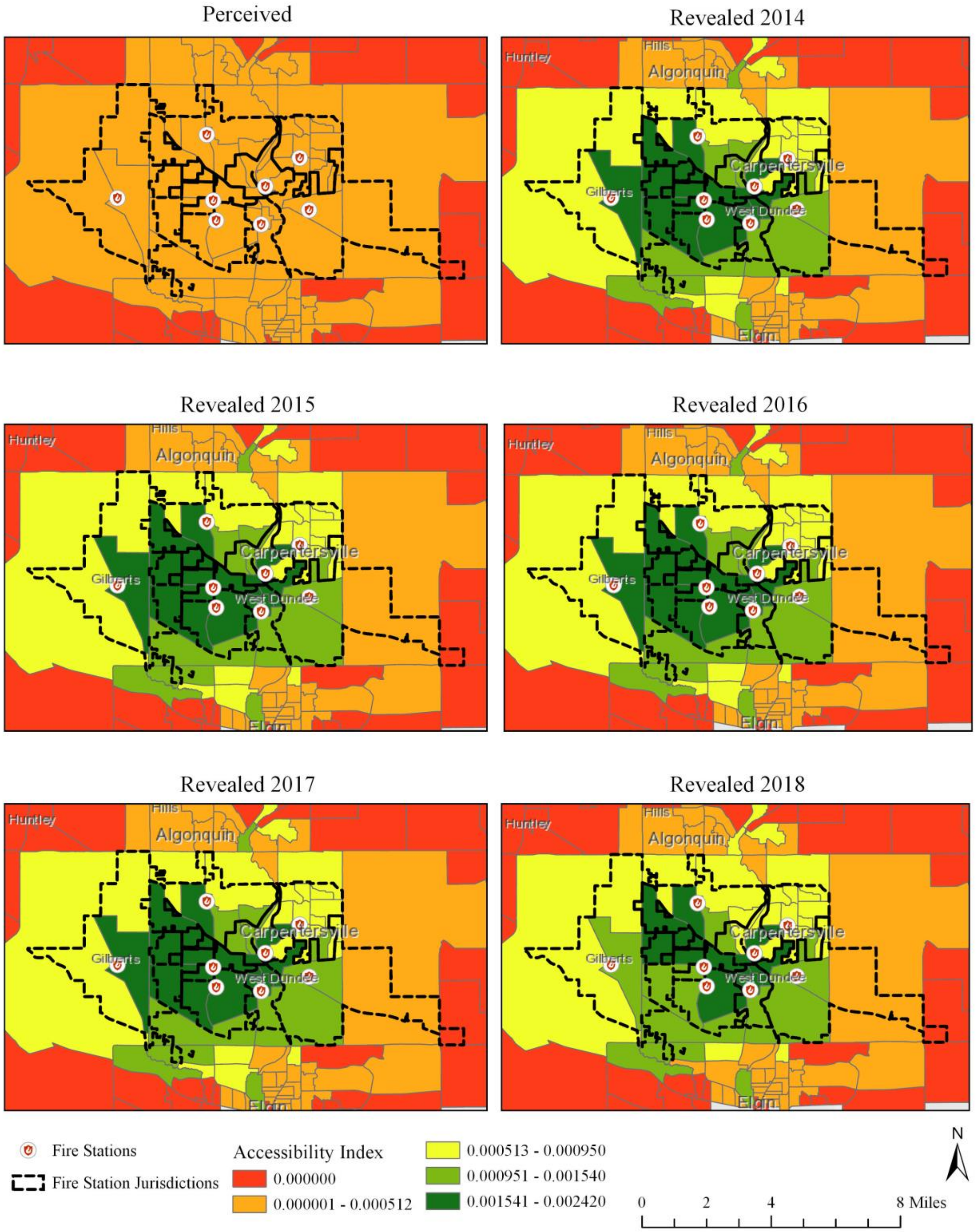


Figure 19. Accessibility for the eight-station configuration, ten-minute drive-time interval. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Table 7. Accessibility indexes, eight station configuration, ten-minute interval. This table shows the accessibility indexes for census block groups with indexes above zero. The data is colored based on class: red = 0, orange = 0.000001 to 0.000512, yellow = 0.000513 to 0.000950, light green = 0.000951 to 0.001540, dark green = 0.001541 to 0.002420

Block Group GEOID	Perceived	2014 Revealed	2015 Revealed	2016 Revealed	2017 Revealed	2018 Revealed
170318042012	0.000034	0.000474	0.000483	0.000477	0.000452	0.000427
170318043111	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170318044031	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170318044032	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170318044033	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170318044044	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898501011	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898501012	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898501031	0.000122	0.001888	0.001937	0.001828	0.001862	0.001716
170898501032	0.000155	0.002362	0.00242	0.002305	0.002313	0.002144
170898501051	0.000038	0.000638	0.000651	0.000615	0.00063	0.000585
170898501052	0.000122	0.001888	0.001937	0.001828	0.001862	0.001716
170898501061	0.000037	0.000435	0.000445	0.000438	0.000417	0.000396
170898501062	0.000067	0.001044	0.001066	0.001015	0.001018	0.00095
170898501063	0.000038	0.000638	0.000651	0.000615	0.00063	0.000585
170898501064	0.000094	0.001399	0.001428	0.001359	0.001371	0.001273
170898502011	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898502012	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898502021	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898502022	0.00008	0.001115	0.001134	0.001103	0.001066	0.001001
170898502023	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503011	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898503012	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503013	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503014	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898503021	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503022	0.000128	0.001873	0.001911	0.001837	0.001823	0.001701
170898504001	0.000108	0.001469	0.001496	0.001447	0.001419	0.001324
170898504002	0.000128	0.001873	0.001911	0.001837	0.001823	0.001701
170898505001	0.000155	0.002362	0.00242	0.002305	0.002313	0.002144
170898505002	0.000108	0.001469	0.001496	0.001447	0.001419	0.001324
170898505003	0.000108	0.001469	0.001496	0.001447	0.001419	0.001324
170898505004	0.000128	0.001873	0.001911	0.001837	0.001823	0.001701
170898506001	0.000135	0.002119	0.002172	0.00206	0.00208	0.001923
170898506002	0.000105	0.001696	0.00174	0.001636	0.001678	0.00154
170898506003	0.000087	0.001226	0.001248	0.001201	0.001185	0.001103
170898507011	0.000105	0.001696	0.00174	0.001636	0.001678	0.00154
170898507012	0.000046	0.000723	0.000745	0.000694	0.000717	0.000651
170898508001	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898508002	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508003	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508004	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508005	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508006	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898510001	0.000058	0.000803	0.000816	0.000778	0.000783	0.000721
170898510002	0.000039	0.000568	0.00058	0.000553	0.000556	0.000512
170898510003	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898511021	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898511022	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898511023	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898513011	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898513013	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898513021	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898513022	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898513023	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898513024	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898514002	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898519101	0.000085	0.001292	0.001325	0.001247	0.001274	0.001163
170898519102	0.000085	0.001292	0.001325	0.001247	0.001274	0.001163
170898519103	0.000039	0.000568	0.00058	0.000553	0.000556	0.000512
170898546001	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898546003	0.000087	0.001226	0.001248	0.001201	0.001185	0.001103
171118711072	0.000028	0.000489	0.000509	0.000469	0.000491	0.000443
171118712052	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118712061	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118712062	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118712063	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118713101	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118713102	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118713103	0.000067	0.001044	0.001066	0.001015	0.001018	0.00095
171118713104	0.000037	0.000435	0.000445	0.000438	0.000417	0.000396
171118713112	0.000041	0.000647	0.000663	0.000635	0.000637	0.000597
171118713113	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118714041	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
171118714042	0.000034	0.000474	0.000483	0.000477	0.000452	0.000427

Table 5 shows the absolute average difference in accessibility from year to year. The average difference at the ten-minute interval was 0.000018 between 2014 and 2015, 0.000033 between 2015 and 2016, 0.000020 between 2016 and 2017, and 0.000054 between 2017 and 2018. Overall, the ten-minute interval had an average difference of 0.000031.

4.3. Seven-Station Configuration: WDFD #2 Removed

The first of the two seven-station configuration scenarios represents how accessibility indexes would change if WDFD #2 was closed. For this scenario, the perceived and revealed indexes were recalculated for each of 184 census block groups using the same 2SFCA method used for the eight-station configuration. Like before, accessibility was analyzed at six, eight, and ten-minute intervals.

4.3.1. Six-Minute Drive-Time Interval

At the six-minute interval, there were thirty-two census block groups with perceived and revealed indexes (Figure 20 and Table 8). Only thirty of those block groups intersect with the department jurisdictions, leaving eleven with both perceived and revealed accessibility indexes of zero. All 32 census block groups have perceived below 0.000336 with the highest at 0.000313 and the lowest at 0.000030.

Overall, the revealed accessibility indexes were more varied than the perceived accessibility. In 2014, four block groups had indexes of 0.000327, fifteen were between 0.000337 and 0.001066, eight between 0.001067 and 0.001722, three between 0.001723 and 0.002538, and two between 0.002539 and 0.003642 with the highest index at 0.003049. The breakdown in 2015 was the same as in 2014, but the lowest revealed accessibility index was 0.000336 and the highest index was 0.003082, the overall highest revealed accessibility index of the six-minute interval.

Figure 20. Accessibility for the seven-station configuration with WDFD #2 removed, six-minute drive-time interval. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Table 8. Accessibility indexes, seven-station configuration with WDFD #2 removed, six-minute interval. This table shows the accessibility indexes for census block groups with indexes above zero. The data is colored based on class: red = 0 to 0.000336, orange = 0.000337 to 0.001066, yellow = 0.001067 to 0.001722, light green = 0.001723 to 0.002538, dark green = 0.001724 to 0.003642

Block Group GEOID	Perceived	2014 Revealed	2015 Revealed	2016 Revealed	2017 Revealed	2018 Revealed
170898501011	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898501012	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898501031	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898501032	0.000313	0.003049	0.003082	0.002848	0.002983	0.002749
170898501051	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898501052	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898501063	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898501064	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898502011	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502012	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502021	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502022	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502023	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898503011	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898503012	0.000144	0.001313	0.001336	0.00131	0.001221	0.001154
170898503013	0.000093	0.000822	0.000849	0.000828	0.000781	0.000739
170898503014	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898503021	0.000144	0.001313	0.001336	0.00131	0.001221	0.001154
170898503022	0.000093	0.000822	0.000849	0.000828	0.000781	0.000739
170898504001	0.000155	0.001425	0.001434	0.001402	0.001328	0.001247
170898504002	0.000217	0.00192	0.001947	0.001894	0.0018	0.001693
170898505001	0.000308	0.002708	0.002681	0.002511	0.002547	0.002326
170898505002	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898505003	0.000124	0.001098	0.001098	0.001066	0.001019	0.000954
170898505004	0.000187	0.001593	0.001611	0.001557	0.001491	0.0014
170898506001	0.000194	0.001722	0.00168	0.001537	0.001635	0.001466
170898506002	0.000122	0.001115	0.00107	0.000953	0.001056	0.000927
170898506003	0.000194	0.001722	0.00168	0.001537	0.001635	0.001466
170898507011	0.000209	0.002538	0.002433	0.00232	0.00277	0.002037
170898507012	0.000209	0.002538	0.002433	0.00232	0.00277	0.002037
170898508001	0.000052	0.000491	0.000487	0.000482	0.00044	0.000414
170898546003	0.000073	0.000607	0.000611	0.000583	0.000579	0.000539

The distribution slightly changed in 2016. There were four block groups with 0.000336 revealed indexes, seventeen between 0.000337 and 0.001066, six between 0.001067 and 0.001722, four between 0.001723 and 0.002538, and one index at 0.002848. 2017 saw more change as well where four block groups were at 0.000309, seventeen between 0.000337 and 0.001066, six between 0.001067 and 0.001722, one between 0.001723 and 0.002538, and four between 0.002539 and 0.003642 with the highest at 0.002983. Finally, the distribution again changed in 2018 with four below 0.000336 at 0.000293, seventeen between 0.000337 and

0.001066, seven between 0.001067 and 0.001722, three between 0.001723 and 0.002538, and one at 0.002749.

As Table 5 demonstrates, the average difference from year to year at the six-minute interval rose steadily. Between 2014 and 2015, there was an average absolute difference of 0.000028. Then from 2015 to 2016 the difference was 0.000053, then 0.000087 between 2016 and 2017, then 0.000110 between 2017 and 2018. Overall, the average difference for the six-minute interval was 0.000070.

4.3.2. Eight-Minute Drive-Time Interval

Figure 21 and Table 9 show the results at the eight-minute interval. At eight minutes, fifty-five census block groups have perceived and revealed accessibility indexes. Thirty-six of those intersect with the department jurisdictions. There are also five census block groups which intersect the jurisdictions, but they have perceived and revealed accessibility indexes of zero. The perceived accessibility indexes for the eight-minute interval were all below 0.000300. The highest perceived index was 0.000206 and the lowest was 0.000018.

Between 2014 and 2018, the revealed accessibility indexes were fairly consistent, but there was some slight variation. In 2014, fifteen block groups had indexes below 0.000300 with the lowest index at 0.000284, twenty-six block groups were between 0.000301 and 0.000922, nine between 0.000923 and 0.001392, one between 0.001393 and 0.001956, and four between 0.001957 and 0.003464 with the highest at 0.003021. Then in 2015 there were also fifteen block groups below 0.000300 with the lowest at 0.000292, 23 between 0.000301 and 0.000922, eleven between 0.000923 and 0.001392, two between 0.001393 and 0.001956, and four block groups between 0.001957 and 0.003464.

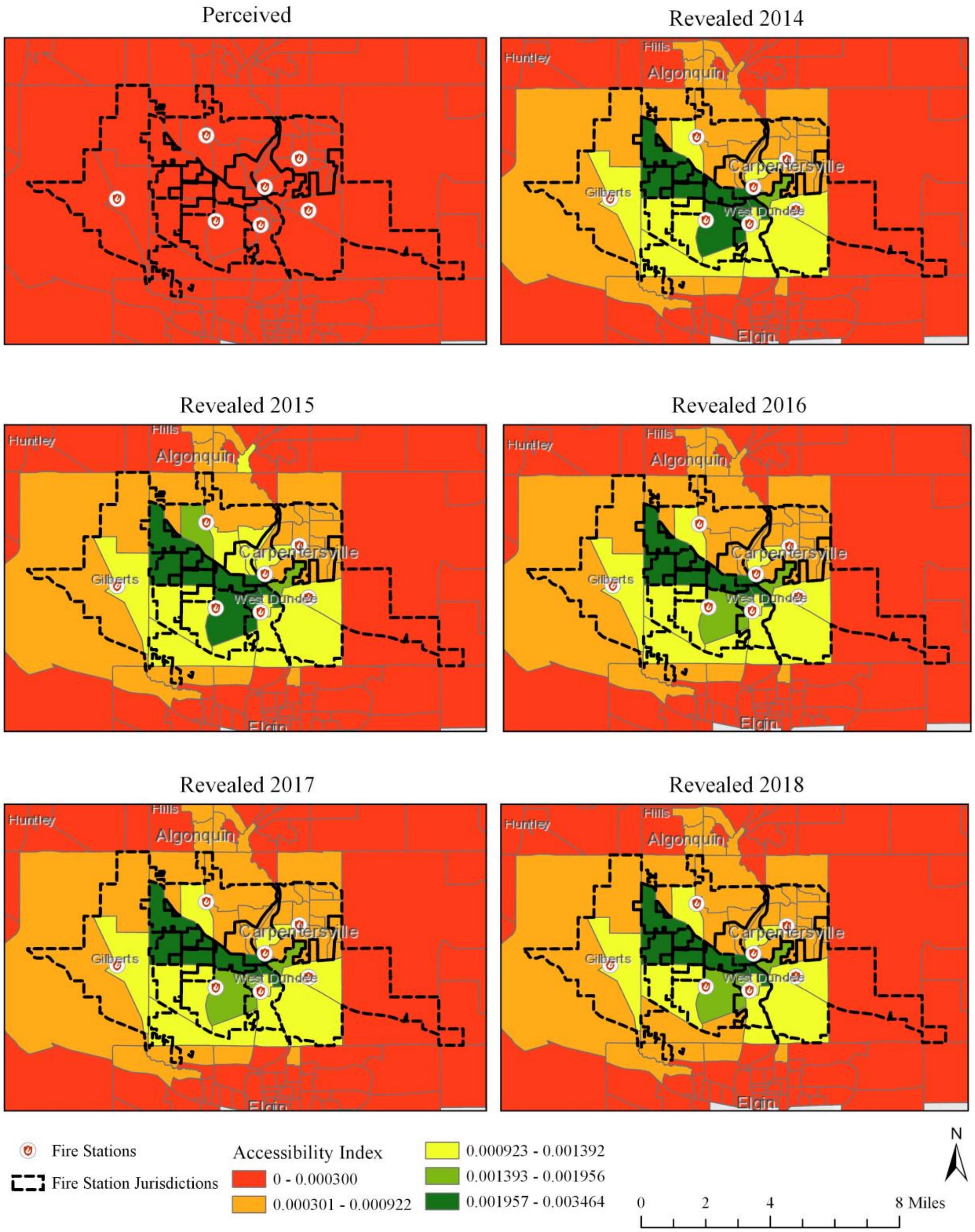


Figure 21. Accessibility for the seven-station configuration with WDFD #2 Removed, eight-minute drive-time interval. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Table 9. Accessibility indexes, seven-station configuration with WDFD #2 Removed, eight-minute interval. This table shows the accessibility indexes for census block groups with indexes above zero. The data is colored based on class: red = 0 to 0.000300, orange = 0.000301 to 0.000922, yellow = 0.000923 to 0.001392, light green = 0.001393 to 0.001956, dark green = 0.001957 to 0.003464

Block Group GEOID	Perceived	2014 Revealed	2015 Revealed	2016 Revealed	2017 Revealed	2018 Revealed
170318042012	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170318043111	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170318044032	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898508003	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898508004	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898508005	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898508006	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898513021	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898501061	0.000024	0.000284	0.000293	0.000288	0.000271	0.000256
171118714041	0.000024	0.000284	0.000293	0.000288	0.000271	0.000256
171118714042	0.000024	0.000284	0.000293	0.000288	0.000271	0.000256
170898510003	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898511021	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898511023	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898546003	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898503011	0.000047	0.000508	0.000526	0.000513	0.000487	0.000459
170898501011	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898501012	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898502011	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898503014	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898508001	0.000042	0.000591	0.000588	0.00057	0.000551	0.000515
170898501051	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
170898501063	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118712061	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118712063	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118713101	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118713113	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
170898507012	0.000044	0.000759	0.000776	0.000712	0.000792	0.000685
170898519102	0.000044	0.000759	0.000776	0.000712	0.000792	0.000685
170898510001	0.000064	0.000771	0.000776	0.000725	0.000737	0.000687
170898519101	0.000064	0.000771	0.000776	0.000725	0.000737	0.000687
170898502012	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898502021	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898502022	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898502023	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503012	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503013	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503021	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898501062	0.000056	0.000916	0.000964	0.000893	0.000922	0.000893
170898501064	0.000056	0.000916	0.000964	0.000893	0.000922	0.000893
171118713103	0.000056	0.000916	0.000964	0.000893	0.000922	0.000893
170898506003	0.000087	0.000995	0.001009	0.00095	0.000953	0.000891
170898503022	0.000089	0.0011	0.001113	0.001083	0.001039	0.000975
170898504001	0.000089	0.0011	0.001113	0.001083	0.001039	0.000975
170898505002	0.000089	0.0011	0.001113	0.001083	0.001039	0.000975
170898506002	0.000084	0.00123	0.001257	0.001157	0.001247	0.001114
170898507011	0.000084	0.00123	0.001257	0.001157	0.001247	0.001114
170898505003	0.000106	0.001287	0.001301	0.00124	0.001223	0.001148
170898505004	0.000106	0.001287	0.001301	0.00124	0.001223	0.001148
170898501052	0.000096	0.001387	0.001444	0.001338	0.001377	0.001321
170898504002	0.00013	0.001571	0.001594	0.001528	0.001494	0.001403
170898506001	0.000139	0.001978	0.002032	0.001908	0.001928	0.001837
170898501031	0.00014	0.002146	0.002221	0.00205	0.002168	0.002007
170898505001	0.000163	0.002262	0.002325	0.002196	0.002199	0.002093
170898501032	0.000206	0.003021	0.003101	0.002908	0.002991	0.002778

In 2016 the lowest revealed accessibility index was 0.000280 and there were fifteen census blocks below 0.000300. Additionally, there were twenty-six census block groups between 0.000301 and 0.000922, nine with indexes between 0.000923 and 0.001392, two between 0.001393 and 0.001956, and three above 0.001957 with the highest index at 0.002908. 2017 had the exact same breakdown as 2016 with the lowest index at 0.000270 and the highest at 0.002991. Like in the other scenarios and intervals, there were slight changes to the distribution of revealed accessibility indexes in 2018. Overall, there were fifteen census block groups below 0.0003000, with the lowest at 0.000256, twenty-seven between 0.000301 and 0.000922, eight between 0.000923 and 0.001392, two block groups between 0.001393 and 0.001956, and three above 0.001957 with the highest index at 0.002778.

Table 5 shows the absolute average difference in accessibility from year to year. For the eight-minute interval, the difference was 0.000021 between 2014 and 2015, 0.000042 between 2015 and 2016, 0.000034 between 2016 and 2017, and 0.000047 between 2017 and 2018. The overall average difference for the eight-minute interval was 0.000036.

4.3.3. Ten-Minute Drive-Time Interval

At the ten-minute interval, a total of 75 census block groups have perceived and revealed accessibility indexes as calculated by the 2SFCA method. The results of that method are presented in Figure 22 and Table 10. Of those 75, 37 census block groups intersect with the department jurisdictions. There are four additional block groups which intersect the jurisdictions but have no perceived or revealed accessibility. For the 75 census block groups with perceived accessibility indexes, they all fall between 0.000001 and 0.000512. The lowest index is 0.000012 and the highest is 0.000137.

In terms of revealed accessibility, the ten-minute interval has the same distribution from 2014 through 2017. In each year, there were 37 block groups between 0.000001 and 0.000512, twenty between 0.000513 and 0.000950, ten between 0.000951 and 0.001540, and eight with revealed indexes between 0.001541 and 0.002420. Across those four years, the lowest revealed index occurred in 2017 with a value of 0.000204. On the other hand, the highest index, 0.002184, occurred in 2015.

The only variation in distribution occurred in 2018. Forty census block groups had revealed accessibility indexes between 0.000001 and 0.000512. The lowest index in this category was 0.000189. There were also nineteen block groups between 0.000513 and 0.000950, thirteen between 0.000951 and 0.001540, and three between 0.001541 and 0.002420. The highest revealed accessibility index in 2018 was 0.001935.

For the ten-minute interval, there was an average absolute difference (Table 5) of 0.000017. Then the difference was 0.000030 between 2015 and 2016, 0.000020 between 2016 and 2017, and 0.000047 between 2017 and 2018. The overall average difference for the ten-minute interval was 0.000028.

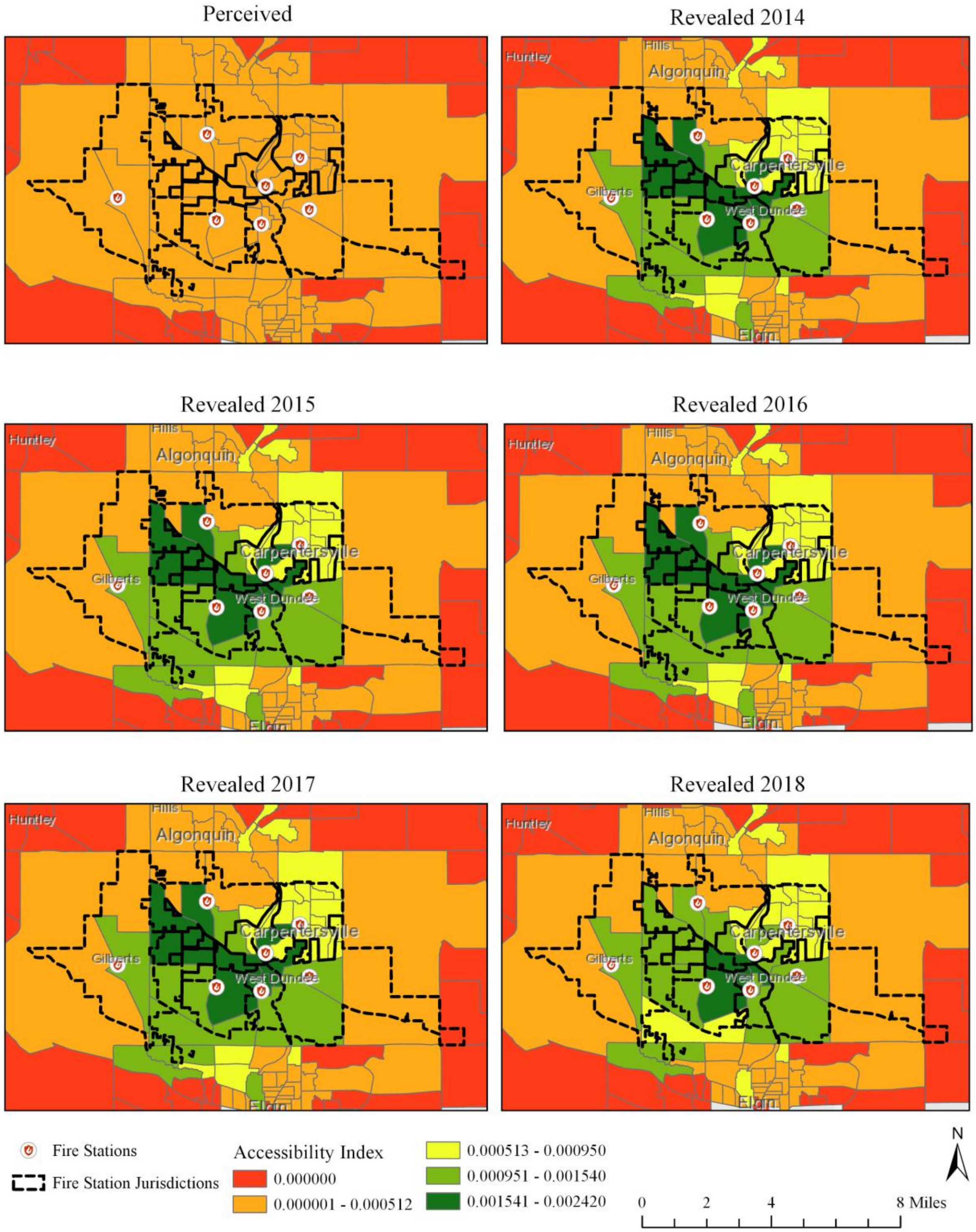


Figure 22. Accessibility for the seven-station configuration with WDFD #2 removed, ten-minute drive-time interval. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Table 10. Accessibility indexes, seven-station configuration with WDFD #2 removed, ten-minute interval. This table shows the accessibility indexes for census block groups with indexes above zero. The data is colored based on class: red = 0, orange = 0.000001 to 0.000512, yellow = 0.000513 to 0.000950, light green = 0.000951 to 0.001540, dark green = 0.001541 to 0.002420

Block Group GEOID	Perceived	2014 Revealed	2015 Revealed	2016 Revealed	2017 Revealed	2018 Revealed
170318042012	0.000034	0.000474	0.000483	0.000477	0.000452	0.000427
170318043111	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170318044031	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170318044032	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170318044033	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170318044044	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898501011	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898501012	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898501031	0.000104	0.001654	0.001701	0.001603	0.001635	0.001508
170898501032	0.000137	0.002128	0.002183	0.00208	0.002087	0.001935
170898501051	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
170898501052	0.000104	0.001654	0.001701	0.001603	0.001635	0.001508
170898501061	0.000037	0.000435	0.000445	0.000438	0.000417	0.000396
170898501062	0.000049	0.00081	0.00083	0.00079	0.000792	0.000742
170898501063	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
170898501064	0.000076	0.001165	0.001192	0.001134	0.001144	0.001065
170898502011	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898502012	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898502021	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898502022	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898502023	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503011	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898503012	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503013	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503014	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898503021	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503022	0.00011	0.001639	0.001674	0.001611	0.001596	0.001492
170898504001	0.00009	0.001235	0.00126	0.001222	0.001192	0.001115
170898504002	0.00011	0.001639	0.001674	0.001611	0.001596	0.001492
170898505001	0.000137	0.002128	0.002183	0.00208	0.002087	0.001935
170898505002	0.00009	0.001235	0.00126	0.001222	0.001192	0.001115
170898505003	0.00009	0.001235	0.00126	0.001222	0.001192	0.001115
170898505004	0.00011	0.001639	0.001674	0.001611	0.001596	0.001492
170898506001	0.000117	0.001885	0.001935	0.001834	0.001854	0.001715
170898506002	0.000087	0.001461	0.001504	0.001411	0.001451	0.001332
170898506003	0.000069	0.000992	0.001012	0.000976	0.000959	0.000895
170898507011	0.000087	0.001461	0.001504	0.001411	0.001451	0.001332
170898507012	0.000028	0.000489	0.000509	0.000469	0.000491	0.000443
170898508001	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898508002	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508003	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508004	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508005	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508006	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898510001	0.000039	0.000568	0.00058	0.000553	0.000556	0.000512
170898510002	0.000039	0.000568	0.00058	0.000553	0.000556	0.000512
170898510003	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898511021	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898511022	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898511023	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898513011	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898513013	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898513021	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898513022	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898513023	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898513024	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898514002	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898519101	0.000067	0.001057	0.001089	0.001022	0.001047	0.000955
170898519102	0.000067	0.001057	0.001089	0.001022	0.001047	0.000955
170898519103	0.000039	0.000568	0.00058	0.000553	0.000556	0.000512
170898546001	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898546003	0.000069	0.000992	0.001012	0.000976	0.000959	0.000895
171118711072	0.000028	0.000489	0.000509	0.000469	0.000491	0.000443
171118712052	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118712061	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118712062	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118712063	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118713101	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118713102	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118713103	0.000049	0.00081	0.00083	0.00079	0.000792	0.000742
171118713104	0.000037	0.000435	0.000445	0.000438	0.000417	0.000396
171118713112	0.000041	0.000647	0.000663	0.000635	0.000637	0.000597
171118713113	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118714041	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
171118714042	0.000034	0.000474	0.000483	0.000477	0.000452	0.000427

4.4. Seven-Station Configuration: RDFPD #2 Removed

The second of the two seven-station configuration scenarios demonstrates how accessibility for QuadCom 911 fire departments would change if RDFPD #2 was closed. Like the two other scenarios, perceived and revealed indexes were recalculated for each of 184 census block groups using the 2SFCA method and accessibility was calculated at six, eight, and ten-minute intervals.

4.4.1. Six-Minute Drive-Time Interval

The results of the six-minute interval for this scenario are very similar to the previous two scenarios. There are 32 census block groups with perceived and revealed indexes, and like the other scenarios at the six-minute interval, thirty of those block groups intersect with the fire department jurisdictions, meaning eleven block groups intersect with the jurisdictions but have accessibility indexes of zero.

The results for the six-minute interval are presented in Figure 23 and Table 11. All 32 census blocks had perceived accessibilities below 0.000336. The highest index was 0.000267 and the lowest was 0.000030. As for the revealed accessibility, the distribution of indexes changed every year between 2014 and 2018. In 2014, there were four census block groups below 0.000336, fifteen between 0.000337 and 0.001066, seven between 0.001067 and 0.001722, five between 0.001723 and 0.002538, and one at 0.003074. For 2015, four block groups had revealed accessibility below 0.000336, fifteen were between 0.000337 and 0.001066, seven had indexes between 0.001067 and 0.001722, four were between 0.001723 and 0.002538, and two above 0.002539.

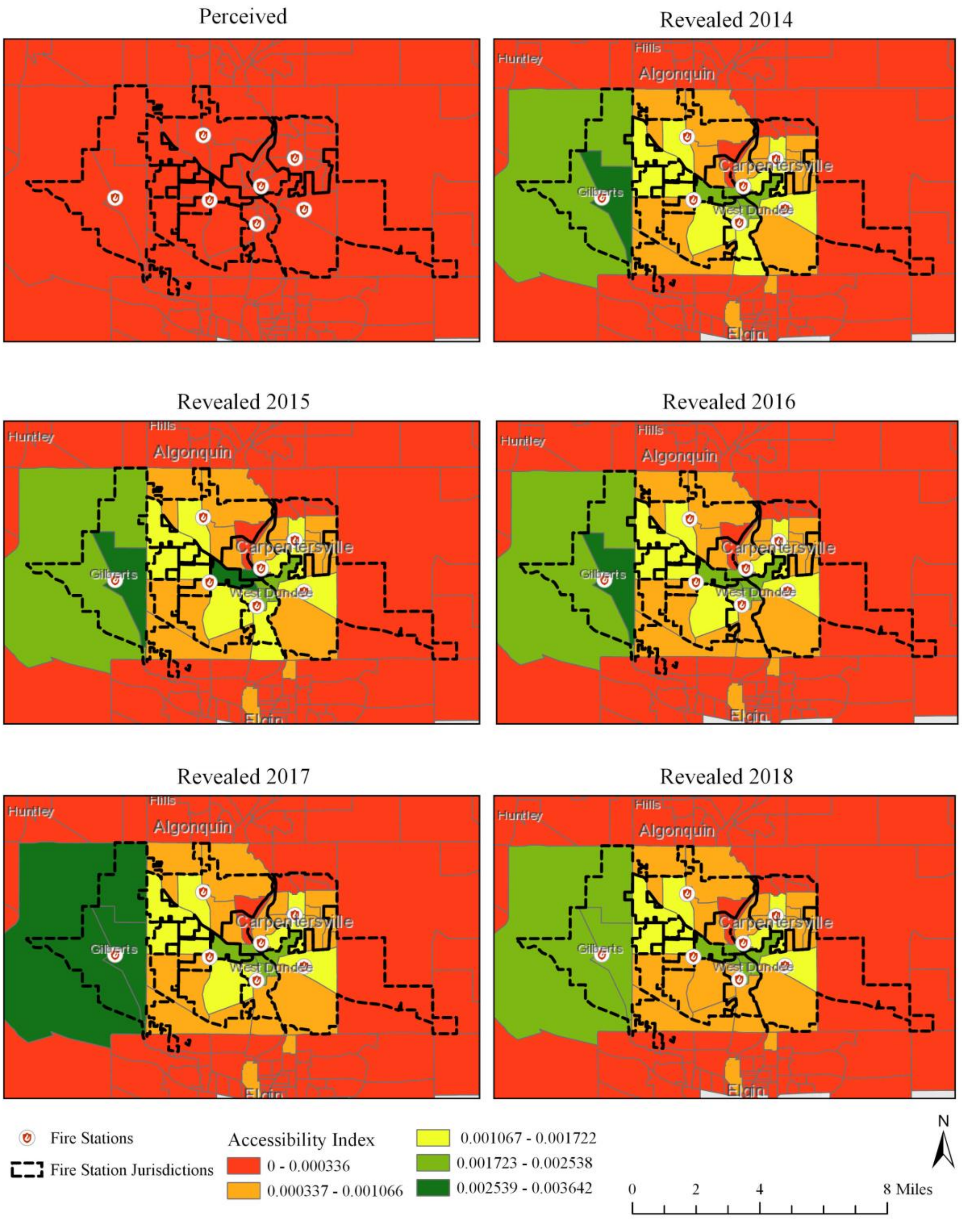


Figure 23. Accessibility for the seven-station configuration with RDFPD #2 Removed, six-minute drive-time interval. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Table 11. Accessibility indexes, seven-station configuration with RDFPD #2 removed, six-minute interval. This table shows the accessibility indexes for census block groups with indexes above zero. The data is colored based on class: red = 0 to 0.000336, orange = 0.000337 to 0.001066, yellow = 0.001067 to 0.001722, light green = 0.001723 to 0.002538, dark green = 0.001724 to 0.003642

Block Group GEOID	Perceived	2014 Revealed	2015 Revealed	2016 Revealed	2017 Revealed	2018 Revealed
170898501011	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898501012	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898501031	0.000106	0.001368	0.001448	0.001338	0.001411	0.00132
170898501032	0.000241	0.002469	0.002572	0.002413	0.002462	0.002305
170898501051	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898501052	0.000106	0.001368	0.001448	0.001338	0.001411	0.00132
170898501063	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898501064	0.000056	0.000832	0.000888	0.000819	0.000876	0.000837
170898502011	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502012	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502021	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502022	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898502023	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898503011	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898503012	0.000144	0.001313	0.001336	0.00131	0.001221	0.001154
170898503013	0.000093	0.000822	0.000849	0.000828	0.000781	0.000739
170898503014	0.00003	0.000327	0.000336	0.000336	0.000309	0.000293
170898503021	0.000144	0.001313	0.001336	0.00131	0.001221	0.001154
170898503022	0.000093	0.000822	0.000849	0.000828	0.000781	0.000739
170898504001	0.000155	0.001425	0.001434	0.001402	0.001328	0.001247
170898504002	0.000267	0.002456	0.002507	0.002413	0.002335	0.002176
170898505001	0.000237	0.002128	0.002171	0.002076	0.002026	0.001883
170898505002	0.000082	0.000818	0.000823	0.000819	0.000749	0.000708
170898505003	0.000124	0.001098	0.001098	0.001066	0.001019	0.000954
170898505004	0.000237	0.002128	0.002171	0.002076	0.002026	0.001883
170898506001	0.000123	0.001142	0.001171	0.001102	0.001115	0.001023
170898506002	0.000051	0.000536	0.00056	0.000519	0.000535	0.000483
170898506003	0.000073	0.000607	0.000611	0.000583	0.000579	0.000539
170898507011	0.00026	0.003074	0.002993	0.002839	0.003305	0.00252
170898507012	0.000209	0.002538	0.002433	0.00232	0.00277	0.002037
170898508001	0.000052	0.000491	0.000487	0.000482	0.00044	0.000414
170898546003	0.000073	0.000607	0.000611	0.000583	0.000579	0.000539

In 2016, four block groups were below 0.000336, sixteen were between 0.000337 and 0.001066, six block groups were between 0.001067 and 0.001722, five between 0.001723 and 0.002538, and one at 0.002839. As for 2017, there were four census block groups with revealed accessibility indexes below 0.000336, sixteen between 0.000337 and 0.001066, six from 0.001067 to 0.001722, four between 0.001723 and 0.002538, and two block groups between 0.002539 and 0.003642. Finally, in 2018, there were four census block groups below 0.000336, seventeen from 0.000337 to 0.001066, five between 0.001067 to 0.001722, and six between

0.001723 and 0.002538. For 2018, there were not any block groups between 0.002539 and 0.003642.

Table 5 shows the average absolute differences year to year. For the six-minute interval, the difference was 0.000031 between 2014 and 2015, 0.000047 between 2015 and 2016, 0.000077 between 2016 and 2017, and 0.00104 between 2017 and 2018. Overall, the average difference for the six-minute interval was 0.000065.

4.4.2. Eight-Minute Drive-Time Interval

Just like the other two scenarios, 55 census block groups have perceived and revealed accessibility indexes at the eight-minute interval and 36 of those block groups intersect with the fire station jurisdictions. The remaining five intersecting block groups all have perceived and revealed accessibility indexes of zero. The results of the 2SFCA method at the eight-minute interval are presented in Figure 24 and Table 12. When it comes to the 55 block groups that actually have perceived accessibility, all of them are below 0.000300 with the lowest index at 0.000018 and the highest was at 0.000204.

When it comes to the revealed accessibility indexes, there was some stability in the distribution of indexes and some small variety. For each year between 2014 to 2018, there were seventeen census block groups below 0.000300. In addition, 2014, 2016, 2017, and 2018 each had twenty-three block groups with indexes between 0.000301 and 0.000922. 2015 on the other hand only had twenty-one block groups with indexes in that range.

There was much more variety as indexes increased. 2014 and 2016 each had eight block groups with revealed accessibility between 0.000923 and 0.001392, while 2015 had ten and 2017 and 2018 each had eleven. Between the range of 0.001393 and 0.001956, 2014 and 2015 had four, 2016 had five, 2017 had one, and 2018 had two. Finally, 2014, 2015, and 2017 each had three indexes between 0.001957 and 0.003464 while 2016 and 2018 only had two apiece.

The average absolute differences from year to year are displayed in Table 5. For the eight-minute interval, the difference was 0.000021 from 2014 to 2015, 0.000039 from 2015 to 2016, 0.000034 from 2016 to 2017, and 0.000049 from 2017 to 2018. The overall average difference was 0.000036.

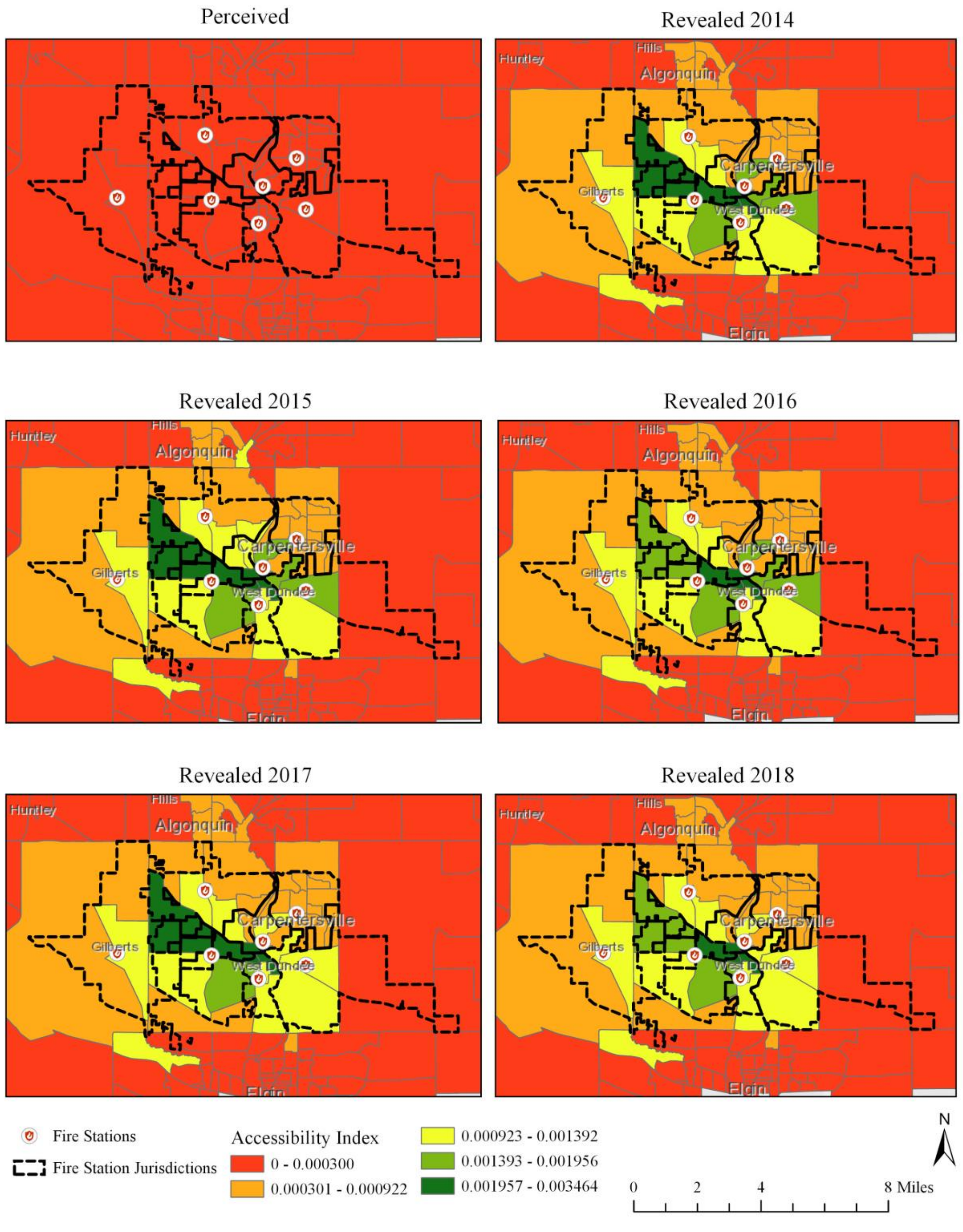


Figure 24. Accessibility for the seven-station configuration with RDFPD #2 removed, eight-minute drive-time interval. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Table 12. Accessibility indexes, seven-station configuration with RDFPD #2 Removed, eight-minute interval. This table shows the accessibility indexes for census block groups with indexes above zero. The data is colored based on class: red = 0 to 0.000300, orange = 0.000301 to 0.000922, yellow = 0.000923 to 0.001392, light green = 0.001393 to 0.001956, dark green = 0.001957 to 0.003464

Block Group GEOID	Perceived	2014 Revealed	2015 Revealed	2016 Revealed	2017 Revealed	2018 Revealed
170318042012	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170318043111	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170318044032	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898501011	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898501012	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898501031	0.000137	0.00203	0.002103	0.00195	0.002067	0.001902
170898501032	0.000204	0.002905	0.002983	0.002808	0.002889	0.002673
170898501051	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
170898501052	0.000094	0.001271	0.001327	0.001238	0.001275	0.001217
170898501061	0.000024	0.000284	0.000293	0.000288	0.000271	0.000256
170898501062	0.000056	0.000916	0.000964	0.000893	0.000922	0.000893
170898501063	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
170898501064	0.000094	0.001271	0.001327	0.001238	0.001275	0.001217
170898502011	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898502012	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898502021	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898502022	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898502023	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503011	0.000047	0.000508	0.000526	0.000513	0.000487	0.000459
170898503012	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503013	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503014	0.000043	0.000575	0.000585	0.000578	0.000541	0.000513
170898503021	0.000066	0.0008	0.000818	0.000803	0.000757	0.000716
170898503022	0.000127	0.001455	0.001476	0.001428	0.001392	0.001299
170898504001	0.000127	0.001455	0.001476	0.001428	0.001392	0.001299
170898504002	0.000127	0.001455	0.001476	0.001428	0.001392	0.001299
170898505001	0.00016	0.002146	0.002207	0.002096	0.002097	0.001988
170898505002	0.000089	0.0011	0.001113	0.001083	0.001039	0.000975
170898505003	0.000103	0.001171	0.001183	0.00114	0.001121	0.001043
170898505004	0.000103	0.001171	0.001183	0.00114	0.001121	0.001043
170898506001	0.000136	0.001862	0.001914	0.001808	0.001827	0.001732
170898506002	0.000081	0.001115	0.001139	0.001057	0.001145	0.001009
170898506003	0.000085	0.00088	0.000891	0.00085	0.000852	0.000786
170898507011	0.000081	0.001115	0.001139	0.001057	0.001145	0.001009
170898507012	0.000044	0.000759	0.000776	0.000712	0.000792	0.000685
170898508001	0.000042	0.000591	0.000588	0.00057	0.000551	0.000515
170898508003	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898508004	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898508005	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898508006	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898510001	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898510003	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898511021	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898511023	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898513021	0.000018	0.000292	0.000292	0.00029	0.00027	0.000257
170898519101	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
170898519102	0.000081	0.001115	0.001139	0.001057	0.001145	0.001009
170898546003	0.000024	0.0003	0.000295	0.00028	0.000282	0.000258
171118712061	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118712063	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118713101	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118713103	0.000056	0.000916	0.000964	0.000893	0.000922	0.000893
171118713113	0.000033	0.000691	0.000731	0.000668	0.000705	0.000689
171118714041	0.000024	0.000284	0.000293	0.000288	0.000271	0.000256
171118714042	0.000024	0.000284	0.000293	0.000288	0.000271	0.000256

4.4.3. Ten-Minute Drive-Time Interval

Just like the six and eight-minute intervals, the results for the ten-minute interval were similar to the results of the previous scenarios. In total there were 75 census block groups with perceived and revealed accessibility indexes. Thirty-seven of those block groups intersected with the jurisdictions. Since 41 block groups intersect with the jurisdictions, the remaining five all had accessibility indexes of zero. The results of the 2SFCA method are shown in Figure 25 and Table 13.

In regards to the perceived indexes at the ten-minute interval, the 75 block groups all fell between 0.000012 and 0.00128. The revealed accessibility indexes were also largely consistent. Between 2014 and 2018, each year saw thirty-seven block groups with indexes between 0.000001 and 0.000512. For the next range, 0.000513 to 0.000950, 2014, 2016, and 2017 each had twenty-one block groups, while 2015 had nineteen and 2018 had twenty-four. Next, there were fourteen block groups between 0.000951 and 0.001540 in 2014, 2016, and 2017. 2015 and 2018 each had eleven census block groups. Finally, 2014 and 2016 to 2018 each had three census block groups between 0.001541 and 0.002420 and 2015 had eight.

Finally, Table 5 shows the average absolute difference from year to year in accessibility. In regards to the ten-minute interval, the difference was 0.000015 from 2014 to 2015, 0.000028 from 2015 to 2016, 0.000020 from 2016 to 2017, and 0.000045 from 2017 to 2018. The overall average difference for the ten-minute interval was 0.000027.

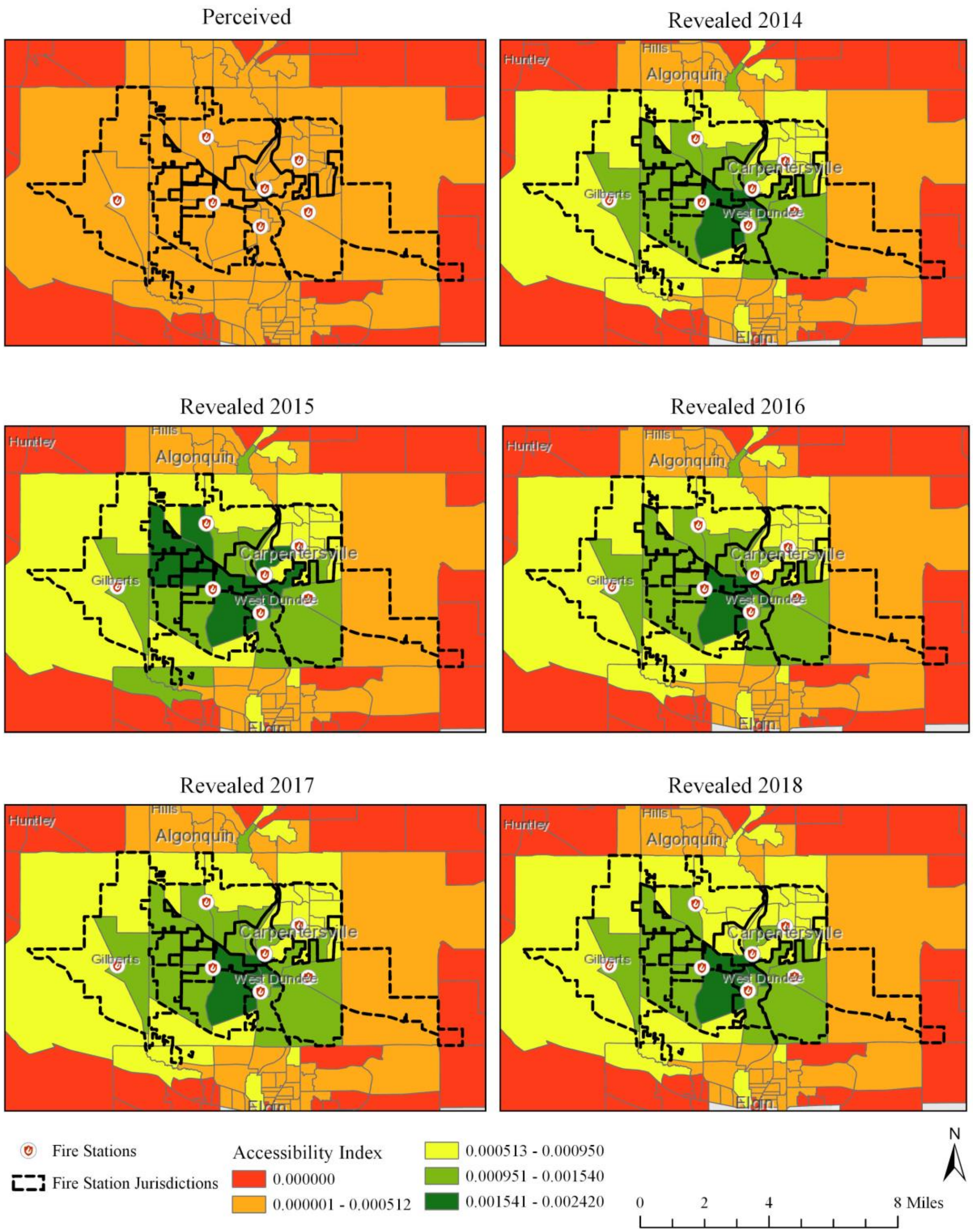


Figure 25. Accessibility for the seven-station configuration with RDFPD #2 removed, ten-minute drive-time interval. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

Table 13. Accessibility indexes, seven-station configuration with RDFPD #2 removed, ten-minute interval. This table shows the accessibility indexes for census block groups with indexes above zero. The data is colored based on class: red = 0, orange = 0.000001 to 0.000512, yellow = 0.000513 to 0.000950, light green = 0.000951 to 0.001540, dark green = 0.001541 to 0.002420

Block Group GEOID	Perceived	2014 Revealed	2015 Revealed	2016 Revealed	2017 Revealed	2018 Revealed
170318042012	0.000034	0.000474	0.000483	0.000477	0.000452	0.000427
170318043111	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170318044031	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170318044032	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170318044033	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170318044044	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898501011	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898501012	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898501031	0.000094	0.001533	0.001575	0.001484	0.001509	0.001393
170898501032	0.000128	0.002008	0.002058	0.001961	0.001961	0.001821
170898501051	0.000038	0.000638	0.000651	0.000615	0.00063	0.000585
170898501052	0.000094	0.001533	0.001575	0.001484	0.001509	0.001393
170898501061	0.000037	0.000435	0.000445	0.000438	0.000417	0.000396
170898501062	0.000067	0.001044	0.001066	0.001015	0.001018	0.00095
170898501063	0.000038	0.000638	0.000651	0.000615	0.00063	0.000585
170898501064	0.000067	0.001044	0.001066	0.001015	0.001018	0.00095
170898502011	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898502012	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898502021	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898502022	0.00008	0.001115	0.001134	0.001103	0.001066	0.001001
170898502023	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503011	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898503012	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503013	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503014	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
170898503021	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898503022	0.0001	0.001519	0.001549	0.001492	0.00147	0.001378
170898504001	0.00008	0.001115	0.001134	0.001103	0.001066	0.001001
170898504002	0.0001	0.001519	0.001549	0.001492	0.00147	0.001378
170898505001	0.000128	0.002008	0.002058	0.001961	0.001961	0.001821
170898505002	0.00008	0.001115	0.001134	0.001103	0.001066	0.001001
170898505003	0.00008	0.001115	0.001134	0.001103	0.001066	0.001001
170898505004	0.0001	0.001519	0.001549	0.001492	0.00147	0.001378
170898506001	0.000108	0.001765	0.00181	0.001715	0.001728	0.0016
170898506002	0.000078	0.001341	0.001378	0.001292	0.001325	0.001217
170898506003	0.00006	0.000872	0.000886	0.000857	0.000833	0.000781
170898507011	0.000078	0.001341	0.001378	0.001292	0.001325	0.001217
170898507012	0.000046	0.000723	0.000745	0.000694	0.000717	0.000651
170898508001	0.000062	0.000881	0.000898	0.000878	0.00084	0.000793
170898508002	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508003	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508004	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508005	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898508006	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898510001	0.00003	0.000448	0.000454	0.000434	0.00043	0.000398
170898510002	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898510003	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898511021	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898511022	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898511023	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898513011	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898513013	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898513021	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898513022	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898513023	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898513024	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898514002	0.000013	0.000231	0.000235	0.000231	0.000219	0.000207
170898519101	0.000058	0.000937	0.000963	0.000902	0.000921	0.000841
170898519102	0.000058	0.000937	0.000963	0.000902	0.000921	0.000841
170898519103	0.000012	0.000214	0.000218	0.000208	0.000204	0.000189
170898546001	0.000025	0.000445	0.000453	0.00044	0.000422	0.000396
170898546003	0.00006	0.000872	0.000886	0.000857	0.000833	0.000781
171118711072	0.000028	0.000489	0.000509	0.000469	0.000491	0.000443
171118712052	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118712061	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118712062	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118712063	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118713101	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118713102	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118713103	0.000067	0.001044	0.001066	0.001015	0.001018	0.00095
171118713104	0.000037	0.000435	0.000445	0.000438	0.000417	0.000396
171118713112	0.000041	0.000647	0.000663	0.000635	0.000637	0.000597
171118713113	0.00002	0.000404	0.000415	0.000389	0.000404	0.000377
171118714041	0.00005	0.000667	0.00068	0.000669	0.000636	0.000603
171118714042	0.000034	0.000474	0.000483	0.000477	0.000452	0.000427

Chapter 5 Discussion and Conclusions

This project had two desired outcomes. The first was to analyze how access to emergency services would be affected by the merger and consolidation of two local fire departments. The second desired outcome was to use to propose an initial range of acceptable accessibility indexes for suburban, regional emergency services.

The analysis of access to the QuadCom 911 emergency services utilized the 2SFCA Method to calculate the perceived and revealed accessibility within the study area. The method was originally developed to analyze access to primary care physicians for defined population groups. For this project, the primary care physicians were replaced with emergency services at fire stations. Perceived accessibility is a ratio of emergency services to a population and represents a projected, hypothetical accessibility index for an area. Revealed accessibility, on the other hand, is a ratio of emergency services to actual uses of those services and represents a measured accessibility index for that same area.

Accessibility indexes were calculated, using drive-time based catchments at intervals of six, eight, and ten minutes, for 184 census block groups from 2014 to 2018 and using an eight-station configuration. The indexes were then recalculated in two other, seven-station scenarios: one where WDFD #2 was removed and another where RDFPD #2 was removed instead. The results for the eight-station configuration act as a baseline as it represents the current, real-world system. The results of the two seven-station configurations are then compared to the eight-station configuration to examine how accessibility changes when stations are consolidated.

The second outcome builds off of the work to achieve the first outcome. The results of the analysis are compared across the three drive-time intervals and examined to determine how effective each is at providing accessible services to the QuadCom 911 service area. Through these comparisons, an initial range of ideal accessibility values for suburban, regional emergency services is proposed. It is the hope of this project that the proposed range of values can be used as a starting point in a larger discussion about access to emergency services.

This chapter discuss the results of the analysis and the implications for QuadCom 911 and the communities they serve, the limitations of the analysis, and the possibilities for future work regarding emergency service accessibility. The first section of this chapter discusses the results of the project's methodology and the implications of those results for QuadCom 911 and the study of emergency service access as a whole. This is followed by a section which discusses the limitations of the analysis. The third section discusses future avenues for research and ways the analysis can be improved and expanded. The final section summarizes the entire study and assesses how effective it was at achieving its goals.

5.1. Analysis Discussion

The 2SFCA method produced some insightful results in regards to the access to emergency services in the study area at all three drive-time intervals.

5.1.1. Six-Minute Drive-Time Interval

At the six-minute interval, it was surprising how relatively stable the accessibility indexes were from year to year and from scenario to scenario. The eight-station configuration saw an average change in accessibility from year to year (Table 5) of an absolute value of 0.000077, while the seven-station configurations each had average changes of 0.000070 when WDFD #2 was removed and 0.000065 when RDFPD #2 was removed. In fact, the average changes year to year followed a similar pattern. In all three scenarios, the least amount of change occurred between 2014 and 2015, and each year that average change increased from the year before.

The largest average change in all three scenarios occurred between 2017 and 2018. This was not especially surprising as the difference in the amount of calls QuadCom 911 serviced was the most significant between 2017 and 2018. However, this does not justify why the difference in accessibility indexes continually rose from year to year as the number of calls fluctuated regularly between 2014 and 2018. Even with the absolute average change rising every year, those changes are not enough for the accessibility of single census block groups to drastically change. There are only 21 out of 384 potential cases in all of the scenarios where a census block group's accessibility index changed enough from year to year to cause it to change classes. And when it did, most of those changes occurred between the highest two classes. In fact, there are only five instances across all three scenarios of a census block group changing classes between any of the lower three classes.

Even though there is little variation from year to year in each of the scenarios, there is significantly more variation between each of the scenarios. When WDFD #2 is removed, there is a marked effect on access to emergency services in the central part of the service area. Most of the census block groups surrounding WDFD #2 see a significant drop in their accessibility indexes across all years and there are even some cases where the indexes of block groups closer to other stations drop as well as they lose the support of WDFD #2. A very similar pattern occurs when RDFPD #2 is removed, except that the areas most effected are in the southern portion of the community. The main difference between the two patterns however is that the three census block groups at the center of the service area remain mostly unaffected by the removal of WDFD #2 while they see a recognizable decrease in access when RDFPD #2 is removed.

This was a fairly surprising trend. It was expected that the areas in the center of the study area would experience slight drops in access, especially those areas closest to the removed station. And this did occur, but what was unexpected what how much of an effect there was on the areas closest to either WDFD #2 or RDFPD #2 depending on which was removed. In both cases the block groups nearest the remaining station also suffered significant access changes. These two stations are so close together and within minutes of two other fire stations, that it was expected that access in the areas nearest to the remaining stations would drop only slightly. This suggests there are enough calls for service within the center of the community that the loss of one of these two stations would have a measurable effect on service at a response threshold of six minutes.

5.1.2. Eight-Minute Drive-Time Interval

Accessibility at the eight-minute interval behaved a little differently than at the six-minute interval. In all three scenarios, the absolute difference from year to year (Table 5) increased from 2014-2015 to 2015-2016, then decreased slightly from 2015-2016 to 2016-2017, and then increased again slightly from 2016-2017 to 2017-2018. In addition, the total absolute difference for the eight-station scenario was 0.000040 and 0.000036 when either WDFD #2 or RDFPD #2 was removed.

Overall, the absolute differences from year to year in each of the three scenarios is relatively stable. The average differences all hover between 0.000021 and 0.000055, only a difference of 0.000034. The stability of access also visible when looking at how many census block groups changed classes. Across all three scenarios, block groups changed classes only twenty-six times out of 660 possible opportunities, and in nine of those cases the accessibility actually increased a class.

At the eight-minute interval, the effects of removing a station were a little more widespread. While the affects were more limited to the areas surrounding a station, effects can be seen at much greater distances at the eight-minute interval. And with this, many of the census block groups affected by the loss of one station are the same areas affected by the loss of the other station. For the most part the block groups in the center of the service area remain relatively unaffected. The effects of losing either station begin to take effect the farther from the center you go. The most significant changes occur to the south and west, but there are a couple of census block groups to the north and east whose accessibility are affected by the loss of one station or the other.

5.1.3. Ten-Minute Drive-Time Interval

Like in the other two drive-time intervals, the accessibility indexes were fairly consistent over time in all three scenarios. Overall, the average absolute difference between accessibility indexes (Table 5) was at 0.000031 for eight stations, 0.000028 when WDFD #2 is removed, and 0.000027 when RDFPD #2 is removed. In addition, the average difference between values increased from 2014-2015 to 2015-2016, decreased from 2015-2016 to 2016-2017, and increased again from 2016-2017 to 2017-2018.

In addition, the changes that did occur year to year in accessibility were all relatively minor. There were only 33 cases out of 900 opportunities where the change in accessibility was great enough to change the census block groups class. About half of those cases involved the class either rising into or dropping into the 0.000513-0.000950 range. All the other changes occurred between the top two classes.

Spatially, the middle of the service area saw a drop in accessibility when either RDFD #2 or WDFD #2 were removed, but the most significant changes between the eight-station configurations and the seven-station configurations occurred when WDFD #2 was removed. In this situation, areas within the service area to the south, west, and north were all effected by the removal of the station beyond just those areas near its location. When RDFPD #2 was removed the only census block groups that saw classes drop out of the 0.000513-0.000950 range were outside of QuadCom's jurisdiction. However, significant portions of QuadCom's service area dropped out of that range when WDFD #2 was removed from the equation.

5.1.4. Implications for QuadCom 911

As discussed earlier, there are three ideas about what a standard response time should be for emergency services and each of the drive-time intervals used in this project represents each of these accepted standards. For each of these intervals, the results were slightly different and have different implications for QuadCom, except for one area.

Figure 26 shows the eastern portion of the jurisdiction which follows a major road through the region and has relatively low population. In fact, the population-weighted centroids for both census block groups that intersect with the jurisdiction lie outside of QuadCom's boundary. A vast majority of the calls coming from this area lie along this road, which falls within all three drive-time standards, but due to how the analysis process works, those calls were aggregated to the centroids, which do not fall within the drive-time standards. Overall, these two block groups and that eastern portion in general should be ignored as the results of the analysis dramatically skew the actual, real-world locations of incidents in that region and do not accurately depict, within reasonable doubt, how that area actually behaves.

5.1.4.1. Six-Minute Standard

With that said, most of the areas immediately surrounding the interior stations have adequate access to emergency services at a six-minute standard, but as you approach the boundary of QuadCom's service area, that accessibility dramatically drops. There is also a tendency for areas between stations that are farther apart to have lower access than areas between

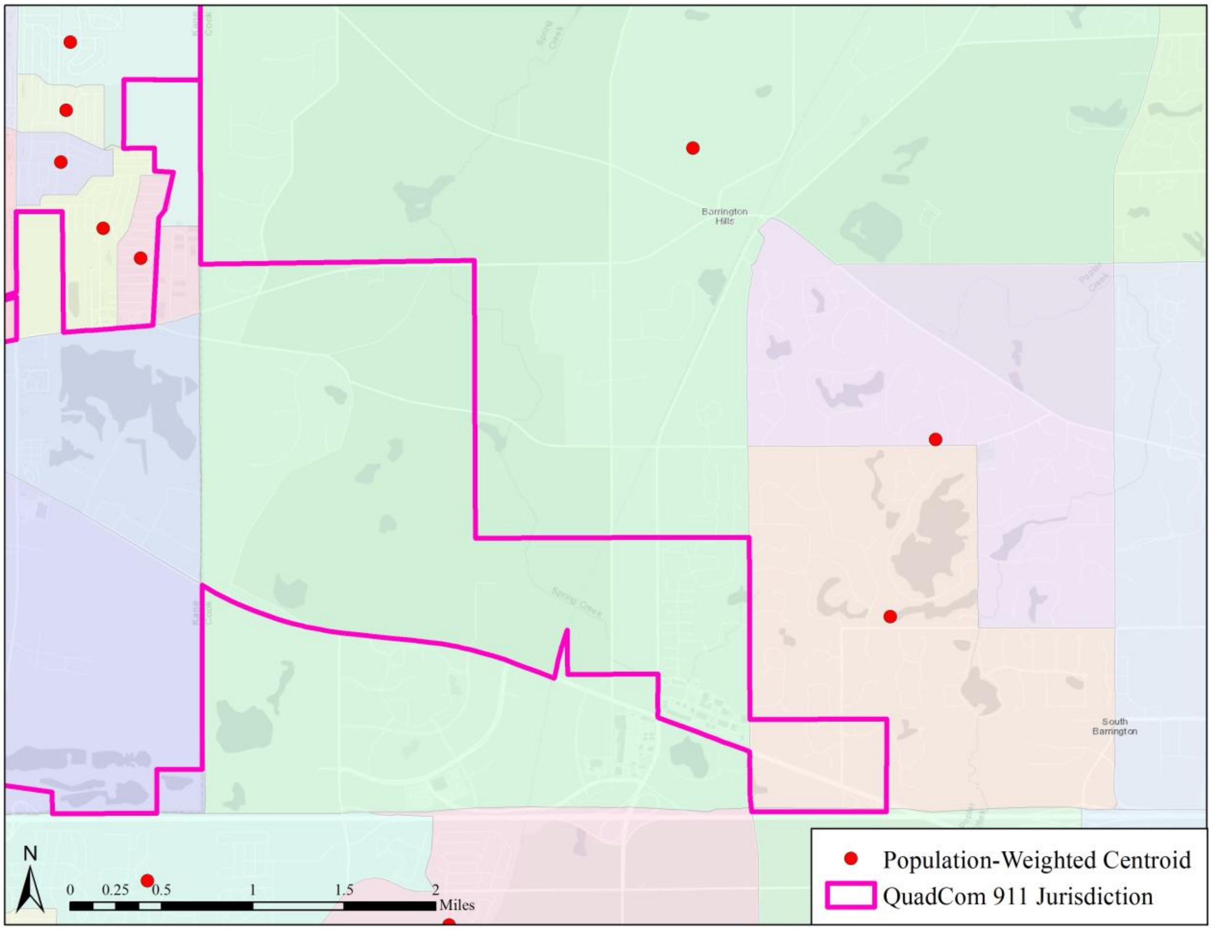


Figure 26. Eastern section of QuadCom 911's jurisdiction. Basemap courtesy of Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS user community.

stations that are closer to each other. When mapped, there are two noticeable accessibility hot spots, one at the center of the service area and another in the western part of the region, with a gap in between with decreased accessibility. None of this is particularly surprising.

However, at this standard the removal of either WDFD #2 or RDFPD #2 would have a significant impact in access to emergency service for residents. In both cases large areas in the center of the jurisdiction and along the northern and southern boundaries see marked drops in access. The exact census block groups affected are not necessarily the same, but either way the significant portions of the resident population would see and experience a drop in access which could result in longer wait times for service. In situations where multiple calls for service come from the same area, some of those residents needing assistance might not be served as efficiently as they could be. In addition, the northeast corner of the service area has very low access to emergency services whether a station is removed or not. In the end, removing a station if a six-minute standard is in practice would put significant amounts of additional stress on the local emergency services.

5.1.4.2. Eight-Minute Standard

The behavior of the system changes slightly when an eight-minute standard is put in place. At this interval each station is responsible for a larger area, but there is more overlap between the stations and due to this more of the census block groups have access to more than one fire station. Unlike at the six-minute interval, there no longer two hotspots for accessibility. Instead, accessibility behaves in a radial pattern with an area of accessibility high in the center and decreasing as you move away from the center. This makes sense as the interior block groups are serviced by multiple stations, in some cases as many as four or five, and the outer areas are served by in many places by one station.

When either WDFD #2 or RDFPD #2 are removed from this system, the changes in accessibility mostly occur in the center, as the two stations are really interior stations. The edges of the service area are not nearly impacted as much as they were at the six-minute interval. In fact, when RDFPD #2 was removed no interior areas dropped into the lowest two classes. The two census block groups that do see drops into the lower classes intersect with the southern boundary. This is not nearly as significant as it could be because most of the population in those block groups live in the jurisdiction of neighboring fire departments and are not in fact serviced by QuadCom 911.

On the other hand, when WDFD #2 is removed one of the interior block groups drops into the lower accessibility classes and areas of higher population on the east side of the river within the service area also see decreases in access to emergency service. The southern border areas are more stable, but there are more significant changes to interior, higher populace areas. Finally, the northeastern areas that lacked almost any access to emergency services now have some limited access to service no matter which scenarios you look at. Overall, the eight-minute standard provides more uniform access to emergency services to more residents than at the six-minute standard. And while the removal of a fire station does affect the access to services, the effects of removing WDFD #2 are significantly higher than if RDFPD #2 is removed.

5.1.4.3. Ten-Minute Standard

Now in regards to the results at the ten-minute standard, all but two of the census block groups which intersect with or are within the service area are in the top three accessibility classes. The two block groups that are not are the same block groups that were discussed in Map (NUMBER). The only difference is one of the centroids for those block groups now falls within the drive-time range of East Dundee's fire station. At this interval, the areas with high access to emergency services has grown and most of the edges have accessibility no lower than 0.000513.

There are some changes to accessibility that occur when RDFPD #2 is removed. For example, some of the interior census block groups' accessibility decreases, but their values remain in the top two classes. In this case none of the interior block groups drop below 0.000513 and none of the areas already between 0.000513 and 0.000950 dropped below 0.000513. The system was surprisingly stable when compared to the other two standards.

On the other hand, this was not the case when WDFD #2 was removed. In this scenario, the interior census block groups actually were stable and maintained their accessibility indexes and did not experience significant drops. However, the northern and western border areas saw significant decreases in accessibility. This is significant because those areas, especially the ones along the northern boundary contain significant populations.

What is really interesting about the results for the ten-minute standard is how the system absorbs the additional stress when a station is removed. When RDFPD #2 was removed, that additional stress was distributed across the whole system and its responsibilities are shared by many other stations. But when WDFD #2 is removed, the northern and western areas suffer the brunt of the system stress. This is probably due to RDFPD #2's location in a residential area and its more extreme southern location. Because of this location, it is unable to cover nearly as much of WDFD #2's responsible areas, which is now being covered almost exclusively by RDFPD #1 and CFD #3, whereas WDFD #2, along with WDFD #1, is able to cover all of RDFPD #2's responsible areas when it is removed. Overall, similar to the eight-minute standard, it appears that the ten-minute standard provides adequate access to emergency services across the QuadCom service area, has stable accessibility from year to year, and responds better to the pressure of losing a station if RDFPD #2 is removed instead of WDFD #2.

5.1.5. Cross Comparison

At first glance it appears the ten-minute drive-time interval provides the best coverage of accessibility indexes for QuadCom 911's service area. There were more census block groups are in the top three classes than at other intervals. Furthermore, the interval had the lowest percentage of class changes out of the three intervals, and the lowest average absolute difference in accessibility values from year to year. But does that necessarily mean the ten-minute standard provide the most effective range of appropriate accessibility indexes?

Well, when looking exclusively at the average absolute difference in accessibility from year to year, the six-minute standard had the highest averages, followed by the eight-minute standard, and then the ten-minute standard had the lowest averages. This exact pattern holds true for the overall, average absolute difference for each of the intervals. However, the differences between the eight and ten-minute intervals are fairly small especially when compared against the six-minute interval. Based on this, the six-minute interval should not be considered as an industry standard. The variation from year to year and overall is too great, and when the results are visualized on a map, the system is more susceptible to minor change changes and those changes have greater effects across the system and finally, the distribution of access is less uniform at that interval.

Therefore, in choosing an acceptable range of accessibility indexes for suburban, regional emergency services, we need to focus on the eight and ten-minute standards. If we analyze the results visually, the maps suggest that the ten-minute interval is more successful. More of the regions are covered in yellows or greens, less areas are changing drastically from year to year, and the slightly lower average absolute differences would generally support this.

The visual comparison however is misleading. In truth, the accessibility indexes at the ten-minute interval, in general, have lower values than the indexes at the eight-minute interval. For example, the average accessibility index for the eight-minute standard was 0.000895 while the average at the ten-minute standard was 0.000790. In addition, the breaks between each class were also lower for the ten-minute standard compared to the eight-minute standard. The most striking example is the lowest class at ten-minutes was just 0.0 while at eight minutes the range was 0.0 to 0.000300. The difference in the breaks makes it easy to visually misinterpret the results for the ten-minute standard. For example, an area might have an index of 0.000274 at the eight-minute standard and an index of 0.000218 at the ten-minute standard. In this example the area falls in the lowest class at eight minutes and in the second to lowest class at ten minutes. Even though its access is measurably worse at ten minutes, it appears visually that access is slightly better.

The difficulty in proposing a standard range of acceptable accessibility indexes is that you want to produce a range that provides context. You do not want to propose a range that is too high, which would suggest that most systems are drastically inadequate and you don't want a range that sets the thresholds too low as this could inadvertently show a system as better than it really is. Based on the results of this project, the best drive-time standard to use in analyzing accessibility for emergency services and eventually determining an acceptable range of values is eight minutes. At this interval we are provided with a range of values that seem to accurately represent a real-world system. It has enough breadth to show whether access is consistent across time and space but is also sensitive enough to help identify areas with less access and not generalize the data too much. Unfortunately, the ten-minute standard seems to over generalize the accessibility across a region.

5.2. Limitations

Even though the project was moderately successful in achieving its goals, there are items which limit the effectiveness of the project and the impact on both QuadCom 911 and, more significantly, the study of GIS and access to emergency services. The first significant limitation this project has is the size of its study area. As work progressed, it became abundantly clear the project provided valuable insights into how accessible emergency services are for residents in the QuadCom area. But because the study focused on QuadCom departments, the data and scope of the project only focused on that area and did not provide a large enough sample size to justify proposing a specific range of acceptable accessibility indexes for suburban, regional EMS.

Another significant limitation is the drive-time catchments do not account for traffic and how it would affect how far emergency services could travel in a set time. There is a real possibility that if traffic had been accounted for in the model, that the drive-time catchments would have been smaller. This would have resulted in a different distribution of accessibility values. For example, each fire station could have had a higher accessibility index because they would directly serve less people. As a byproduct, each census block group within range of a fire station would have had higher indexes, but it is probable more census blocks would have fallen beyond the range of the stations and result in significantly lower accessibility or even have no access.

Finally, the third major limitation this project faces is its aggregation method. As is, population and the calls for service are all generalized and aggregate to the census block groups and then analyzed using the census block groups' population-weighted centroids. This means the data is shifted spatially and, in many cases, loses its spatial specificity. This is particularly apparent in the eastern part of QuadCom's jurisdictions where calls for service, mainly traffic related incidents, occur within the jurisdiction and within driving range of fire stations, but are aggregated to population-weighted centroids outside of the jurisdiction and beyond the range of the fire stations. Thus, the accessibility of those areas is misrepresented due to the spatial distortion cause by the aggregation method.

5.3. Future Research

This project demonstrates how this type of analysis can be successful for analyzing emergency services and with that success, new avenues open for future research. The first area for future research would be to duplicate the process used in this study but expand the study area to include more fire departments and more calls for service. By expanding the study, a larger sample size would be created and enable the second goal of this project to be achieved. The larger sample size of accessibility indexes would result in a more reliable range of values that could be used to establish a viable standard for what acceptable accessibility looks like for suburban fire departments.

Another avenue for future research would be to refine the methods used. For example, one of the limitations of the project was that the drive-time catchments did not account for how traffic could limit how far a vehicle could get in an allotted timeframe. Identifying how traffic should or could be accounted for is beyond the scope of this project, but future work could be done in this area. Refined catchments would further improve the accuracy of the accessibility indices. This could be done by implementing one of the variations of the 2SFCA method, such as the E2SFCA method or the ST-E2SFCA method, which has shown some promising results in other EMS accessibility applications.

The methodology could be further refined by using a different aggregation method. Instead of census block groups, census blocks could be used. For the 2SFCA method to work in this method the calls for service data have to be aggregated and generalized. But a smaller area of aggregation would limit how far calls would be spatially distorted. They would remain as local as possible and in turn the results of the method would be finer and produce a more localized analysis.

Another area future research could examine is how the different variations of the 2SFCA method could be implemented and what types of impact the differences in the methods would have on the analysis of fire and ems accessibility. There are a number of variations on the method, some of which were discussed in Chapter 2. It is my opinion that one of the methods which utilize a gravity model would be particularly effective in not only refining the analysis but also bring a different perspective to the analysis as well. It is possible a gravity model variation could produce different accessibility indexes and change our understanding of accessibility.

Finally, the most logical next step, and potentially the most valuable, is to examine if access to fire and ems service has any correlation to demographics such as race, age, or even wealth. I would expect accessibility to definitely correlate to different demographic traits, especially wealth. It makes logical sense that communities with increased wealth, and the higher tax revenue that wealth generates, could result in those communities having increased access to emergency services when compared to poorer communities. I would also not be surprised if access correlated to racial demographics as well. Understanding how these different aspects of our population interact with access could have profound impacts on how we think about emergency services and help society create more equitable access to those services.

5.4. Final Conclusions

This project generated a number of important conclusions when it comes to the accessibility of QuadCom 911's fire departments. The first major conclusion drawn from the analysis is accessibility is best measured using an eight-minute drive-time interval. The results demonstrate the eight-minute interval is sensitive enough to show changes and consistencies in accessibility across time and space, but also generalizes the access of the system enough to accurately depict how the system actually behaves. In contrast, the ten-minute interval over generalizes accessibility so subtle changes are lost and the six-minute interval is to small and causes the model to be hyper-sensitive to minor fluctuations in accessibility.

The next major conclusions involve the direct implications this project has for QuadCom 911. In general, we see accessibility in the QuadCom 911 service area is pretty stable across all the drive-time intervals, especially when using the eight and ten-minute intervals. Under the current system, there are only minor fluctuations in accessibility from year to year across the entire area. So, when a fire station is removed from that system, slightly different accessibility patterns emerged. Based on the results, it appears that removing WDFD #2 causes more significant changes to accessibility across the system. In theory, this could put significant strain on particular populations and specific stations. On the other hand, the system seems to better absorb the added stress of no longer having a fire station when RDFPD #2 is removed. The center of the service area sees a decrease in access, but those values remain high when compared to the values of those same, central areas when WDFD #2 is removed. Based on the current results, this thesis recommends that if WDFD and RDFPD merge and need to consolidate, RDFPD #2 should be closed instead of WDFD #2 as closing RDFPD #2 has fewer potential impacts to accessibility.

One of the main goals of this project was to identify and propose a standard range of acceptable accessibility indexes for suburban, regional emergency services. This goal was only partially achieved. Unfortunately, the sample size was too small to propose a definitive range. Three ranges of accessibility were identified, one for each of the drive-time intervals, but the data did not support the proposal of an industry standard. However, the results to suggest such a proposal could be possible with a larger sample size.

Overall, the project was a resounding success. By using the 2SFCA method, accessibility was analyzed for the fire departments dispatched by QuadCom 911. The project was able to quantify and demonstrate how access to emergency services could be affected if one of the fire stations were to close due to the consolidation of two QuadCom 911 fire departments. Furthermore, the project was able to show that an identifying and proposing a standard for acceptable accessibility for emergency services is possible with a large enough sample size, even though that goal could not be achieved in this project. In the end this project is an effective starting point for studying the accessibility of emergency services and indicates further research is not only possible but could have a significant and beneficial impact on the organization and operation of emergency services around the world and make a valuable contribution to the study of GIS as a whole.

References

Bass, Robert R. 2015. "History of EMS." In *Emergency Medical Services: Clinical Practice and Systems Oversight*, edited by David C. Cone, Jane H. Brice, Theodore R. Delbridge, and J. Brent Myers. John Wiley & Sons, Inc: 1-16.

Brodsky, Harold, and A. Shalom Hakkert. 1983. "Highway Fatal Accidents and Accessibility of Emergency Medical Services." *Social Science Medicine* 17, no. 11: 731-740.

Chen, Lin Xiao, and Song Zhou. 2016. "Estimating the effect of traffic congestion on accessibility to emergency medical care services: take Guangzhou as an example." *Progressive Geography* 35, no. 1: 431–439.

Cramer, Dan, Albert Arthur Brown, and Gongzhu Hu. 2012. "Predicting 911 Calls Using Spatial Analysis." *Software Engineering, Research, Management & Application*. SCI 377:15-26.

Delamater, Paul L. 2013. "Spatial accessibility in suboptimally configured health care systems: a modified two-step floating catchment area (m2sfca) metric." *Health Place* 24: 30–43.

Dewulf, Bart, Tijs Neutens, Yves DeWeerdt, and Nico Van de Weghe. 2013. "Accessibility to primary health care in Belgium: an evaluation of policies awarding financial assistance in shortage areas." *BMC Family Practice* 14, no. 122: 1-13.

Dai, Dajun, and Fahui Wang. 2011. "Geographic disparities in accessibility to food stores in southwest Mississippi." *Environment and Planning B: urban Analytics and City Science* 38, no. 4: 659-677.

Dai, Dajun. 2011. "Racial/ethnic and socioeconomic disparities in urban green space accessibility: where to intervene?" *Landscape Urban Planning* 102, no. 4: 234-244.

Evarts, Ben, and Gary Stein. 2019. *U.S. Fire Department Profile 2017.* National Fire Protection Association. Quincy, MA.

Federal Interagency Committee on Emergency Medical Services. 2012. *2011 National EMS Assessment.* U.S. Department of Transportation, National Highway Traffic Safety Administration. Washington, DC.

Freyssenge, J, R. Renard, A. M. Schott, L. Derex, N. Nighoghossian, K. Tazarourte, and C. El Khoury. 2018. "Measurement of the potential geographic accessibility from call to definitive care for patient and acute stroke." *International Journal of Health Geographics* 17, no. 1: 1-14.

Goodloe, Jeffrey M., and Paul D. Biddinger. 2012. "Emergency Medical Services." In *Principles of Emergency Medicine*, edited by S. V. Mahadevan and Gus M. Garmel, 115-126. Cambridge: Cambridge University Press.

Guagliardo, M.F. 2004. “Spatial accessibility of primary care: concepts, methods and challenges.” *International Journal of Health Geography* 3, no. 3.

Hansen, Matthew, William Loker, and Craig Warden. 2016. “Geospatial Analysis of Pediatric EMS Run Density and Endotracheal Intubation.” *Western Journal of Emergency Medicine* 17, no. 5: 656-661.

He, Zhaoxiang, Xiao Quin, Ralph Renger, and Eric Souvannasacd. 2018. “Using spatial regression methods to evaluate rural emergency medical services (EMS).” *American Journal of Emergency Medicine.*

Hibdon, Julie, and Elizabeth R. Groff. 2014. “What You Find Depends on Where You Look: Using Emergency Medical Services Call Data to Target Illicit Drug Use Hot Spots.” *Journal of Contemporary Criminal Justice* 30, 2: 169-185.

Kim, Yeeun, Young-Ji Byon, and Hwasoo Yeo. 2018. “Correction: enhancing healthcare accessibility measurements using gis: a case study in Seoul, Korea.” *PLoS One* 13, no. 3.

Langford, Mitchel, Gary Higgs, and Richard Fry. 2016. “Multi-modal two-step floating catchment area analysis of primary health care accessibility.” *Health Place* 38: 70–81.

Lee, EunSu. 2014. “Designing Service Coverage and Measuring Accessibility and Serviceability of Rural and Small Urban Ambulance Systems.” *Systems* 2: 34-53.

Lin, Bo-Cheng, Chao-Wen Chen, Chien-Chou Chen, Chiao-Ling Kuo, I-chun Fan, Chi-Kung Ho, I-Chuan Liu, and Ta-Chien Chan. 2016. “Spatial decision on allocating automated external defibrillators (AED) in communities by multi-criterion two-step floating catchment area (MC2SFCA).” *International Journal of Health Geography* 15, no. 17.

Lu, Yongmei, and Aja Davidson. 2017. “Fatal motor vehicle crashes in Texas: needs for and access to emergency medical services.” *Annals of GIS* 23, no. 1: 41-54.

Luo, Jun. 2014. “Integrating the huff model and floating catchment area methods to analyze spatial access to healthcare services.” *Transportation GIS* 18, no. 3: 436-448.

Luo, Wei. 2004. “Using a GIS-based floating catchment method to assess areas with shortage of physicians.” *Health & Place* 10: 1-11. 113

Luo, Wei, and Yi Qi. 2009. “An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians.” *Health & Place* 15: 1100-1107.

Luo, Wei, and Fahui Wang. 2003. “Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region.” *Environment and Planning B: Planning and Design* 30, no. 6 (March): 865 - 884.

Luo, Wei, and Tara Whippo. 2012. “Variable catchment sizes for the two-step floating catchment area (2sfca) method.” *Health Place* 18, no. 4: 789-795.

Mao, Liang, and Dawn Nekorchuk. 2013. “Measuring spatial accessibility to healthcare for populations with multiple transportation modes.” *Health Place* 24: 115–122.

McArthur, David Philip, Fredrik A. Gregersen, and Terje P. Hagen. 2014. “Modelling the cost of providing ambulance services.” *Journal of Transport Geography* 34: 175-184.

McGrail, Matthew R. 2012. “Spatial accessibility of primary health care utilising the two step floating catchment area method: an assessment of recent improvements.” *International Journal of Health Geographics* 11, no. 50: 1-12.

Mell, Howard K., Shannon N. Mumma, Brian Hiestand, Brendan G. Carr, Tara Holland, and Jason Stopyra. 2017. “Emergency Medical Services Response Times in Rural, Suburban, and Urban Areas.” *JAMA Surgery 152, no. 10:983-984.*

Morrison, Laurie J., Mark P. Angelini, Marian J. Vermeulen, and Brian Schwartz. 2005. “Measuring the EMS Patient Access Time Interval and the Impact of Responding to High-Rise Buildings.” *Prehospital Emergency Care* 9, no. 1: 14-18.

National Fire Protection Association 2016. *NFPA 1701 Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments.* National Fire Protection Association. Quincy, MA.

Neeki, Michael M., Colin MacNeil, Jake Toy, Fanglong Dong, Richard Vara, Joe Powell, Troy Pennington, and Eugene Kwong. 2016. “Accuracy of Perceived Estimated Travel Time by EMS to a Trauma Center in San Bernardino County, California.” *Western Journal of Emergency Medicine* XVII, no. 4: 418-426.

Patterson, P. D., J. C. Probst, and C. G. Moore. 2006. “Expeccted Annual Emergency Miles per Ambulance: An indicator for Measuring Availability of Emergency Medical Services Resources.” *The Journal of Rural Health* 22, no. 2: 102-111.

Tansley, Gavin, Barclay Stewart, Ahmed Zakariah, Edmund Boateng, Christiana Achena, Daniel Lewis, and Charles Mock. 2016. “Population-level Spatial Access to Prehospital Care by the national Ambulance Service in Ghana.” *Prehospital Emergency Care* 20, no. 6: 768-775.

Wan, Neng, Bin Zou, and Troy Sternberg. 2012. “A three-step floating catchment area method for analyzing spatial access to health services.” *International Journal of Geographic Information Science* 26, no 6: 1073-1089.

Wang, Fahui, and Wei Luo. 2005. “Assessing spatial and nonspatial factors for healthcare access: towards an integrated approach to defining health professional shortage areas. *Health & Place* 11: 131–146.

Warden, Craig R., Mohamud Daya, and Lara A. LeGrady. 2007. “Using Geographic Information Systems to Evaluate Cardiac Arrest Survival.” *Prehospital Emergency Care* 11, no. 1: 19-24.

Xia, Tianqu, Xuan Song, Haoran Zhang, Xiaoya Song, Hiroshi Kanasugi, and Ryosuke Shibasaki. 2019. "Measuring Spatio-temporal accessibility to emergency medical services through big GPS data." *Health and Place* 56: 53-62.